Intermittent Fault Detection & Isolation (IFDI)

Information Package

Table of Documents

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INTERMITTENT FAULT DETECTION TECHNOLOGY FROM UNIVERSAL SYNAPTICS

BLUF: Sustainment Technology **now** exists that can Detect and Isolate Electronics Intermittence that can be used across All Commercial Aircraft and Weapons Systems, is a COTS non-platform specific technology, and provides dramatic reductions in AOG and downtime of aircraft and critical weapon systems to greatly improve safety and readiness while reducing costs tied to NFF test results.

- Universal Synaptics is the industry leader in detecting and isolating elusive intermittent faults in compliance with the United States Department of Defense MIL-PRF 32516. The massive digital testing void that exists today with conventional scanning test equipment led to the development of the patented Portable Intermittent Fault Detector™ (PIFD™) and the Intermittent Fault Detection & Isolation System 2.0™ (IFDIS 2.0™) Intermittent Fault Detectors.

- A major cost driver for Department of Defenses (DoD) and Commercial Aviation is the maintenance of electronics and electrical systems that control and operate wide-ranging inventories of weapons, weapon systems, and commercial aircraft. Over $20 billion a year is spent maintaining electronics and systems across the United States DoD. One of the highest contributing causes to these costs is operationally induced intermittent electronic faults that result in No Fault Found (NFF), Cannot Duplicate (CND), and No Trouble Found (NTF) test results.

- Over the past decade the United States DoD has identified and quantified the operational degradation and high cost of NFF primarily driven by undetected and hence unrepaired intermittent faults across the DoD at over $3 billion annually, with 278,000 lost operational days per year. In 2010 the Air Transport Association (ATA) estimated that NFF costs commercial aviation $250k per aircraft per year.

- Several sustainment agencies have participated in focused efforts to identify Electronics Intermittence in Line Replaceable Units (LRUs) and weapons system wiring with confirmed significant results including 3x to 10x improvement in Time on Wing (TOW) with commensurate weapons system operational availability and a 10 to 1 return on investment. Details of these demonstrated instances of exceptional results are available upon request.

- Per the United States DoD Report to Congress on October 5, 2021, Universal Synaptics has the only objectively proven and MIL-PRF certified test technology to detect and reverse the intermittent fault problem across the spectrum of DoD weapons systems with the initial targets being various aircraft, including the F-35, F-16, and F/A-18.

- The Portable Intermittent Fault Detector (PIFD) has Authority to Operate (ATO) on the F-35 global program and is the only approved tester for use on the platform.

- The PIFD is inserted into the Boeing Aircraft Maintenance Manuals (AMM) for all Boeing platforms under COM-20952, Detector - Intermittent Fault, USC-IFD-512.

CONDITION BASED MAINTENANCE PLUS (CBM^+)
JOINT INTERMITTENCE TESTING (JIT)
WORKING INTEGRATED PRODUCT TEAM (WIPT)
CBM^+ JIT WIPT Charter

SEPTEMBER 2012

I. BACKGROUND

The impact across the Department of Defense (DOD) resulting from the removal and replacement of Line Replaceable Units (LRUs)/Weapon Replaceable Assemblies (WRAs) which subsequently test No Fault Found (NFF) during depot testing and are turned right around back to the field, is $2 billion annually. Visual inspection is ineffective in detecting the intermittent faults that are primarily responsible for this high NFF rate. Documented military weapon system verification and validation results indicate that three out of four aircraft in a mission ready status contain electrical interconnect issues.

A modern avionics system has thousands of internal and external circuit paths. These systems are subjected to hostile operating environments and will likely fail intermittently long before they fail permanently. Intermittence occurs randomly in time, place, amplitude and duration. Electromechanical devices go into a long and frustrating period of low-level intermittency as their mechanical tolerances change. It only takes one undetected and hence unrepaired intermittent circuit in an electronic box to cause it to randomly malfunction. It is therefore very important that all intermittent circuits that are present in these boxes be detected, isolated and repaired. With the proper test equipment it is now possible to detect and repair these intermittent circuits.

The known projects currently pursuing the intermittent fault / NFF issues include:

- The Automatic Wire Test Set (AWTS) provides support for Ship and Shore Aviation Maintenance. The AWTS provides automatic test functions to detect wire faults and to determine the distance to the faults within wire bundles at Navy I- and D-Level maintenance activities and at Air Force flight line and back shop facilities. It replaces the obsolete Wire Test Set at Navy I-Level Wire Repair facilities and detects wiring shorts and opens within cable assemblies. Recent capability was extended to test inside the FA-18 radar receiver chassis, with a focus on intermittent fault location. Data shows cost avoidance of $1M/month at the first fielded location, with over 93% of the chassis having wiring faults, of which 26% were intermittent. This effort received the 2011 NAVAIR Innovation Award.

- The Intermittent Fault Detection & Isolation System (IFDIS) targets intermittent faults through the use of a hardware neural network. This functions like multiple latching oscilloscopes on each and every circuit individually, simultaneously and continuously monitoring all circuit paths at the same time ensuring no missed faults, while the units are tested in an environmental chamber and on a shaker table to simulate flight conditions. The IFDIS has the ability to detect faults (micro-breaks) at a greater sensitivity level, faults that previously would go undetected and therefore be coded NFF. The first case study on a F-16 radar Line Replaceable Unit (LRU) resulted in a $50M ROI, tripled the Mean Time Between Depot Repair, and removed this LRU from the Mission Incapable (MICAP) list after sitting at or near the top of the list for over a decade previous to IFDIS testing. IFDIS has also been used on additional F-16 components and has been used to test LRUs and WRAs on the F/A-18, EA-6B, CH-47, RQ-170, Tornado GR4, Typhoon FGR4, Unmanned Aerial Vehicles (UAVs), Boeing 757 and Airbus A320, all with similar results as the first F-16 case study. IFDIS was the winner of the Great Ideas competition at the 2010 DoD Maintenance Symposium, a "Top 5 Finalist" in the 2012 Office of the Secretary of Defense Maintenance Technology Challenge and a 2012 "Top 3 Finalist" in the Aerospace & Defense Category of the American Technology Awards.

II. PURPOSE

This charter establishes the CBM^+ JIT WIPT to leverage current and emerging commercial industry activity for demonstration, testing, and cost analysis. The following WIPT project goals are to:

- Define and validate joint performance requirements for a Joint Service intermittent fault detection system.
- Collect and analyze implementation and operational data on commercial field intermittent fault detection systems in use currently.
- Define the minimum fault detection threshold requirements for the applicable wiring systems, component types, and system architectures.
- Identify, define and validate test methods for ensuring that specified minimum performance requirements for detecting and isolating intermittence are met.
- Publish a joint performance requirements Military-Performance (Mil-PRF) document.
- Brief and publish findings in a technical report and make a recommendation to Service Components on a path forward.

III. IMPACT

For Intermediate Level: A common, transportable, modular, flexible, fault detection system which employs an intuitive graphical user interface that facilitates familiarity with the system and ease of use.

For Depot Level: A common, highly sensitive, flexible, fault detection system which employs an environmental chamber and a vibration table. The test set should be designed to provide an intuitive easy to use interface that facilitates familiarity with the system and ease of use.

Such a system would provide the following advantages to both maintenance levels:

- Quickly detect, isolate and identify intermittent circuit paths, shorts, opens and incorrect wiring problems in complex LRUs / WRAs
- Provide root cause fault identification

- Provide advanced prognostic and diagnostic capability
- Increase mission readiness, availability and reliability
- Remediate bad actor LRUs and WRAs
- Reduce ownership cost through quick and correct intermittent fault detection, isolation and repair

IV. AUTHORITY

The CBM+ JIT WIPT is established under the authority of the DoD CBM+ Advisory Group (AG) Charter.

V. MEMBERSHIP

The CBM+ JIT WIPT consists of the Team Members listed at Attachment A. The leader of the CBM+ JIT WIPT will be designated.

VI. RESPONSIBILITIES

The CBM+ JIT WIPT Chair will direct the preparation and dissemination of required materials. The CBM+ JIT WIPT Members shall represent their organizations on coordination and approving any recommendations for intermittent fault detection system equipment. The CBM+ JIT WIPT Members shall develop initial capability documentation from their respective user level requirements for each Service. After requirements are staffed by the respective service components, the WIPT will seek to consolidate the valid user requirements into a Joint Requirements Document. Upon concurrence from all WIPT members, the team (with an approved Department of Defense Test Organization) will draft and publish a Mil-PFR document which clearly identifies minimum thresholds for detecting and isolating intermittent wiring faults in various common wiring components (i.e. relays, circuit breakers, LRUs/WRAs) and various aircraft wiring architectures (i.e. conventional wire construction, ribbon wire, solder joints, wire wrap).

VII. PROCEDURES

The CBM+ JIT WIPT will meet as required. All relative procedures for WIPTs as outlined in the CBM+ AG Charter pertain.

VIII. SCHEDULE

WIPT will meet monthly to discuss progress and path forward.

Tentative timeline as follows:

TBD

JIT WIPT

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MEMORANDUM FOR: AFSC/ENRB 11 December 2012

FROM: AFSC/FZC
6038 Aspen Ave, BLDG 1289
Hill AFB, UT 84056-5805

SUBJECT: Management Memo of Intermittent Fault Detection and Isolation System (IFDIS)

1. Donald McClenny, AFSC/ENRB, DSN 777-5643 requested an independent evaluation of the estimated cost savings from the implementation of the IFDIS test system. This memo identifies the savings calculated.
2. The IFDIS is a LRU chassis intermittent fault tester that identifies continuity faults that happen intermittently during flight that cannot be identified through current test methods for Line Replaceable Units (LRU).
3. Current testing of the Modular Low Power Radio Frequency (MLPRF) LRU on the IFDIS tests 1,024 channels continuously while simulating vibration and temperature changes that would happen during flight. The two testers have been in operation since 2009 at a total cost of $2.2M (FY12$).
4. Since implementation the MLPRF test shop has tested 403 LRUs, to include those shelved as unrepairable (138 LRUs), that have been returned to service. Actual data from the effect of this implementation is used to identify previous savings and to estimate future savings.

Comments:

Total Investment to Date: **$2.2M**

This includes the development of software and hardware, some of the costs include;

- $2.2M for two MLPRF capable testers already in operation that test 1,024 channels

MLPRF Shop Personnel Reduction **$0 .439M**

The MLPRF shop was able to reduce the number of personnel by 10 due to the effectiveness of the IFDIS tester. These personnel were placed in other locations avoiding hiring new personnel for these positions

MLPRF Shop Overtime Reduction **$0 .028M**

The MLPRF shop was able to reduce the overtime by 646 hours per year due to the effectiveness of the IFDIS tester. (FY07-11 average overtime from the FY12 overtime identified in the Cost and Production Performance Module (CPPM) database for RCC MLABA)

A 10 year period was used to show savings using the estimated timeline for a new Radar System to upgrade the F-16 that is expected in 2020. The table shows a 10 year total savings.

MLPRF Manpower & Overtime Reduction estimated over 10 years

Manpower & Overtime savings FY11-20	FY11	FY12	FY13	FY14	FY15-20	Total over 10 yrs FY12$
Reduction in personnel (10 WG11/3)	$439,559	$439,559	$439,559	$439,559	$2,637,351	$4,395,585
646 hour reduction in O/T @ a FY12 WG11/3 wage rate * 1.5 * burden factor	$27,697	$27,697	$27,697	$27,697	$166,181	$276,968
Total savings						**$4,672,554**

Tangible savings validated: $4.67M per year for Manpower and Overtime reduction

Other costs considered in the analysis of the data:

- Exchange Price - The cost charged to the customer for exchanging a repairable item for a serviceable one
  - Exchange price listed in the CPPM database is **$39,903.11** for 2012
- The reduction value to the AF for assets having a longer Mean Operational Time Between Depot Repairs (MOTBDR).
  - It is estimated that the return to depot for repair has been extended up to 300% of the previous operational service life before repair (~290 days to ~926) of the MLPRF LRU over a three year period. Approximately 33% fewer returns each year for those LRUs tested on the IFDIS.
  - The number of MLPRFs returned each month has dropped from ~54 LRUs to ~17 LRUs, a 68% decrease. (54 @ $39,903 = $2.15M, 17 @ $39,903 = $0.68M, $2.2M - $0.68M = $1.48M)
    Customer cost avoided is **$1.48M** per month **($17.72M / year**)

Increase in repair costs: Latest Repair Cost (LRC)

LRC costs increased on average **$9,400** per MLPRF after implementation of the IFDIS. Using the 403 tested as the baseline this equates to **$3.8M** in increased test costs to date. LRC data retrieved from the CPPM database and normalized to FY12$. FY07 to FY09 represented before the IFDIS and FY10 to FY12 represented after IFDIS implemented. Costs were averaged and the difference is represented by the $9,400. Using the new induction of 17 per month the projected annual cost increase is $**1.93M** per year

Cost Avoidance (FY12$)	FY11	FY12	FY13	FY14	FY15-20	Total over 10 yrs FY12$
MOTBDR avoided	$17,716,981	$17,716,981	$17,716,981	$17,716,981	$106,301,885	$177,169,808
Increase in shop cost	$3,807,818	$1,927,531	$1,927,531	$1,927,531	$11,565,185	$21,155,596
Total avoided cost	$13,909,163	$15,789,450	$15,789,450	$15,789,450	$94,736,700	**$156,014,213**

These costs are an estimate only and reflect the changes in monthly inductions of the MLPRF LRU from 2007 to Mar 2012 (DRILS). An average induction rate for at least a three year period prior to 2007 would be needed for further comparison.

Total annual cost avoided from reduction in MOTBDR: **$17.72M**

Total annual cost avoidance using the data available at the time of this document: **$15.79M**

Total cost avoided over 10 years: **$156.01M**

Intangible Benefits:

- Increase in efficiency by 300% for MLPRF LRUs shown in the average MOTBDR from 290 days to 926 days
- MLPRF caused Mission Incapable aircraft (MICAPS) eliminated
- 138 MLPRFs restored to service and put back into supply that had been identified as 'Bad Actors' or unrepairable. At the Latest Acquisition Cost (LAC) in the D043 the total value of these assets is $46,602,946 in FY12$, however, the last purchase recorded was 18 units in 1991. As these assets are no longer available to purchase only their current value in FY12$ is identified.
  138 * $229,134 * 1.474 (inflation) = $46,602,946)
- Increase in reliability in MLPRFs tested on the IFDIS where greater than 58% of the MLPRFs tested, the IFDIS found at least one intermittent fault not identified with other testing equipment that showed No Fault Found (NFF).
- Relative low cost to develop additional TPSs for other LRUs on multiple weapon systems that experience NFF that the IFDIS would be able to identify continuity intermittent faults while simulating a flight profile.
- Provides testing for assets that have service life extension programs where age and obsolescence affect reliability.

5. Current IFDIS program status
    - $.600M to upgrade the IFDIS for 1,500 channels needed for testing the Central Air Data Computer (CADC)
    - $7M contract being funded for a 8,400 Plus channel testing capability for the Programmable Signal Processor (PSP) LRU on the F-16 radar system.

6. Future intent for the IFDIS is to expand this new testing support to all LRUs that can be identified as having intermittent faults where there would be a cost benefit for development of the TPS. This would encompass multi service support.

Other cost data not available or that is unknown include the transportation costs to ship the LRU to Hill AFB, LRU removal and install, and any additional depot charges not included in the D043 database. Costs were inflated / normalized to FY12 dollars for comparison purposes.

James Hundley
Cost Analyst
AFSC/FZC OL:FZH
DSN 777-5457

Department of Defense Electronic Equipment

Intermittent Fault Characterization

Research Conducted and Compiled by:

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04 December 2014

Introduction:

Intermittency, even down in the nanosecond range, negatively affects reliable electrical equipment functionality and is a leading contributor to No Fault Found (NFF). Significant limitations exist in current Department of Defense (DoD) conventional Automatic Test Equipment (ATE) which masks short duration intermittency. This results in faulty equipment items "passing" conventional ATE scanning, sampling, averaging and multiplexing test methodologies and techniques. To compensate for these ATE testing shortfalls, the DoD needs a means of detecting, isolating and repairing short duration intermittency in electronic pathways in Line Replaceable Unit (LRU) chassis.

The purpose of this study is to capture the duration and ohmic characteristics of actual DoD electrical intermittency that cause electronic equipment malfunctions. This study was requested by the Joint Intermittent Testing (JIT) WIPT.

Statement of the Issue:

Electronic equipment aging, contamination and wear results in a degradation of the circuitry interconnectivity over time. This is aggravated and accelerated by extreme physical forces in severe military operational environments consisting primarily of vibrational stress, temperature and humidity extremes, and a high-operational tempo.

These factors induce intermittent ohmic events that deviate from the circuitry's designed parameters. The duration of these intermittent events can range down to nanoseconds, may occur repeatedly, or may just be one-shot in nature. The reseating of a connector or circuit board adjacent to a degraded connection, solder joint, etc., can temporarily cause the intermittent connection to appear repaired. Invariably the intermittent will re-manifest itself in an operational environment, usually in a relatively short period of time.

Figure 1 illustrates how an intermittent migrates through different stages of severity as it worsens. These events usually occur when environmental stress is present.

- Stage 1: Short duration (under 50 nanosecond) and/or low ohmic (under 10 ohm) intermittent events can cause problems in high frequency (10 MHz or higher) or other sensitive or critically balanced circuits.
- Stage 2: Longer duration (50 nanosecond to 1 millisecond) and/or higher ohmic (10 to 500 ohm) interment events cause problems in many different circuit designs.
- Stage 3: Long duration (1 millisecond or longer) high ohmic (500 ohm to open) intermittent events cause frequent circuit problems. Because the source of the problem (cracked solder joint, loose wire wrap, sprung connector, etc.) has become so severe, the intermittent tends to repeatedly occur in the presence of environmental stress, possibly enabling conventional ATE to detect the problem. These severe problems typically occur at all temperatures in the presence of vibration, whereas the Stage 1 and Stage 2 intermittent events frequently only occur at specific temperatures.

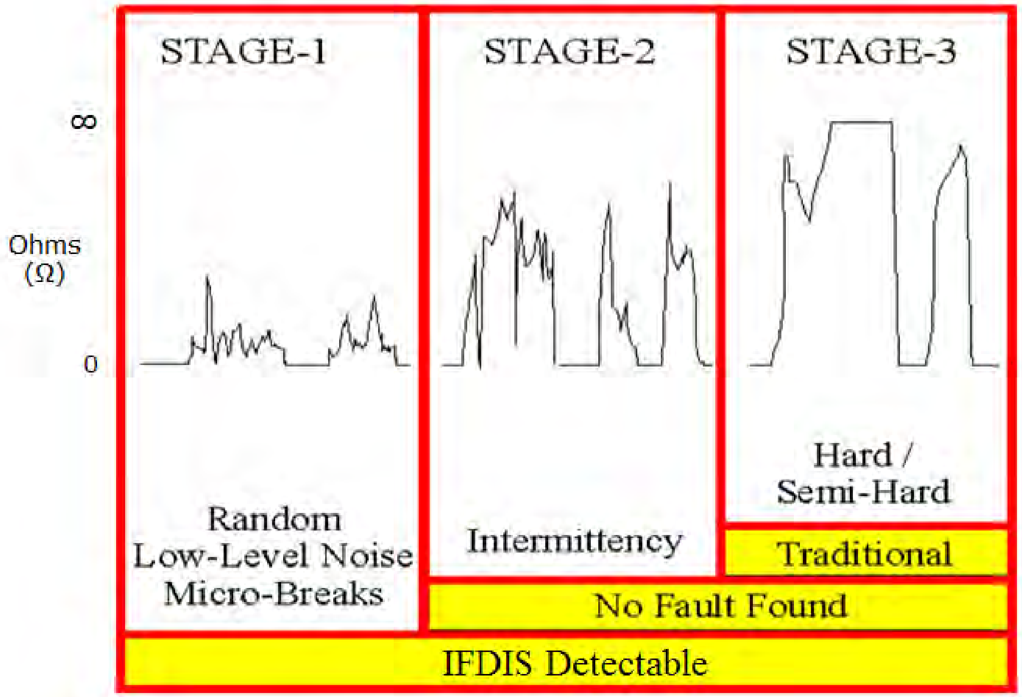


Figure 1. Intermittent Stages

Approach:

The first step was to find intermittent circuits so that the intermittent events in those circuits could be characterized. Due to the random nature of intermittency, the Intermittent Fault Detection and Isolation System (IFDIS) was employed to test F-16 AN/APG-68 Radar System Programmable Signal Processor (PSP) chassis to determine if there were intermittent circuit paths in the units, and if so, precisely which paths were intermittent. This was easily accomplished because the IFDIS monitors all of the circuits individually, concurrently and continuously during testing. The IFDIS also provided the needed vibration and temperature environment. Once intermittent circuits were identified by the IFDIS, an Agilent Technologies Model DSO9254A Digital Storage Oscilloscope with a 2 GHz Radio Frequency Probe (Model N2796A), capable of operation down into the picosecond range, was employed to identify and capture screen shots of actual intermittent events as they occurred.

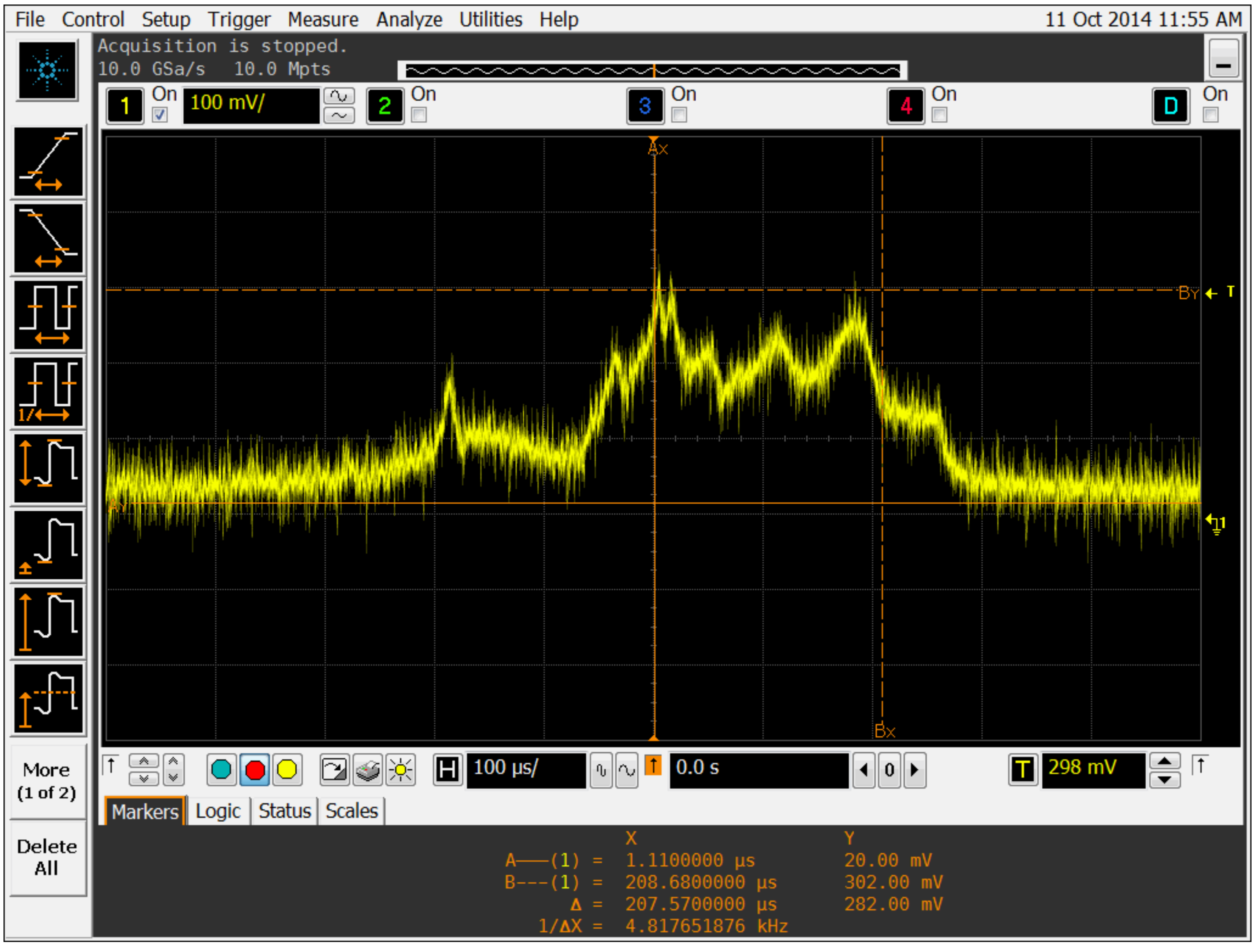
Once the IFDIS identified the exact circuits that were intermittent, it was then possible to test independently of the Intermittent Fault Detector (IFD). This was accomplished by using a battery, resistor and the oscilloscope set-up to capture the circuit's intermittent event characterization. This battery technique, used in some cases, minimized environmental noise and displayed a cleaner screen capture of actual intermittent events.

Intermittent durations in this report were captured by the oscilloscope in the microsecond range. The primary point of interest of this report was whether or not intermittent fault durations repeat at the same duration. Although all the intermittence captured did occur in the microsecond range, no two durations or wave forms were the same, hence no distinct failure pattern or duration pattern exists. Intermittence occurs at irregular intervals, is not continuous or steady and does not follow a specific failure pattern.

Test Results:

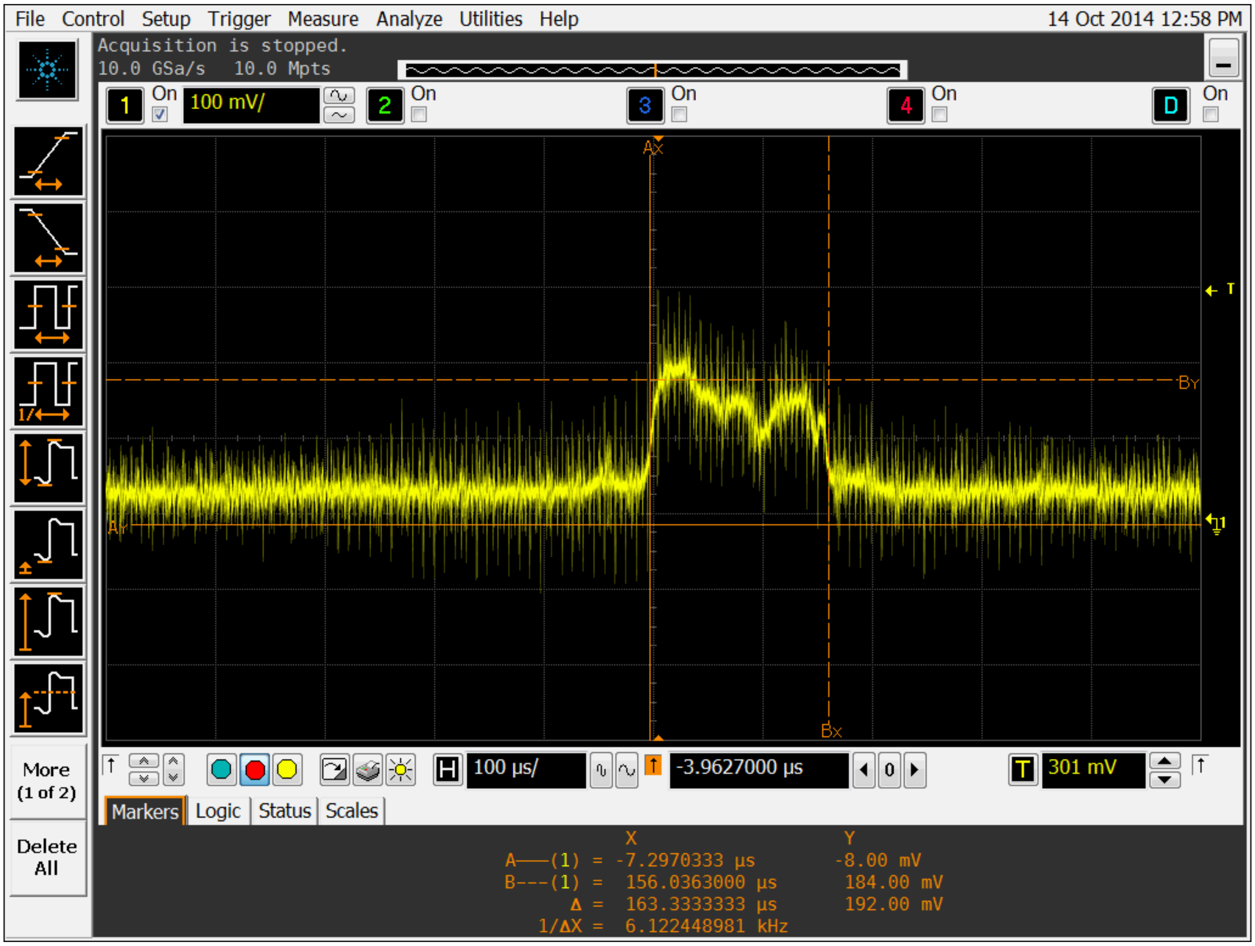
Test Case #1

PSP S/N 11357, intermittent Pin A09-469, five separate oscilloscope captures demonstrate the same intermittent event at different durations. In order to capture this information IFDIS was first required to detect and isolate the intermittent event on Pin A09-469.



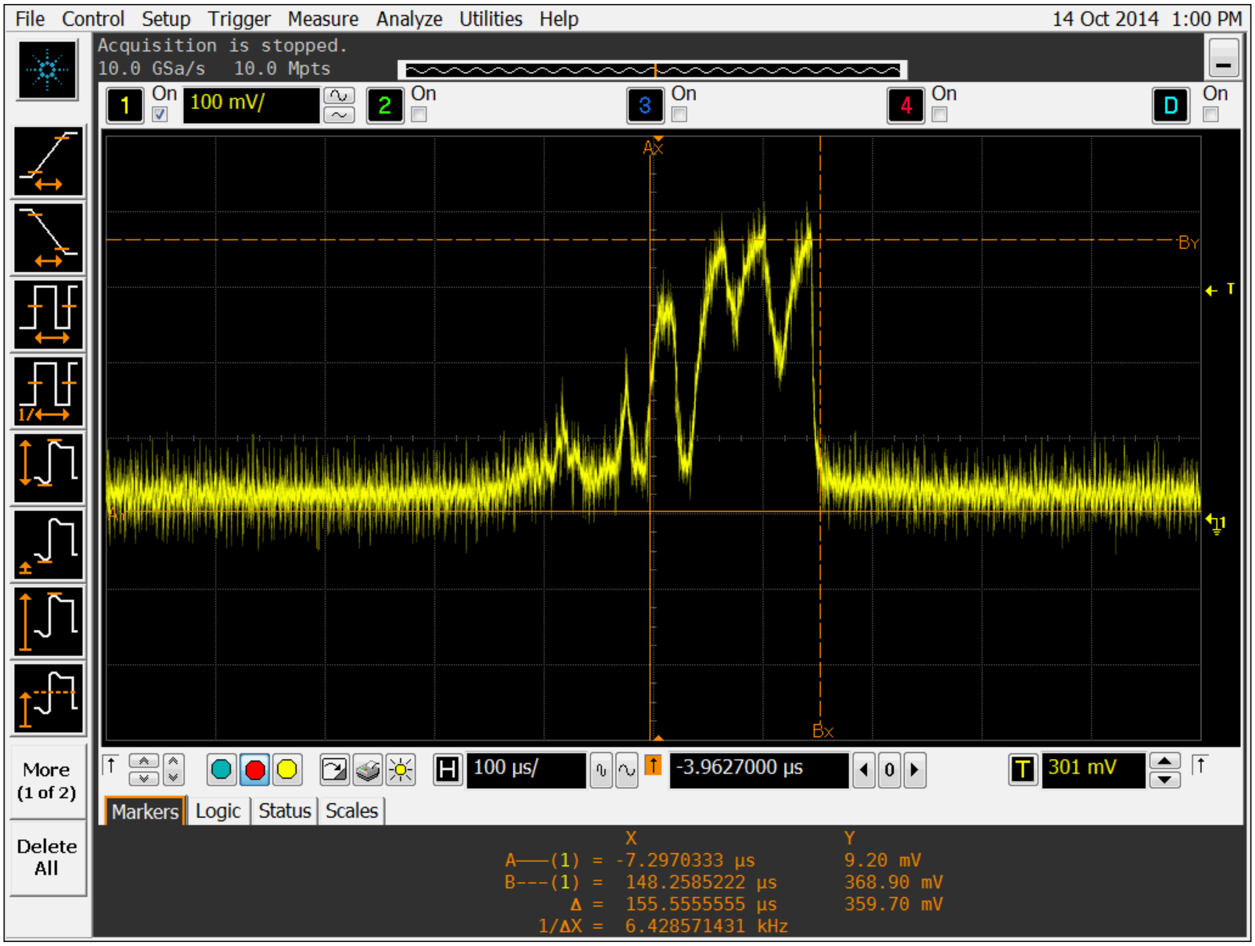
Test Date: 11 October 2014, 11:55am

PSP S/N 11357, Intermittent Pin A09-469 - Intermittent duration approximately 207 microseconds, scope reading taken after IFDIS detected and isolated Pin A09-469



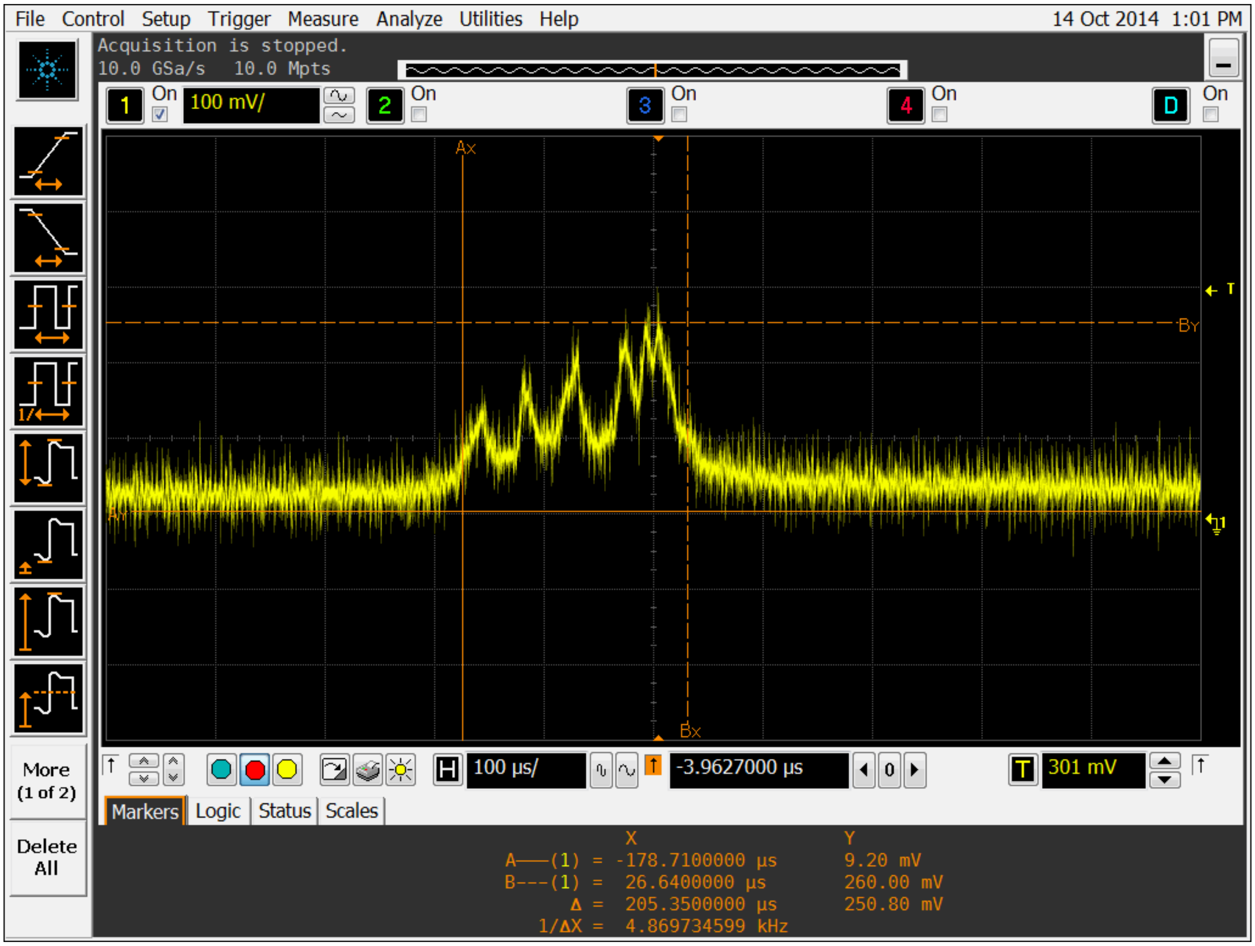
Test Date: 14 October 2014, 12:58pm

PSP S/N 11357, Intermittent Pin A09-469 - Intermittent duration approximately 163 microseconds, scope reading taken after IFDIS detected and isolated Pin A09-469 on second IFDIS test run.



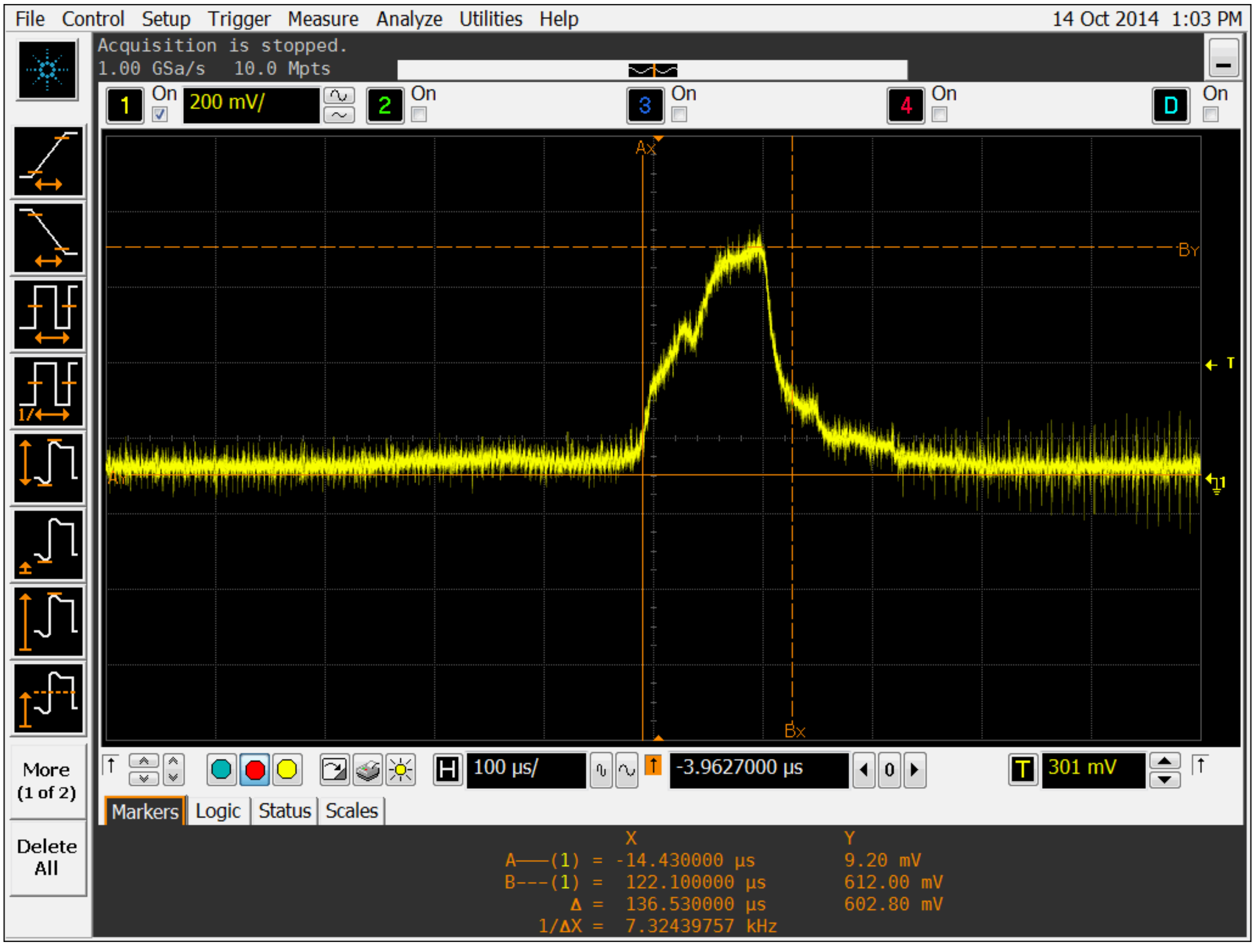
Test Date: 14 October 2014, 1:00pm

PSP S/N 11357, Intermittent Pin A09-469 - Intermittent duration approximately 155 microseconds, scope reading taken after IFDIS detected and isolated Pin A09-469 on second IFDIS test run.



Test Date: 14 October 2014, 1:01pm

PSP S/N 11357, Intermittent Pin A09-469 - Intermittent duration approximately 205 microseconds, scope reading taken after IFDIS detected and isolated Pin A09-469 on second IFDIS test run.



Test Date: 14 October 2014, 1:03pm

PSP S/N 11357, Intermittent Pin A09-469 - Intermittent duration approximately 136 microseconds, scope reading taken after IFDIS detected and isolated Pin A09-469 on second IFDIS test run.

INCH-POUND

MIL-PRF-32516
23 March 2015

PERFORMANCE SPECIFICATION

ELECTRONIC TEST EQUIPMENT, INTERMITTENT FAULT DETECTION AND ISOLATION FOR CHASSIS AND BACKPLANE CONDUCTIVE PATHS

This specification is approved for use by all Departments and Agencies of the Department of Defense.

1. SCOPE

1.1 Scope. This specification covers the minimum performance requirements for equipment to detect and isolate nanosecond, microsecond and millisecond conductive paths (see 6.4.4) and intermittent faults (see 6.4.2), which can occur in any and all of the hundreds to thousands of Line Replaceable Unit (LRU)/Weapon Replaceable Assembly (WRA) chassis and backplane circuits and their wire harnesses. This specification is not intended to address hard opens (see 6.4.11), shorts (see 6.4.12), nor constant function failures found in routine electronics repair.

1.2 Classification. Diagnostic equipment is classified by its intermittent fault duration detection capability, as follows:

Category 1. Short duration intermittent faults (see 6.4.5) that are under 100 nanoseconds across all LRU/WRA backplane circuits and associated wire harnesses.

Category 2. Intermediate duration intermittent faults (see 6.4.6) that are 101 nanoseconds to 500 microseconds across all LRU/WRA backplane circuits and associated wire harnesses.

Category 3. Long duration intermittent faults (see 6.4.7) that are 501 microseconds to 5 milliseconds across all LRU/WRA backplane circuits and associated wire harnesses.

Comments, suggestions, or questions on this document should be addressed to the Naval Air Systems Command, (Commander, Naval Air Warfare Center Aircraft Division, Code 412000B120-3, Highway 547, Joint Base MDL, NJ 08733-5100) or emailed to michael.sikora@navy.mil. Since contact information can change, you may want to verify the currency of this address information using the ASSIST online database at https://assist.dla.mil.

AMSC N/A FSC 6625

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in sections 3 and 4 of this specification. This section does not include documents cited in other sections of this specification or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of the documents cited in sections 3 and 4 of this specification, whether or not they are listed.

2.2 Government documents.

2.2.1 Specifications, standards and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

DEPARTMENT OF DEFENSE SPECIFICATION

MIL-PRF-28800	-	Test Equipment for Use with Electrical And Electronic Equipment, General Specification for

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-130	-	Identification marking of U.S. Military Property
MIL-STD-810	-	Environmental Engineering Considerations and Laboratory Tests
MIL-STD-461	-	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment
MIL-STD-464	-	Electromagnetic Environmental Effects Requirements for Systems
MIL-STD-1472	-	Human Engineering

DEPARTMENT OF DEFENSE HANDBOOK

MIL-HDBK-235-1	-	Military Operational Electromagnetic Environment Profiles Part 1C General Guidance

(Copies of these documents are available online at http://quicksearch.dla.mil.)

2.2.2 Other Government documents, drawings, and publications. The following other Government documents, drawings and publications form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

CODE OF FEDERAL REGULATIONS

29 CFR 1910.1200	-	Occupational Safety and Health Standards
40 CFR 82	-	Protection of Stratospheric Waste
40 CFR 261	-	Identification and Listing of Hazardous Waste
40 CFR 355	-	Emergency Planning and Notification
40 CFR 372.65	-	Specific Toxic Chemical Listings

49 CFR 173 - General Requirements for Shipments and Packaging

(Copies of these documents are available online at http://www.gpo.gov/fdsys/browse/collectionCfr.action?collectionCode=CFR)

2.3 Non-Government publications. The following documents form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

ELECTRONIC COMPONENTS INDUSTRY ASSOCIATION (ECIA)

EIA/ECA 310 - Cabinets, Racks, Panels, and Associated Equipment

(Copies of these documents are available online at http://www.eciaonline.org.)

2.4 Order of precedence. Unless otherwise noted herein or in the contract, in the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. REQUIREMENTS

3.1 First article. When specified (see 6.3), a sample shall be subjected to first article inspection in accordance with 4.2. The number of samples will be defined by the procuring activity (see 6.2).

3.2 Diagnostic equipment capability. The diagnostic equipment shall detect and isolate (see 6.4.3) intermittent faults, one hundred (100) nanoseconds or greater in duration, that may be present in LRU/ WRA chassis/backplane circuitry and/or its wire harness. This testing would typically be conducted on LRUs/WRAs and/or their wire harnesses that have demonstrated low reliability and/or a repair history of No Fault Found (NFF) or quasi-NFF repair (e.g., cannot duplicate (CND), retest OK (RETOK), beyond capability of maintenance (BCM), disassemble-clean-reassemble (DCR), etc.).

3.3 Application. This diagnostic equipment shall interface with the input/output connections such as connectors and terminal boards of a replaceable package of avionic equipment or system (commonly referred to as LRU/WRA). The function of this diagnostic equipment is to troubleshoot the LRU/WRA chassis/backplane conductive paths. The LRU/WRA chassis conductive paths include all of the electrical components that transmit the signal or power from the LRU/WRA input/output connections to the input/output connections of replaceable packages (commonly referred to as SRA/SRU (shop replaceable assemblies/shop replaceable units)) in the LRU/WRA. For chassis/backplane diagnostic troubleshooting, the SRA is removed from the LRU/WRA. For SRA and/or entire LRU/WRA troubleshooting, the designated automatic test equipment (ATE) shall be used.

3.4 Detail requirements. The diagnostic equipment shall comply with all the requirements specified herein.

3.5 Material. The material used shall enable the diagnostic equipment to meet the performance requirements of this specification.

3.6 Operating environment. The diagnostic equipment shall operate in benign operational environments where the environmental conditions are controlled and protected.

Examples include test equipment for use in a fully-protected and environmentally-controlled service area, such as a military depot level repair facility or industrial laboratory environment (see 6.4.10). The diagnostic equipment shall meet the environmental characteristics of this specification. Non-operating temperature shall be -20 degree Celsius (°C) to 71 °C; however, -40 °C is desirable. Operational temperature shall be 10 °C to 40 °C.

3.7 Design and construction. Diagnostic equipment shall be constructed with parts and materials designed to provide the specified performance, reliability, and service life under the environmental and operating conditions specified herein. Static discharge control shall be provided for protection of electronic devices during assembly and handling.

3.7.1 User interface. Diagnostic equipment shall be designed using an open-systems architecture approach, including the use of commercially available non-proprietary software. An open system is one that uses well-established, non-proprietary standards for interfaces, services, hardware, software, and supporting formats (e.g., Microsoft Excel, LabVIEW, USB (Universal Serial Bus), etc.). This enables components to be utilized across a wide range of systems, to interoperate with other components on local and remote systems, and to interact with users in a manner that facilitates portability.

3.7.2 Expandability. The diagnostic equipment shall facilitate test point expansion and growth (see 6.4.1). The diagnostic equipment shall include 256 test points per modular unit and be expandable to 1,280 tests points per 7U rack space (see EIA/ECA 310). The diagnostic equipment shall be expandable up to 10,000 test points without loss of fault detection performance capability. The final number of test points per modular unit and maximum test points shall be specified and approved by the procuring activity (see 6.2.u).

3.8 System physical characteristics (see 6.6).

3.8.1 Size and weight. The individual diagnostic equipment components shall not exceed the portability individual weight requirement of 35 pounds (16 kg) specified in MIL-STD-1472. The equipment shall be able to be safely moved without handles if less than 11 pounds (5 kg) or with handles if greater than 11 pounds (5 kg). The individual equipment shall be compatible with EIA/ECA 310 19-inch rack cabinets. The final size, weight, and EIA/ECA 310 compatibility of the diagnostic equipment shall be specified and approved by the cognizant procuring activity.

3.9 Performance characteristics. Diagnostic equipment shall perform electrical tests to determine the health and integrity of LRU/WRA chassis/backplane conductive paths or single wire/wire harness.

3.9.1 Fault detection. The diagnostic equipment shall detect all faults for the targeted classification category defined in 1.2 of this specification and identifying (see 6.4.3) the precise defective path(s).

3.9.2 Fault detection rate. The diagnostic equipment shall detect a minimum of 95 percent of all intermittent opens and shorts.

3.9.3 Integrity of point-to-point (pin-to-pin) wiring measurements. The diagnostic equipment shall verify test program parameters and output data (see 3.9.4) to indicate the number of occurrences and identify the conductive path(s) in which intermittent faults have occurred.

3.9.4 Stimulus input. If voltage and current is applied during the intermittent diagnostic testing, the voltage and current provided shall not be injurious to the LRU/WRA.

3.9.5 Input power. The diagnostic equipment shall operate in accordance with the nominal and alternate power sources requirements and listed in Table I.

TABLE I. Power source.

Voltage (Vrms)			
	Steady state	Transient state	Interruption
Nominal	108 to 132	84 to 108 132 to 156	0 to 84
Frequency (Hz)			
	Steady state	Transient state	Interruption
Nominal	47.5 to 52.5	45 to 47.5 52.5 to 57	0 to 45
	57 to 63	54 to 57 63 to 66	0 to 54

3.9.6 Diagnostic equipment startup and power-on self test. When energized or restarted, the diagnostic equipment shall run all power-on self-tests and be ready to operate in a typical work center in less than ten minutes. The diagnostic equipment shall provide automatic diagnostic information indicating whether it is operating within performance requirements. If the equipment is outside the limits of the performance specifications, the information provided by the self-test shall identify the likely cause of the fault.

3.9.6.1 Loop back test. The diagnostic equipment shall conduct a loop back test between the diagnostic equipment input/output connections. The purpose of the loop back test is to ensure the inter-connection harness between the diagnostic equipment and the LRU/WRA does not have any open/short circuits. The time to conduct the loop back test is separate and in addition to the startup and power-on self test.

3.9.7 Operating system. The operating system shall be an industry standard employing a "windowing" graphical user interface.

3.9.8 Data transfer. The diagnostic equipment shall have the ability to transfer test data (e.g., test results, wire signatures, and test programs) to an external device such as a memory stick, hard drive, optical drive, or other computer.

3.10 Hazardous materials, ozone depleting substances and hazardous air pollutants.

3.10.1 Ozone depleting substances (ODSs). Title VI, Section 606 of the Clean Air Act calls for the elimination of the production of Class I ODSs by December 1995 and Class II ODSs by 2030 (with a 65 pecent reduction in production of Class II ODSs by 2010). No Class I ODS (as defined in Title VI of the Clean Air Act) or material containing a Class I ODS as an ingredient will be approved for use during any phase of the system's life cycle, which includes manufacture, operation, maintenance, and disposal.

3.10.2 Hazardous materials. The diagnostic equipment shall not require the use of hazardous or environmentally unacceptable materials throughout its life cycle, unless there is no feasible alternative. Hazardous materials are those meeting one or more of the following conditions:

a. Regulated as a hazardous material per 49 CFR 173

b. Requires a Material Safety Data Sheet (MSDS) per 29 CFR 1910.1200

c. Regulated as an Extremely Hazardous Substance (EHS) per 40 CFR 355, Appendices A and B

d. Regulated as a Toxic Chemical per 40 CFR 372.65

e. Meets or has the potential to meet the definition of hazardous waste, as defined by 40 CFR 261 Subparts A, B, C, or D, during end use, treatment, handling, packaging, storage, transportation or disposal

f. Regulated as an Ozone Depleting Substance (ODS) per 40 CFR 82 Subpart A, Appendices A and B

g. Identified in the Clean Air Act, Chapter 85, Subchapter I – 7412 as a Hazardous Air Pollutant (HAP)

3.11 Environmental characteristics. The diagnostic equipment shall meet the following operating/non-operational environmental requirements.

3.11.1 Temperature and humidity. The temperature ranges and humidity limits for both operating and not operating conditions shall be as specified in 3.13.1.1 to 3.13.1.3. A relative humidity of 95 percent (see 3.11.1.3) does not include conditions of precipitation.

3.11.1.1 Temperature, not operating. When tested in accordance with 4.5.6, the diagnostic equipment shall meet the performance characteristics of 3.9 after having been stored at non-operating temperatures of -20 to 71 °C.

3.11.1.2 Temperature, operating. When tested in accordance with 4.5.6 the diagnostic equipment shall meet the performance characteristics of 3.9 when operated at temperatures of 10 to 40 °C.

3.11.1.3 Humidity (see 4.5.6). The diagnostic equipment shall meet the performance characteristics of 3.9 where the relative humidity is 5 to 95±5 percent in the temperature range of 10 to 30 °C. The diagnostic equipment shall be subjected to conditions where the relative humidity is 5 to 75±5 percent in the temperature range of 30 to 40 °C, and where the relative humidity is 5 to 45±5 percent in the temperature range above 40 °C. At temperatures below 0 °C, the humidity is uncontrolled, but the equipment shall meet the performance characteristics of 3.9 (after the specified warm-up period) and shall withstand the effects of humidity up to 100 percent.

3.11.2 Altitude, not operating. The diagnostic equipment shall meet the performance characteristics of 3.9 after return from an altitude of 15,000 feet, when tested in accordance with 4.5.7.

3.11.3 Fungus resistance (see 4.5.8). The diagnostic equipment shall not contain materials that provide nutrients for the growth of fungus.

3.11.4 Random vibration. The diagnostic equipment shall meet the performance characteristics of 3.9 after random vibration conditions specified in Table II, when tested in accordance with 4.5.9.

Table II. Random vibration.

Duration per axis (minutes)	Frequency (Hz)	Slope (dB/Octave)	PSD (g^2/Hz)
10	5-100	0	.015
	100-137	-6	-
	137-350	0	.0075
	350-500	-6	-
	500	-	.0039

3.11.5 Bench handling. The diagnostic equipment shall meet the performance characteristics of 3.9 and there shall be no damage to controls, indicators, or fuse holders after being tested in accordance with 4.5.10.

3.11.6 Electromagnetic compatibility (EMC) (see 4.5.11). The diagnostic equipment shall perform in the following environments listed in Table V of MIL-STD-461: Ground, Navy. Additionally, the diagnostic equipment shall be designed to operate in the electromagnetic environments specified in MIL-STD-464 and MIL-HDBK-235-1 (for guidance only).

3.12 Marking and identification. Diagnostic equipment shall be marked with appropriate identification in accordance with MIL-STD-130.

3.13 Reliability. The diagnostic equipment shall have a mean time between failure in excess of 1500 hours.

3.14 Maintainability. The diagnostic equipment shall meet the maintainability requirements of MIL-PRF-28800.

3.15 Workmanship. The diagnostic equipment shall be free from irregularities or defects that could degrade performance or durability.

3.16 Safety. The diagnostic equipment shall meet the safety requirements of MIL-PRF-28800.

3.17 Government validation. The diagnostic equipment shall be tested in a laboratory environment by the government using an Intermittent Fault Emulator (see Appendix A and 4.5.12).

4. VERIFICATION

4.1 Classification of inspections. The inspections specified herein are classified as specified as follows:

a. First article inspection (see 4.3).

b. Conformance inspection (see 4. 4).

4.2 Inspection conditions. Unless otherwise specified, all inspections shall be performed in accordance with the test conditions specified in 4.5.

4.3 First article. First article inspections shall be performed on diagnostic units when required in accordance with Table III testing requirements. The number of first article units shall be as required in the contract or purchase order (see 6.2.d).

TABLE III. Summary of environmental requirements.

Environmental Conditions/Tests	Requirement	Test Methods
Temperature, not operating	3.11.1.1	4.5.6
Temperature, operating	3.11.1.2	4.5.6
Humidity	3.11.1.3	4.5.6
Altitude, not operating	3.11.2	4.5.7
Fungus resistance	3.11.3	4.5.8
Random vibration	3.11.4	4.5.9
Bench handling	3.11.5	4.5.10
Electromagnetic Compatibility (EMC)	3.11.6	4.5.11

4.4 Conformance inspection. The conformance inspections shall include the following inspection and tests:

4.4.1 Mechanical and visual examination. The equipment shall be given a thorough mechanical and visual examination, and test to determine that all materials, workmanship, and safety characteristics comply with the specified requirements.

4.4.2 Electrical circuit configuration. The equipment shall be examined or tested to confirm that the wiring is correct. Where applicable, the tests shall include the requirements specified in a and b:

a. All intra-module wiring shall be tested to assure correctness.
b. The module grounding system shall be examined or tested to ensure proper separation of shield, signal, and framework grounds, and metal-to-metal contact for panels and components that serve as electromagnetic shields.

4.5 Test methods.

4.5.1 Test conditions. Unless otherwise specified in the detailed test herein, the inspection in 4.5 shall be performed under conditions a through d. Ambient conditions within the specified ranges need not be controlled. Measurements and observations shall only be taken after the diagnostic equipment has been turned-on and allowed to warm up for10 minutes (see 3.9.6).

a. Temperature: 25 °C ±10 °C
b. Humidity: 20 to 70 percent relative humidity.
c. Altitude: Sea level.
d. Power: See Table I.

4.5.2 Installation of test item in test facility. The diagnostic equipment shall be installed in the test facility in a manner that will simulate service usage, making connections and attaching instrumentation as necessary. Plugs, covers, and inspection plates not used in operation, but used in servicing, shall remain in place. When mechanical or electrical connections are not used, the connections normally protected in service shall be covered. For tests where temperature values are controlled, the test chamber shall be at standard ambient conditions when the test item is installed. The diagnostic equipment shall be operated to determine that no malfunction or damage was caused due to faulty installation or handling. The requirement for operation following installation of the test item in the test facility is applicable only when operation is required during exposure to the specified test.

4.5.3 Pretest. Prior to proceeding with the environmental tests, the test item shall be operated under standard ambient conditions (see 4.5.1) to evaluate the performance characteristics of the diagnostic equipment. This test is used to establish the level of performance of the diagnostic equipment at the outset of testing, prior to any environmental tests. This test is performed before, during, and after the environmental tests, whenever a satisfactory operational test is required. Degradation of the diagnostic equipment performance shall be noted if it exceeds any bound established in the purchase description.

4.5.4 Performance check during test. When operation of the diagnostic equipment is required during the test exposure, the pretest (see 4.5.3) shall be performed to determine whether the test exposure is producing changes in performance when compared with pretest qualification.

4.5.5 Post-test inspection. At the completion of each environmental test, the diagnostic equipment shall be inspected in accordance with pretest (see 4.5.3). The diagnostic equipment shall have failed the test when any of the conditions specified in a through g occur:

a. Monitored functional parameters deviate beyond acceptable limits established in 4.5.3.
b. Catastrophic or structural failure.
c. Mechanical binding or loose parts, including screws, clamps, bolts, and nuts, that results in component failure or a hazard to personnel safety.
d. Malfunction.
e. Degradation of performance beyond limits established in the purchase description.
f. Any additional deviations from acceptable criteria established before the test.
g. Deterioration, corrosion, or change in tolerance limits of any internal or external parts that could in any manner prevent the test item from conforming to operational service or maintenance requirements.

4.5.6 Temperature and humidity. The temperature and humidity tests shall be performed in accordance with 4.5.6.1. Figures 1 and 2 show the temperature and humidity profiles. No rust or corrosive contaminants shall be imposed on the test item by the test facility (temperature/humidity chamber).

4.5.6.1 Procedure temperature and humidity. Install the test item in the test facility in accordance with 4.5.2. During the tests specified in 4.5.6.1.1 the relative humidity need not be controlled. Relative humidity of 95 percent (with the applicable tolerance) does not include conditions of precipitation. The rate of temperature change shall be 1 °C to 5 °C per minute. The temperature limits and relative humidity shall be:

Not operating :	-20 °C to +70 °C
Operating:	+10 °C to +40 °C at 5 to 75 percent relative humidity.
	+10 °C to +30 °C at 5 to 95 percent relative humidity.

Precipitation is not authorized during the temperature and humidity test.

4.5.6.1.1 Temperature test procedure. The temperature test procedure consists of a five independent tests (a through e) that can be performed in any sequence, except as indicated for test (a). The profiles provided on Figure 1 demonstrate only one possible sequence of testing. The detailed test procedure at the time of testing shall define the actual test sequence. The humidity during the test is uncontrolled for all tests except test (d), where the humidity shall be controlled within the range of 5 to 20 percent relative humidity (with the applicable tolerance), to simulate an arid environment. The testing may be interrupted after any test, a through e. Performance of the satisfactory operation test shall occur at the end of each temperature test period, adding whatever time is required to perform the satisfactory operation test. (This means that the total time required to perform the temperature testing will be the cumulative total consisting of: the time required for each temperature test, the time required to perform a satisfactory operation test at each temperature test, and any interruption period).

a. Test (a). Place the test item in the test chamber in accordance with 4.5.2. This test is the initial operation verification test. With the temperature at the room ambient the equipment is operating for 2 hours, after which the satisfactory operational test is performed. Test (a) shall always be performed first in the test sequence.

b. Test (b). The temperature is maintained at 10 °C. The equipment is not operating for 4 hours. Operate the test item for the warm-up period recommended by the manufacturer. Perform the satisfactory operation test and compare the results with test (a) in accordance with 4.5.3. No alignment or adjustment of other than the operating controls shall be permitted throughout the test specified.

c. Test (c). The temperature is maintained at -40 °C. The equipment is not operating for 4 hours. Following the 4 hour cold storage soak, the temperature is raised to 23 °C. For an additional 4 hours the equipment is maintained at these conditions. Operate the test item for the warm-up period recommended by the manufacturer. Perform the satisfactory operation test and compare the results with test (a) in accordance with 4.5.3. No alignment or adjustment of other than the operating controls shall be permitted throughout the test specified.

d. Test (d). The humidity during this test is controlled at within the range of 5 to 20 percent (with the applicable tolerance). The temperature is maintained at 40 °C. The equipment is operating for 4 hours. Following the 4 hour arid heat operating soak, perform the satisfactory operation test and compare the results with test (a) in accordance with 4.5.3. No alignment or adjustment of other than the operating controls shall be permitted throughout the test specified.

e. Test (e). The temperature is maintained at 71 °C. The equipment is not operating for 4 hours. Following the 4 hour hot storage soak, the temperature is lowered to 23 °C. For an additional 4 hours the equipment is maintained at these conditions. Operate the test item for the warm-up period recommended by the manufacturer. Perform the satisfactory operation test and compare the results with test (a) in accordance with 4.5.3. No alignment or adjustment of other than the operating controls shall be permitted throughout the test specified.

4.5.6.1.2 Procedure, humidity cycle. The humidity cycle testing follows immediately after the testing of 4.5.6.1. This procedure consists of 5 days of temperature humidity cycling, with each day's cycle consisting of the profile displayed on Figure 2. Satisfactory operational tests are performed at the times indicated on the figures with a diamond symbol, noted as (a), (b), and (c) (as applicable). The following Notes 1 through 4 apply:

a. Note 1. A satisfactory operational test (at normal room ambient conditions) shall be conducted prior to and at-the-conclusion of the five-day humidity test.

b. Note 2. During the humidity cycle, the diagnostic equipment is only operating during the warm-up period and the satisfactory operational test.

c. Note 3. The satisfactory operation tests, as annotated by (a), (b), and (c) shall each be performed at least once each during the 5 days of humidity cycling, at the indicated times. Satisfactory operation tests (a) and (b), as appropriate, shall be performed at any of cycles 2, 3, 4, or 5. Satisfactory operation tests (c) shall be performed at least at Cycle 5. Satisfactory operation tests may also be performed at any, or all cycles at the indicated times.

d. Note 4. To accommodate varying times for completing satisfactory operational tests, the cycle timing after a test maybe adjusted to allow a return back to the regular profile timing. However, a minimum 4 hour dwell time prior to period of operation should be observed.

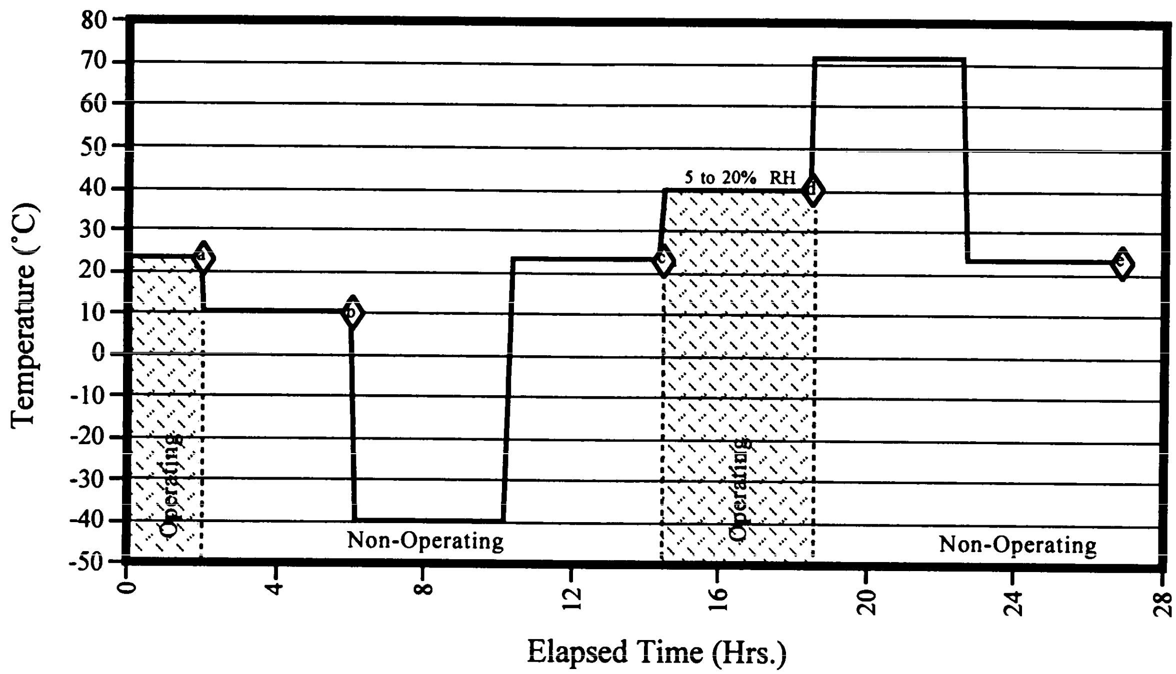


FIGURE 1. Temperature testing profile (including arid climate test).

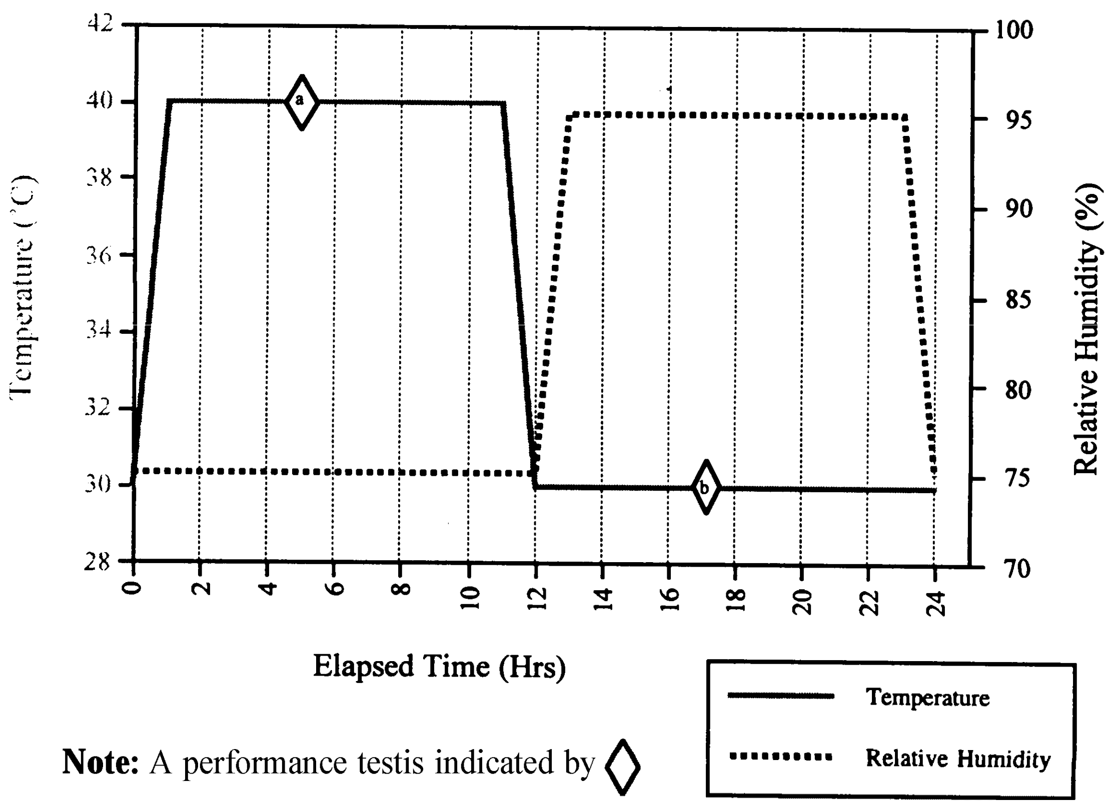


FIGURE 2. Five day humidity cycle profile that follows initial temperature test.

4.5.7 Altitude test, not operating (see 3.11.2). The altitude test shall be performed as specified in Steps 1 through 4 at the simulated altitude.

a. Step 1. Prepare the test item in accordance with 4.5.2 and maintain the temperature within the specified operating range for the duration of the test. The equipment shall be configured in a mode that can easily be accessed for measurement of conformance to specification. A performance test shall be made at this starting point to determine conformance to specification for the equipment.

b. Step 2. Decrease the chamber pressure to 15,000 feet at a rate not to exceed 2000 feet per minute with the diagnostic equipment not operating for 1 hour.

c. Step 3. With the diagnostic equipment not operating, return the chamber to standard ambient conditions at a rate not to exceed 2,000 feet per minute.

d. Step 4. Perform the satisfactory operation test after return to the test conditions of 4.5.3. Degradation of equipment performance beyond the specified requirements shall constitute a failure.

4.5.8 Fungus resistance (see 3.11.3).

4.5.8.1 Fungus resistance test. The diagnostic equipment shall be tested in accordance with MIL-STD-810, Test Method 508. The diagnostic equipment shall be removed from the test chamber and excess moisture may be removed by turning the diagnostic equipment upside down or by shaking. No washing or wiping of the diagnostic equipment is permitted.

4.5.8.2 Alternative fungus test method. As an alternative, the procuring activity may specify that the manufacturer provide a certified statement stating that no organic material is used in the manufacturing of the diagnostic equipment.

4.5.9 Random vibration tests (see 3.11.4). The vibration tests shall be as specified in 4.5.9.1. If a diagnostic equipment failure occurs, the diagnostic equipment may be repaired at the discretion of the procuring activity. If repair is allowed, testing will continue from the point at which the failure occurred until the remaining test period is completed. The portion of the test period prior to the failure will be repeated to evaluate the integrity of the repair. Failure modes that are not related to the original failure will be disregarded during the retest. At the discretion of the procuring activity, a second unit maybe subjected to the test in lieu of retesting the unit that failed.

4.5.9.1 Background information. Vibration levels on Figure 3 shall be applied to the diagnostic equipment, with durations of 10 minutes per axis. The diagnostic equipment shall be powered off during the vibration test. The diagnostic equipment is to be hard mounted to the table by gripping the equipment's structure. Unless the diagnostic equipment's feet are integral parts of the structure, they should be removed during the test; if they are integral, the diagnostic equipment should be fixed so that the vibration is applied to the structural frame of the diagnostic equipment. At the conclusion of the vibration test, conduct a physical evaluation and a performance test of the diagnostic equipment (see 4.5.2).

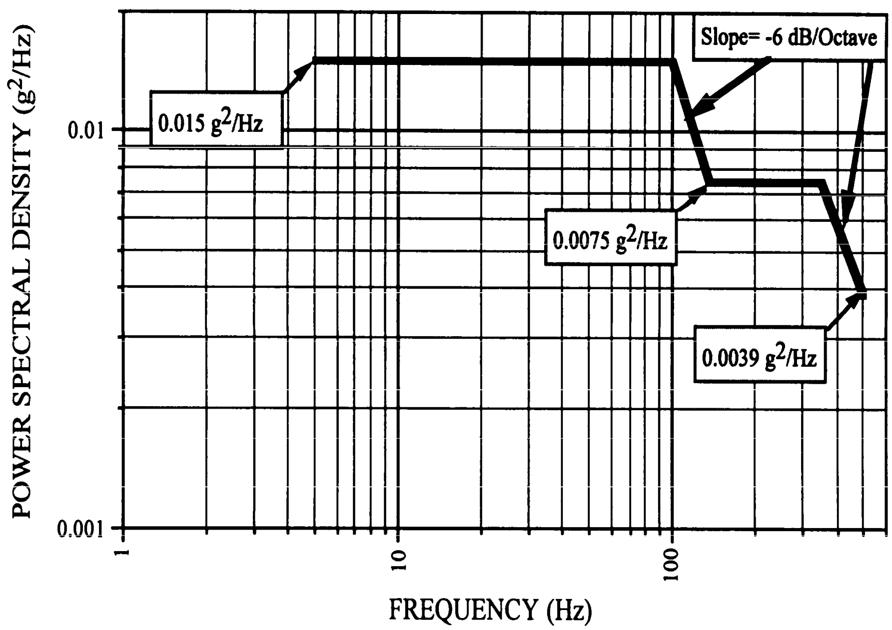


FIGURE 3. Random vibration profile.

4.5.10 Bench handling test (see 3.11.5). With the diagnostic equipment operating as in the satisfactory operating check, place the diagnostic equipment in a suitable position for its servicing on a horizontal, solid wooden bench top at least 4.1 centimeters (cm) thick. The test shall be performed as specified in Steps 1 through 5, in a manner simulating shocks liable to occur during its servicing.

a. Step 1. Using one edge as a pivot, lift the opposite edge of the chassis until one of the conditions specified in a through c occurs (whichever occurs first):

(1) The chassis forms an angle of 45 degrees with the horizontal bench top.

(2) The lifted edge of the chassis has been raised 4 inches above the horizontal bench top.

(3) The lifted edge of the chassis is just below the point of perfect balance.

Let the chassis drop back freely to the horizontal bench top. Repeat, using other practical edges of the same horizontal face as pivot points, for a total of four drops.

b. Step 2. Repeat Step 1, with the diagnostic equipment resting on other faces until the test item has been dropped for a total of four times on each face on which the test item could reasonably be placed during its servicing.

c. Step 3. Repeat Steps 1 and 2 with diagnostic equipment not operating and cabinet or case removed, except for equipment where the case serves as the only chassis or support structure.

d. Step 4. Examine the diagnostic equipment for mechanical damage. Damage to the instrument, other than cosmetic, will constitute a failure.

e. Step 5. Perform the satisfactory operation test.

4.5.11 Electromagnetic compatibility (EMC) (see 3.11.6). The diagnostic equipment shall be tested in accordance with MIL-STD-461 specific requirements of CE102, CS101, CS114, CS115, CS116, RE102, and RS103.

4.5.12 Government validation. The emulator is capable of generating multiple intermittent faults to simulate 256 LRU/WRA conductive paths. The emulator is capable generating controlled intermittent faults of various durations from 100 nanoseconds to one second at pseudo random time intervals. The diagnostic equipment must successfully detect all the intermittent faults (see 3.17).

5. PACKAGING

5.1 Packaging. For acquisition purposes, the packaging requirements shall be as specified in the contract or order (see 6.2). When packaging of materiel is to be performed by DoD or in-house contractor personnel, these personnel need to contact the responsible packaging activity to ascertain packaging requirements. Packaging requirements are maintained by the Inventory Control Point's packaging activities within the Military Service or Defense Agency, or within the military service's system commands. Packaging data retrieval is available from the managing Military Department's or Defense Agency's automated packaging files, CD-ROM products, or by contacting the responsible packaging activity.

6. NOTES

(This section contains information of a general or explanatory nature that may be helpful, but is not mandatory.)

6.1 Intended use. The diagnostic equipment covered by this specification is intended for use in detecting and isolating intermittent faults in LRU/WRA, chassis and backplanes and their wire harnesses. The diagnostic equipment is intended to be used with the LRU/WRA (with SRAs removed) being stimulated by temperature, vibration or vibration/temperature to emulate the environment in which the fault originally occurred. Appendices A through C provide recommended guidelines for defining this external stimulation.

6.2 Acquisition requirements. Acquisition documents should specify the following:

a. Title, number, and date of this specification.
b. Title, number, and date of the applicable purchase description.
c. Appropriate category (see 1.2).
d. Number of first article samples (see 4.2).
e. Packaging (see 5.1)
f. If required, the specific issue of documents.
g. First article inspection.
h. Production lot, conformance inspection.
i. The quantity of maintenance and calibration aid sets required will be as specified by the procuring activity, including: circuit board extenders, special adapters, special tools, and patch cables.
j. Waivers are required for equipment that incorporates restricted materials (see 3.10.2). The restricted materials are prohibited except where such materials are

fabricated into completed approved standard parts, or use of the material is approved by the procuring activity.
k. The equipment manufacturer must have a standard commercial quality assurance program. For example the program could be, but is not required to be certified to ISO 9001 or 9002. Other such recognized commercial quality assurance programs are acceptable.
l. Failure criteria.
m. If required, the location of the identification plate on a transit case must be specified.
n. The requirement for nomenclature assignment and the nomenclature to be assigned.
o. The equipment manufacturer should have a standard Electrostatic Discharge Control Program that complies with the requirements of MIL-STD-1686.
p. The quantity of accessories including, but not limited to: power cords, fuses (if required) , interface cables, etc.
q. The requirement for technical manuals (see technical manuals as defined in MIL-PRF-28800).
r. Microsoft Windows operating system version or Non-Windows operating system.
s. The requirement for Government Validation.
t. Marking (see 3.12).
u. Number of test points per modular unit and maximum amount of test point expansion.

6.3 First article inspection. When first article inspection is required, the equipment should be first production units. The contracting officer should include specific instructions in procurement documents regarding arrangements for examinations, approval of first article test results, and disposition of first articles.

6.4 Definitions.

6.4.1 Expandability. The ability of the base equipment to be interfaced with expansion equipment in logical increments to handle a growing amount of test points in a capable manner or its ability to be enlarged to accommodate that growth (e.g., increments of 64, 128, 256, test points, etc.).

6.4.2 Intermittent faults. Intermittent faults are short duration discontinuities (opens/shorts) that occur in conductive paths in LRU/WRA chassis/ backplanes. Intermittent faults occur as a result of various operational environmental stimuli, including, but not limited to, thermal stress, vibrational stress, gravitational G-force loading, moisture and/or contaminant exposure, as well as changes in the material due to age and use, such as the growth of tin whiskers, metal migration and delamination of materials. These faults can occur individually and /or in rapid succession on any chassis or backplane circuit. Fault durations range in time from nanoseconds to milliseconds and have variable impedances. These circuit path disruptions are frequently caused by: cracked solder joints; intermittent coax lines (e.g., shield corrosion, damaged center conductor, etc.); broken, cracked or frayed wires; loose clamps; and unsoldered pins. These circuit path disruptions often cause functional failures/faults in LRU/WRA chassis and backplanes whose root cause(s) cannot be detected and isolated using traditional automatic test equipment (ATE) and troubleshooting processes. Lacking the ability to detect and isolate intermittent failures and provide environmental stimuli during test and repair process, such assets are commonly reported as no-fault-found (NFF) or as one of the quasi-NFF repair codes (e.g., cannot duplicate (CND), retest OK (RETOK), beyond capability of maintenance (BCM), disassemble-clean-reassemble (DCR), etc.).

6.4.3 Fault isolation. The ability to locate the fault to a single/multiple conductive path(s).

6.4.4 Conductive path. Includes but is not limited to: wiring, circuit board traces, shields, bonding straps, connectors, jumpers, solder joints, connectors, etc.

6.4.5 Short duration fault. A short duration fault is a fault with duration under 100 nanoseconds and/or low resistance under 10 ohms. The random occurrence of these short duration faults can cause problems in high frequency (10 MHz or higher) or sensitive or critically balanced circuits.

6.4.6 Intermediate duration fault. An intermediate duration fault is a fault which has duration between 101 nanoseconds and 501 microseconds and/or low resistance between 50 to 500 ohms.

6.4.7 Long duration fault. A long duration fault is a fault which has duration between 500 microseconds and 5 milliseconds and/or high resistance (500 ohm to open).

6.4.8 Failure. Equipment failure as used herein is any departure from the required performance or operation outside of the required accuracies (not correctable by normal use of the operating controls), or deviation from the criteria of 4.5 after the test is initiated.

6.4.9 Bench-top equipment. Bench-top equipment is designed to be used on a fixed bench or table or on a mobile cart. Equipment that exceeds 5 kg in weight and has no handles, or exceeds 20 kg with or without a handle, is considered to be bench-top equipment.

6.4.10 Depot maintenance. Maintenance performed on material requiring major overhaul or a complete rebuild of parts, subassemblies and end items, including the manufacture of parts, modifications, testing, and reclamation. Depot maintenance serves to support lower echelons of maintenance by providing technical assistance and performing maintenance beyond their capability. Depot maintenance provides stocks of serviceable equipment by using more extensive facilities for repair than are available in lower level maintenance activities.

6.4.11 Open. An open, commonly referred to as an open circuit, is an abnormal or unintended loss of continuity that can occur in one or more conductive paths in the LRU/WRA chassis/backplane. This results in an interruption or loss electric current in the case of a power circuit or an abnormal or interruption or loss of signal in one or more conductive paths. The impedance of this conductive path is equal to the total impedance of the abnormal/unintended conductive path. The open impedance of the abnormal/unintended conductive path is defined as greater than 10 kilohms.

6.4.12 Short. A short, commonly referred to as a short circuit, is an abnormal or unintended connection between two conductive paths in the LRU/WRA chassis/backplane. This results in an increased electric current/over current in the case of a power circuit or an abnormal or unintended signal on two or more conductive paths. The impedance of this conductive path is equal to total impedance of the abnormal/unintended conductive path. The short impedance of the abnormal/unintended conductive path is defined as less than 10 ohms.

6.5 Government validation. The diagnostic equipment may be tested in a laboratory environment by the government using an Intermittent Fault Emulator. The emulator is capable of generating multiple intermittent faults to simulate 256 LRU/WRA conductive paths. The emulator is capable generating controlled intermittent faults of various durations from 100 nanoseconds to one second at pseudo random time intervals.

6.6 Physical characteristics. Diagnostic equipment design should consider the human factors engineering design principles of MIL-STD-1472, to ensure the equipment can be operated effectively and safely in its intended environment by appropriately trained personnel. All components should be selected and located for maximum ease of operation, inspection, and maintenance.

6.7 Subject term (key word) listing.

Connectors
Intermittent
Long Duration
Shorts
Terminal Boards
Wire Harness

VIBRATION STIMULATION

A.1 SCOPE

A.1.1 Scope. This appendix details ways to isolate failures related to vibration. This appendix is not a mandatory part of the specification. The information contained herein is for guidance only.

A.2 DETERMINING CAUSES OF INTERMITTENT FAILURES

A.2.1 Introduction. Each LRU/WRA is different in its function and operational environment. As a result, no single test method or procedure can adequately replicate an intermittent fault occurrence for all LRUs/WRAs. A careful review of the nature of the failure and the operational conditions under which the failure occurred is required. The following steps are recommended when by careful analysis it is determined that the failures occur during ground or flight operating conditions, and the operating temperature does not appear to be contributing to the occurrence of the failures.

A.2.2 Typical resulting effects. The following is a list of typical resulting effects of vibration-induced problems (this list is not intended to be all-inclusive):

a. Chafed wiring.
b. Loose fasteners/components
c. Intermittent electrical contacts
d. Electrical shorts.
e. Deformed seals.
f. Failed components.
g. Optical or mechanical misalignment.
h. Cracked and/or broken structures.
i. Migration of particles and failed components.
j. Particles and failed components lodged in circuitry or mechanisms.
k. Excessive electrical noise.
l. Fretting corrosion in bearings.

A.2.3 Operational vibration environment. A review should be conducted of technical manuals, operating manuals and any available information which provides insight into the operational vibration environment of the LRU/WRA. As much as practical this information should be used to tailor a vibration envelope for vibrating the LRU/WRA while troubleshooting the LRU/WRA for intermittent faults. It is not necessary to vibrate the LRU/WRA at full qualification levels which may induce additional failure modes. It is recommended that where the operational are not known, the qualification vibration test levels may be reduced by a factor of eight and used during troubleshooting of the LRU/WRA. The intent is to subject the LRU/WRA to a vibration level high enough to stimulate the intermittent fault, but not reduce the operational life of the LRU/WRA.

A.2.3.1 Unknown operational limits. Where the vibration operational limits are unknown, MIL-STD-810, Test Method 514 should be used to tailor the LRU/WRA vibration stimulation test sequence as a function of the life cycle environments of the LRU/WRA:

A.2.3.1.a. General. The accumulated effects of vibration-induced stress may affect LRU/WRA performance under other environmental conditions such as temperature, altitude, humidity, leakage, or electromagnetic interference (EMI/EMC). When evaluating the cumulative environmental effects of vibration and other environments, expose the LRU/WRA to all environmental conditions, with vibration testing generally performed first. If another environment (e.g., temperature cycling) is projected to produce damage that would make the LRU/WRA more susceptible to vibration, perform tests for that environment before vibration tests. For example, thermal cycles might initiate a fatigue crack that would grow under vibration or vice versa.

A.2.3.1.b. Unique to this method. Generally, expose the LRU/WRA to the sequence of individual vibration tests that follow the sequence of the life cycle. For most tests, this can be varied if necessary to accommodate test facility schedules, or for other practical reasons. Complete any maintenance associated preconditioning prior to tests representing mission environments. Perform tests representing critical end-of-mission environments last.

A.2.4 Worst case operational vibration. Functional testing is conducted to verify that the LRU/WRA functions as required while exposed to worst case operational vibration. Functional level vibration testing in accordance with MIL-STD-810, Test Method 514 is recommended. Fully verify the function at the beginning, middle and end of each test segment. Monitor basic separate functional and endurance tests are required, split the functional test duration, with one half accomplished before the endurance test, and one half after the endurance test (in each axis). The duration of each half should be sufficient to fully verify materiel function. This arrangement has proven to be a good way of adequately verifying that materiel survives endurance testing in all respects. In some cases, materiel that must survive severe worst case environments may not be required to function or function at specification levels during worst case conditions. Typically "operating" and "non-operating" envelopes are established. Tailor functional tests to accommodate non-operating portions by modifying required functional monitoring requirements as appropriate.

A.2.4.1 Category 7 (see MIL-STD-810, Test Method 514), jet aircraft. Vibration environments on jet aircraft are broadband random in nature. The maximum vibrations are usually engine exhaust noise generated and occur during takeoff. Levels drop off rapidly after takeoff to lower level cruise levels that are boundary layer noise generated.

A.2.4.2 Category 8 (see MIL-STD-810, Test Method 514), propeller aircraft. Vibration environments on propeller aircraft are dominated by relatively high amplitude, approximately sinusoidal spikes at propeller passage frequency and harmonics. Because of engine speed variations, the frequencies of the spikes vary over a bandwidth. There is wide band vibration at lower levels across the spectra. This wide band vibration is primarily due to boundary layer flow over the aircraft.

A.2.4.3 Category 9 (see MIL-STD-810, Test Method 514), helicopter. Vibration environments on helicopters are characterized by a continuous wideband, low-level background with strong narrowband peaks superimposed. This environment is a combination of many sinusoidal or near sinusoidal components due to main and tail rotors, rotating machinery and low-level random components due to aerodynamic flow.

TEMPERATURE STIMULATION

B.1 SCOPE

B.1.1 Scope. This appendix deals with ways to isolate faults related to operating temperature. This appendix is not a mandatory part of the specification. The information contained herein is for guidance only.

B.2 DETERMINING CAUSES OF INTERMITTENT FAILURES

B.2.1 Introduction. Each LRU/WRA is different in its function and operational environment. As a result, no single test method or procedure can adequately replicate an intermittent fault occurrence for all LRUs/WRAs. A careful review of the nature of the failure and the operational conditions under which the failure occurred is required. The following steps are recommended when by careful analysis it is determined that the failures occur during ground or flight operating conditions, and the operating temperature appears to be contributing to the occurrence of the failures.

B.2.2 Typical resulting effects. The following is a list of typical resulting effects of temperature-induced problems (this list is not intended to be all-inclusive):

a. Binding or slackening of moving parts.
b. Deformation or fracture of components.
c. Cracking of surface coatings.
d. Leaking of sealed compartments.
e. Failure of insulation protection.
f. Differential contraction or expansion rates or induced strain rates of dissimilar materials.
g. Intermittent electrical contacts.
h. Electrical shorts/opens.
i. Failed components.
j. Changes in electrical and electronic components.
k. Electronic or mechanical failures due to rapid water or frost formation.
l. Excessive static electricity.

B.2.3 Operational temperature environment. A review should be conducted of technical manuals, operating manuals and any available information that provides insight into the operational temperature environment of the LRU/WRA. As much as practical, this information should be used to tailor a temperature cycling profile for temperature stressing the LRU/WRA while troubleshooting the LRU/WRA for intermittent faults. It is not necessary to temperature cycle the LRU/WRA at full qualification levels which may induce additional failure modes. It is recommended that where the operational temperature test levels are not known that the qualification temperature levels during troubleshooting of the LRU/WRA be reduced in order to not over stress the LRU/WRA. The intent is to subject the LRU/WRA to a temperature level low/high enough to stimulate the intermittent fault, but not reduce the operational life of the LRU/WRA.

B.2.3.1 Unknown temperature operational limits. Where the temperature operational limits are unknown, MIL-STD-810, Test Method 503 should be used to tailor the LRU/WRA temperature stimulation test sequence as a function of the life cycle environments of the

LRU/WRA. It should be noted that Test Method 503 is a temperature shock test method and should be tailored to represent the operational temperature changes that the LRU/WRA is exposed to in its operating environment. Procedure I-C, Multi-cycle shocks from constant extreme temperature or Procedure I-D, Shocks to or from controlled ambient temperature is recommended depending on the operational environment of the LRU/WRA.

B.2.3.1.1 Information collection. During the temperature cycling testing, the following information should be collected:

a. Record of chamber temperature versus time conditions.
b. Test item temperatures (measured locations).
c. Transfer times (e.g., "door open" to "door closed").
d. Duration of each exposure.
e. Conductive path intermittent fault location.

TEMPERATURE/VIBRATION STIMULATION

C.1 SCOPE

C.1.1 Scope. This appendix deals with ways to isolate faults related to a combination of operating temperature and vibration. This appendix is not a mandatory part of the specification. The information contained herein is for guidance only.

C.2 DETERMINING CAUSES OF INTERMITTENT FAILURES

C.2.1 Introduction. LRU/WRAs are different in their function and operational environments. As a result, no single test method or procedure can adequately replicate an intermittent fault occurrence for all LRUs/WRAs. A careful review of the nature of the failure and the operational conditions under which the failure occurred is required. The following steps are recommended when by careful analysis it is determined that the failures occur during ground or flight operating conditions.

C.2.2 Typical failures. Temperature, humidity, vibration, and altitude can combine synergistically to produce the following failures. Although altitude is included in the following discussion typically in regards to LRU/WRA operating environment it mainly impacts cooling and is a function of temperature. Typically Combined Environmental Test facilities do not include altitude test capability. The following examples are not intended to be comprehensive:

a. Shattering of optical material. (Temperature/Vibration/Altitude)
b. Binding or loosening of moving parts. (Temperature/Vibration)
c. Separation of constituents. (Temperature/Humidity/Vibration/Altitude)
d. Performance degradation in electronic components due to parameter shifts (Temperature/Humidity)
e. Electronic optical (fogging) or mechanical failures due to rapid water or frost formation. (Temperature/Humidity).
f. Differential contraction or expansion of dissimilar materials. (Temperature/Altitude)
g. Deformation or fracture of components. (Temperature/Vibration/Altitude)
h. Cracking of surface coatings. (Temperature/Humidity/ Vibration/Altitude)
i. Leakage of sealed compartments. (Temperature/Vibration//Altitude)
j Failure due to inadequate heat dissipation. (Temperature/Vibration /Altitude)

C.2.3 Combined forcing functions. A review should be conducted of technical manuals, operating manuals and any available information, apply the tailoring process in MIL-STD-810 to determine where these combined forcing functions of temperature, humidity, vibration, and altitude are foreseen in the LRU/WRA operational environment Use this method only if the proper engineering has been performed such that the environmental stresses associated with the individual methods are encompassed by the combined test. If appropriate, tailor storage thermal environments into the combined environmental cycle; or, perform them as separate tests, using the individual test methods. Use the following to aid in selecting this method and placing it in sequence with other methods.

C.2.3.1 Unknown operational limits. Where the temperature/vibration/humidity/altitude operational limits are unknown, MIL-STD-810, Test Method 520 should be used to tailor the

LRU/WRA temperature/vibration stimulation test sequence as a function of the life cycle environments of the LRU/WRA:

C.2.3.1.1 Vibration. Four vibration profiles may be used:

a. A random test profile with the following parameters is an example of temperature/vibration:
b. A 20-800 Hz random profile where $G^2/Hz = 0.0051282$ and G RMS = 2
c. A 20-300 Hz sine sweep that runs for 3:54 where G = 2
d . A 20-300 Hz sine sweep that runs for 0:15 where G = 2

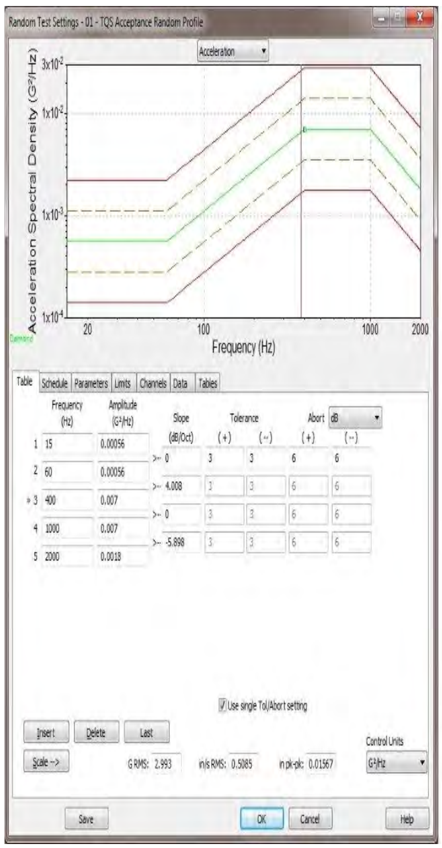


FIGURE C-1. Example random vibration test profile.

C.2.3.1.2 Temperature:

a. Initially the vibration profiles are run at room temperature, approximately 24 °C
b. The temperature is then dropped to -0 °C at 5 °C/minute and vibration profiles are run as the temperature drops.
c. The temperature is then held at -0 °C for a 15-minute soak time, during which time the vibration profiles are run.

d. The temperature is then dropped to -40 ^{o}C at 5 ^{o}C/minute and vibration profiles are run as the temperature drops.
e. The temperature is then held at -40 ^{o}C for a 15-minute soak time, during which time the vibration profiles are run.
f. The temperature is then raised to 70 ^{o}C at 5^{o}C/minute and vibration profiles are run as the temperature rises.
g. The temperature is then held at 70 ^{o}C for a 15-minute soak time, during which time the vibration profiles are run.
h. Finally, the temperature is returned to room temperature at 5 ^{o}C/minute and vibration profiles are run as the temperature falls.

CONCLUDING MATERIAL

Custodians:
Army - MI
Navy - AS
Air Force - 85

Review activity:
Air Force - 99

Preparing activity:
Navy - AS
(Project 6625-2014-025)

NOTE: The activities listed above were interested in this document as of the date of this document. Since organizations and responsibilities can change, you should verify the currency of the information above using the ASSIST database at https://assist.dla.mil.

MIL-PRF-32516

October 27, 2015

Presented to:

Joint Technology Exchange Group (JTEG)

Prepared by:

John Garrett

AIR-1.3.1.8.2, AWSEC Team Lead

JIT Charter

- Tri-Service Team from DoD automatic test and wiring communities.
  - IPT Lead: Mr. Greg Kilchenstein (OSD, Director of Enterprise Maintenance Technology)
    - Purpose: Leverage current and emerging commercial industry activity for demonstration, testing, and cost analysis.
      - Define and validate joint performance requirements
      - Collect and analyze data on COTS intermittent fault detection systems currently in use
      - Define the minimum fault detection threshold requirements for UUTs
      - Identify, define and validate test methods for detecting and isolating intermittent faults
      - Publish Joint performance requirement (MIL-PRF) document.
      - Brief and publish findings in a technical reports, as well as make a recommendation to Service Components on path forward

Intermittence Scope

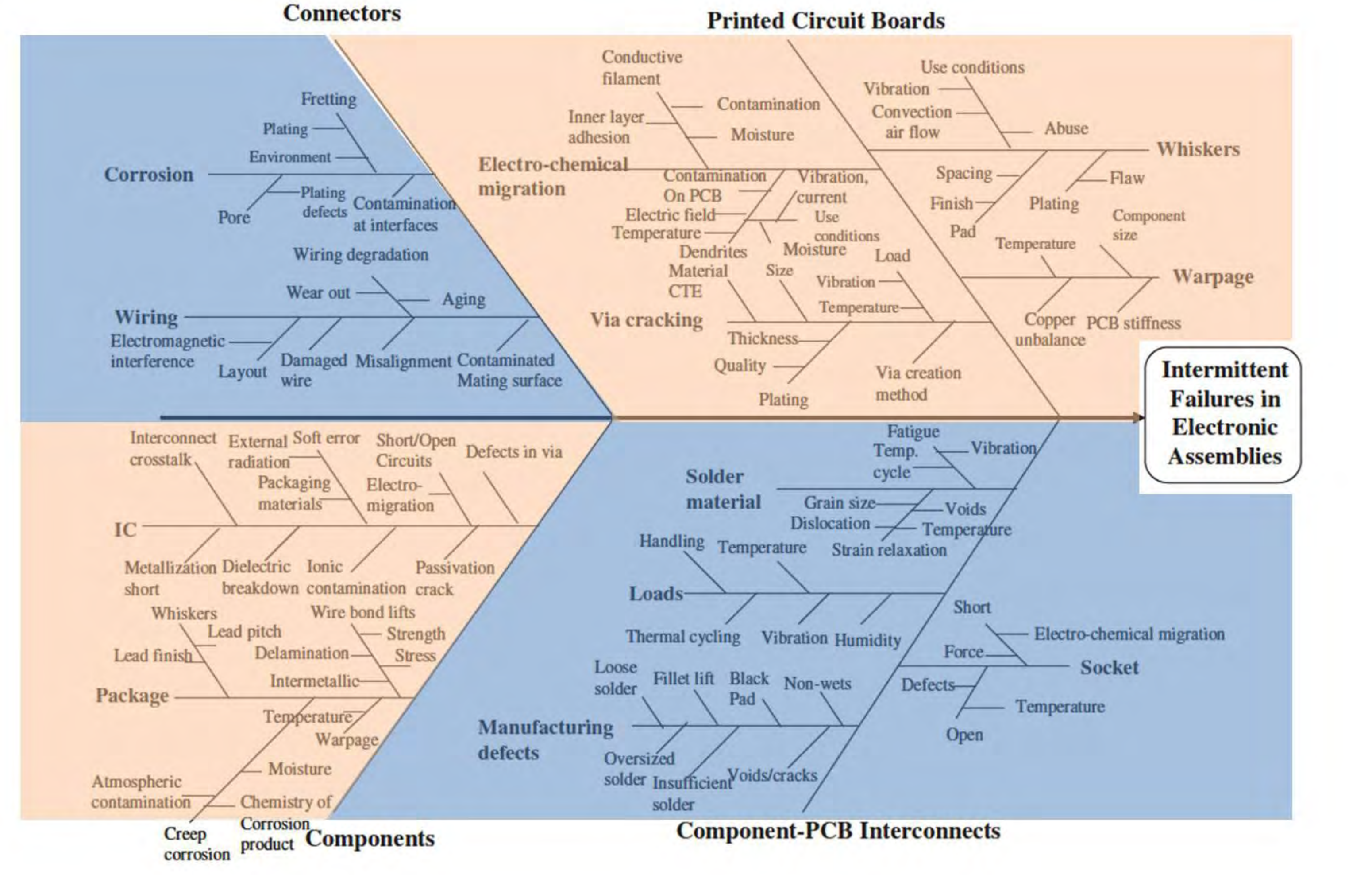
<u>JIT Team Definition of "Environmentally Induced Intermittent Fault"</u>

A discontinuity that occurs in LRU/WRA chassis and backplane conductive paths as a result of various operational environmental stimuli, including, but not limited too:

- thermal stress
- vibrational stress
- gravitational G-force loading
- moisture and/or contaminant exposure

- As well as changes in the material due to age and use, such as tin whiskers, metal migration and delamination of materials. These faults can occur individually and/or in rapid succession on any chassis or backplane circuit.

Intermittence Scope (Cont)



Source: H. Qi, S. Ganesan, M. Pecht, “No-fault-found and intermittent failures in electronic products”, in *Microelectronics Reliability,* vol. 48, pp. 663–674, (2008).

MIL-PRF-32516

- “Electronic Test Equipment, Intermittent Fault Detection and Isolation for Chassis and Backplane Conductive Paths”
- Published: March 23, 2015
- Purpose: Assist in the writing of specifications for intermittent fault test equipment acquisitions

MIL-PRF-32516 (Cont)

- Scope:
  - Covers the minimum performance requirements for equipment to detect and isolate nanosecond, microsecond and millisecond conductive paths and intermittent faults.
  - Faults can occur in any and all of the hundreds to thousands of Line Replaceable Unit (LRU)/Weapon Replaceable Assembly (WRA) chassis and backplane circuits and their wire harnesses.

MIL-PRF-32516 (Cont)

- Establish a tailorable performance requirements framework for intermittent fault test equipment to detect and isolate nanosecond, microsecond and millisecond conductive path intermittent faults in chassis and backplane circuits of WRAs/LRUs and their wire harness.

- Not intended to address hard opens, shorts, or constant function failures found in routine electronics repair.

Fault Classifications

- Category 1. Short duration fault which is under 100 nanoseconds across all LRU/WRA backplane circuits and their wire harness.
- Category 2. Intermediate duration fault which is 101 nanoseconds to 500 microseconds across all LRU/WRA backplane circuits and their wire harness.
- Category 3. Long duration fault which is 501 microseconds to 5 milliseconds across all LRU/WRA backplane circuits and their wire harness.

Intermittent Fault Emulator (IFE)

- Purpose
  - Evaluate the performance of intermittent fault detection diagnostic equipment (i.e. the 'Tester Under Test' (TUT))
    - Induces conductive path faults that emulate intermittent faults in Line Replaceable Units (LRUs)/Weapon Replaceable Assemblies (WRAs)
    - Per user defined requirements, provides the DoD an objective evaluation tool of the TUT's ability to detect intermittent faults

Intermittent Fault Emulator (IFE)

- Acquired through CTMA, in partnership with National Center for Manufacturing Sciences (NCMS)
- Manufactured by Copernicus Technologies, UK
- Formal Verification Complete
- 2 assets received
- Parallel Validation efforts underway at Hill AFB and NAVAIR LKE

IFE Technical Details

- The IFE is similar in appearance to an aircraft WRA/LRU
- Connects to Windows-based computer via USB, using the IFE software application
- The IFE has 8 connectors, A to H, on the front panel for connection to the tester-under-test (TUT)
  - MIL-DTL 38999 Series 1 type with a 66-pin, 19-35 insert configuration with #22D male contacts.
  - The IFE generates one of five selectable resistances to any of 256 channels, to represent intermittent fault events for the TUT to detect.
  - Sequences of these events are run from the IFE software application.
    - Event sequences can be pseudo-random or user-defined event sequences;
    - All sequences are saved and time-stamped and they can be repeated, modified, analysed and downloaded.

Questions?

NOT MEASUREMENT SENSITIVE

MIL-HDBK-527
13 April 2017

DEPARTMENT OF DEFENSE HANDBOOK

GUIDANCE FOR INTERMITTENT FAULT EMULATOR (IFE)

This handbook is for guidance only.
Do not cite this document as a requirement.

AMSC N/A

FSC 6625

FOREWORD

1. This handbook is approved for use by all Departments and Agencies of the Department of Defense (DoD).

2. This handbook provides guidance on use and application of the Copernicus Technology Ltd. part number CTL990495 Intermittent Fault Emulator (IFE). This handbook does not assume prior knowledge of the IFE. It is recommended that both beginner and advanced users read the entire user manual for both the intermittent fault diagnostic equipment and IFE before starting any diagnostic equipment evaluation. The IFE is used to verify or qualify the ability of technologies, methods, and devices to detect and isolate intermittent faults. These intermittent faults occur in the conductive path(s) in Line Replaceable Unit/Weapon Replaceable Assembly (LRU/WRA) chassis or backplanes. The chassis or backplanes may contain hundreds to thousands of conductive paths and solder connections.

3. This handbook is intended to aid acquisition organizations in procuring intermittent fault detection and isolation (IFDI) technology. This IFDI technology is designed to be capable of detecting and isolating LRU/WRA chassis and backplane conductive paths, which are exhibiting intermittent behavior when the LRU/WRA is subjected to operational stresses such as temperature and vibration. This intermittent behavior results in the removal and replacement/repair of the LRU/WRA with no fault found resulting in aircraft loss of mission capability and high maintenance costs.

4. Comments, suggestions, questions or additional information on this document should be addressed to: Naval Air Warfare Center Aircraft Division, Code 4.1.2.2, Highway 547, Mail Stop 120-3, Joint Base MDL, NJ 08733-5100 or by email to michael.sikora@navy.mil. Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online database at https://assist.dla.mil.

CONTENTS

CONTENTS

PARAGRAPH PAGE

CONTENTS

CONTENTS

1. SCOPE

1.1 Scope. This handbook provides guidance and lessons learned for acquisition organizations using the Intermittent Fault Emulator (IFE) to evaluate Intermittent Fault Detection and Isolation (IFDI) technologies, methods, and/or devices prior to acquisition. This information includes: the IFE User Manual, IFE programming considerations, and IFE pinouts for constructing an Interface Adaptor Harness (IAH). IFDI manufacturers and suppliers can demonstrate and verify their test equipment capabilities to detect and isolate intermittent faults by using the IFE. This handbook is for guidance only and cannot be cited as a requirement.

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

2.2 Government documents.

2.2.1 Specifications and standards. The following specifications and standards form a part of this document to the extent specified herein.

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-PRF-32516 - Electronic Test Equipment, Intermittent Fault Detection and Isolation for Chassis and Backplane Conductive Paths

MIL-DTL-38999 - Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded or Breech Coupling), Environment Resistant with Crimp Removable Contacts or Hermetically Sealed with Fixed, Solderable Contacts, General Specification for

DEPARTMENT OF DEFENSE STANDARD

MIL-STD-1560 - Insert Arrangements for MIL-DTL-38999, MIL-DTL-27599 and SAE-AS29600 Series A Electrical Circular Connectors

(Copies of these documents are available online at http://quicksearch.dla.mil/.)

2.3 Non-Government publications. The following documents form a part of this document to the extent specified herein.

COPERNICUS TECHNOLOGY LTD.

CTL-229-01 - IFE User Manual

(Copies of this document are available from www.copernicustechnology.com.)

NATIONAL CENTER FOR MANUFACTURING SCIENCES

Joint Intermittence Testing (JIT) Capability Final Report 2015
Joint Intermittence Testing (JIT) Capability, Phase II 2016

(Copies of these documents are available from www.ncms.org.)

SAE INTERNATIONAL

SAE AS39029 - Contacts, Electrical Connector, General Specification for (DoD adopted)

(Copies of this document are available online at http://www.sae.org.)

UNIVERSAL SYNAPTICS CORPORATION

Universal Synaptics Technical Evaluation and Simulated Intermittent Event Characterization Report

(Copies of this document are available from www.ussynaptic.com.)

3. ACRONYMS AND DEFINITIONS

3.1 Acronyms. The following acronyms are applicable to this handbook.

ATE	Automatic Test Equipment
BCM	Beyond Capability of Maintenance
CND	Cannot Duplicate
dB	Decibel
DoD	Department of Defense
DCR	Disassemble -Clean-Reassemble
ESD	Electrostatic Discharge
GUI	Graphical User Interface

GCU	Generator Converter Unit
IAH	Interface Adaptor Harness
IDE	Intermittent Diagnostic Equipment
IDFE	Intermittent Fault Diagnostic Equipment
IFDI	Intermittent Fault Detection and Isolation
IFE	Intermittent Fault Emulator
kV	kilovolt
kHz	kilohertz
LRU	Line Replaceable Unit
MHz	megahertz
µs	microseconds
mA	milliamperes
ms	milliseconds
MTBDR	Mean Time Between Depot Repair
nA	nanoamperes
ns	nanoseconds
NFF	No Fault Found
OSD/AT&L	Office of the Secretary of Defense for Acquisition, Technology and Logistics
pF	picofarad
RETOK	Retest OK
SG	Signal Generator
WRA	Weapons Replaceable Assembly

3.2 Definitions. The following definitions are applicable to this handbook.

3.2.1 Cable harness. Cable harness is a generic term for multiple cables gathered together to form a number of circuit paths.

3.2.2 DeltaT. The duration in microseconds of an event. This definition only applies to flexible event profiles. (See figures 2 through 7 and Appendix B, Notes after table B-I.)

3.2.3 Intermittent faults. Intermittent faults are short duration discontinuities (opens/shorts) that occur in conductive paths in LRU/WRA chassis/backplanes and cable harnesses. Intermittent faults occur as a result of various operational environmental stimuli, including, but not limited to, thermal stress, vibrational stress, gravitational G-force loading, moisture and/or contaminant exposure. Intermittent faults can also occur because of changes in the material due to age and use, such as the growth of tin whiskers, metal migration and delamination of materials. These faults can take place individually and/or in rapid succession on any chassis or backplane circuit. Fault durations range in time from nanoseconds to milliseconds and have variable impedances. These circuit path disruptions are frequently caused by: cracked solder joints; intermittent coaxial lines (e.g., shield corrosion, damaged center conductor, etc.); broken, cracked or frayed wires; loose clamps; and unsoldered pins. LRU/WRA chassis and backplanes are commonly reported as NFF or as one of the quasi-NFF repair codes (e.g., CND, RETOK, BCM, DCR, etc.) due to the inability to detect and isolate intermittent failures and provide environmental stimuli during test and repair process.

3.2.4 Intermittent fault emulator (IFE). The IFE is test equipment designed to emulate intermittent faults that occur in the LRU/WRA conductive paths and cable harnesses. The emulator has 256 test channels available that can be programmed with variable resistance faults of 100 nanoseconds to 500 milliseconds duration individual faults, which can also be grouped into burst faults as a 5 MHz pulse from 3 to 5 microseconds. The IFE contains software controlled semiconductor switches, which can simulate combined individual and burst conductive path faults of programmed or pseudorandom duration on programmed or pseudorandom conductive paths. The purpose of the IFE is to emulate an intermittent fault of known duration on a known conductive path to verify the capability of test equipment to detect and isolate this simulated fault. Each IFE channel has four software controlled semiconductor switches to randomly create four variable fault resistances.

3.2.5 LRU. LRU is an essential aircraft support item such as aircraft avionics equipment that is replaced at the field level to restore the aircraft to an operationally ready condition. LRU is a used most commonly by the Air Force to identify aircraft avionics equipment and is often used interchangeably with the term weapons replaceable assembly (WRA).

3.2.6 NFF. NFF is a term used in the field of failure analysis used to describe a situation where an originally reported mode of failure can't be duplicated by the evaluating technician and therefore the potential defect can't be fixed. NFF can be attributed to oxidation, defective connections of electrical components, or temporary shorts or opens in the circuits. These faults can also occur due to software bugs, temporary environmental factors, and operator error. Large numbers of devices that are reported as NFF during the first troubleshooting session often return to the failure analysis lab with the same NFF symptoms or a permanent mode of failure.

3.2.7 WRA. WRA is a generic term that includes all replaceable packages of a system installed in the weapons system with the exception of cables, mounting provisions, and fuse boxes or circuit breakers. WRA is generally modular in form and designed to facilitate an organizational level and maintenance concept. The preferred form of WRA is the light replaceable assembly that is easily removed and replaced in the weapons system by one man in not more than 15 minutes. WRA is a used most commonly by the Navy to identify aircraft avionics equipment and is often used interchangeably with the term LRU.

4. GENERAL GUIDANCE

4.1 Background. According to OSD/AT&L, “bad” LRUs/WRAs cost DoD at least two billion dollars annually. Bad LRUs/WRAs are those LRUs/WRAs having a history of failing during in-flight operation, but the failure cannot be duplicated when it is analyzed at the repair depot. The inability to duplicate the failure results in LRUs/WRAs being classified as NFF/BCM by the depot repair facility. Recent engineering efforts have led to the development of a database of serialized repair data used to identify bad LRUs/WRAs by their maintenance histories and significant advances in intermittent fault detection and isolation of LRU/WRA chassis and backplane conductive paths. The combination of these two advances has led to significant increases in MTBDR. The development of this database and improved fault detection and isolation techniques have provided insight into this previously unidentified intermittent failure mode and cyclic stress fatigue induced intermittence in LRU/WRA chassis and backplane wiring and connections. These advances have also led to the discovery that current ATE is unable to detect these failure modes and to the development of intermittent fault diagnostic equipment. To evaluate effectiveness of intermittent fault diagnostic equipment, OSD AT&L developed the IFE. The IFE is a device capable of being programmed to emulate the failure signals of an LRU/WRA experiencing intermittence.

4.2 Known intermittence. As stated in the MIL-PRF-32516, Appendix A: "Each LRU/WRA is different in its function and operational environment. As a result, no single test method or procedure can adequately replicate an intermittent fault occurrence for all LRUs/WRAs. A careful review of the nature of the failure and the operational conditions under which the failure occurred is required."

4.3 IFE background. The part number CTL990495 IFE was designed by Copernicus Technology Ltd. for the DoD to emulate intermittent faults that were commonly classified as NFF when the LRU/WRA was failure analyzed by the repair depot. The IFE is capable of generating individual variable resistance faults and burst of multiple resistance faults. The durations, profiles and pulse durations of the faults are software programmable by the user using IFE profile codes. In addition, the IFE is capable of emulating nodal and data bus circuit types. The IFE allows the evaluator to determine individual intermittent fault diagnostic equipment technology voids or abilities to detect and isolate faults by generating known intermittent faults. The IFE was evaluated against contract design requirements during a joint testing event at Naval Air Warfare Center Aircraft Division Lakehurst, Joint Base MDL NJ using a PicoScope to generate individual and peak signals.

4.4 Two-stage evaluation. A best practice when using the IFE is to have a two-step procedure. The first step is to evaluate the multi-channel capability of the IDFE using the IFE. The second step is to evaluate using a signal generator to determine the equipment's capability to detect events down to 100 nanoseconds. This two-step procedure is particularly important when the IDE stimulus voltages and currents are below 5 volts and 30 milliamps for frequencies from 40 KHz to 10 MHz (see 5.1).

5. DETAILED GUIDANCE

5.1 IFE description. The purpose of the IFE is to evaluate the performance of intermittent fault detection diagnostic equipment by inducing conductive path faults that emulate intermittent faults in LRUs/WRAs. As a result, the IFE enables an evaluation of the diagnostic equipment's ability to detect intermittent faults. Two events were hosted by DoD: Industry Week on 5-6 January 2016 and Industry Day on 22 March 2016. During these events, diagnostic equipment made by Eclypse International Corp.; Ridgetop Group, Inc.; Solavitek, Inc.; and Universal Synaptics Corp., were evaluated with the IFE.

The IFE is similar in appearance to an aircraft LRU/WRA and consists of the IFE unit connected to a host computer running Windows® and the IFE software application. The host computer is the user interface to the IFE. The IFE has 8 connectors, A to H, on the front panel (see figure 1) for connection to the diagnostic equipment. The connectors are MIL-DTL-38999 Series 1 with insert arrangement layout 19-35 (see MIL-STD-1560) having 66 size 22D (see SAE AS39029) male contacts.

The IFE input power is designed to tolerate 90 to 175 volts, or 132 to 264 volts at 47 to 63 Hz, and is protected by in-line fuse in the input connector. The maximum current requirement at 90 volts AC is 1.6 amps with a 55 watt load. The IFE is supplied with a polarized 120 volt 60 Hz plug having one blade wider than the other.

The IFE generates a variance in resistance across 256 channels on connectors A to H, to represent intermittent fault events for the diagnostic equipment to detect. Full details of how the IFE test channels are configured to the connector pin-out are specified in Annex B of the CTL-229-01 User Manual. Sequences of these simulated fault events are run from the IFE software application. Event sequences can be pseudo-random or user-defined event sequences; all sequences are saved and time-stamped and they can be repeated, modified, analyzed and downloaded.

FIGURE 1. Front of intermittent fault emulator.

FIGURE 2. Back of the intermittent fault emulator.

5.1.1 GUI application. During use, the IFE is connected to a host computer running Windows® and GUI application supplied with the IFE on a compact disc. This application is downloadable on to the host computer, is the user interface with the IFE, and is menu-driven. The GUI application is used to set up intermittent event sequences and to manage, save, and download the sequences and corresponding runs or emulations. The primary screens and indications of the application are detailed in the User Manual (see CTL-229-01).

5.1.2 IFE interface requirements. An interface adapter harness is not provided with the IFE and must be constructed. In addition, the GUI application includes profile codes that may be used to define event sequences and single events, but are limited in scope. These profile codes may be used as building blocks to emulate intermittent faults. It is recommended that the following interface elements be considered prior to evaluation of intermittent fault diagnostic equipment.

5.1.2.1 Detailed test design. An analysis should be performed of the LRU/WRA components that are expected to be tested with the intermittent fault diagnostic equipment. This analysis should include: LRU/WRA expected to be analyzed and failure data; types of intermittent faults (short or long duration, bursts); multiple or single faults; periodic or random; nodal or bus channel architecture; etc. In addition, the intermittent fault diagnostic equipment output per channel should not exceed the following:

±15 V tolerant
Continuous current 100 mA
Peak current 200 mA pulsed at 1 ms with a 10 percent duty cycle
Leakage current 0.04 nA typical, 1 nA max
Charge Injection 20 pF typical, 30 pF max
Channel Cross Talk -90 dB at 1 MHz, -30 dB at 100 Mhz

5.1.2.2 Interface adapter harness design. A wire harness will be required to connect the diagnostic equipment to the IFE. The harness design considerations may include: wiring for the total number of channels to be evaluated simultaneously; shielding if required; and the connectors to interface with the diagnostic equipment and IFE. The harness will require MIL-DTL-38999 Series 1 with insert arrangement 19-35 (see MIL-STD-1560) service M 66-way with type #22D female contacts.

Caution

All of the IFE channels have limited ESD protection of 2 kV. Take appropriate precautions to prevent risk of ESD during connecting and disconnecting the intermittent fault diagnostic equipment to the IFE.

5.1.2.3 Coding and compiling. A GUI software application is provided with the IFE. Information on setting up and controlling the intermittent fault diagnostic equipment will be required and is not included with the IFE. IFE programming will be required to test the required test sequences, depending on the information determined during the detail design test development (see 5.1.2.1) for the diagnostic equipment.

5.1.2.4 Integration. Give consideration to how the diagnostic equipment will be integrated with the IFE. For example, determine if an automated program can be used to test all of the diagnostic functions or determine if an operator will be required to step the diagnostic equipment or IFE through various test steps.

5.1.2.5 Acceptance testing. IDE acceptance testing should include: pre-performance testing (startup, hookup, verification that IFE is properly connected to diagnostic equipment, safe-to-turn-on); performance testing (functional test of the diagnostic equipment, compliance of the diagnostic equipment to operational specification, ability of the diagnostic equipment to locate and isolate simulated intermittent faults; time to complete fault analysis; operator intervention (adjustments or alignments). In addition, criteria should be established for acceptance: time to find faults and percentage of faults located and isolated.

5.1.3 Concept of operation. The IFE can generate individual, variable resistance faults of 100 nanoseconds to 500 milliseconds nominally, and “burst” conductive faults as a 5 MHz pulse, from 3 to 5 microseconds. All time-based fault durations, profiles and pulse durations (above 100 nanoseconds) are software programmable by the user defining the test by use of the profile codes described in full at Annex A of the User Manual (see CTL-229-01).

There are 3 basic approaches to using the IFE for evaluating the intermittent fault detection performance of the diagnostic equipment being evaluated:

- **Pseudo-Random:** the user generates a pseudo-random event sequence lasting 15 minutes and containing 100 randomly occurring, intermittent single and burst events.

- **User-Defined:** the user creates an Event Sequence with each individual intermittent event defined in terms of channel, timing, profile and burst parameters.

- **Single Event:** the user triggers ad hoc single intermittent events with user-defined parameters.

5.1.4 IFE profiles. Annex A of the User Manual (see CTL-229-01) provides details on the full range of simulated fault profiles that can be selected when populating user-defined event sequences and single events. The 'shape,' ohmic variation, duration and burst settings are defined using preset simulated fault profiles. Figures 3 through 8 (images courtesy of Copernicus Technology Ltd.) are graphic representations of the different profile types:

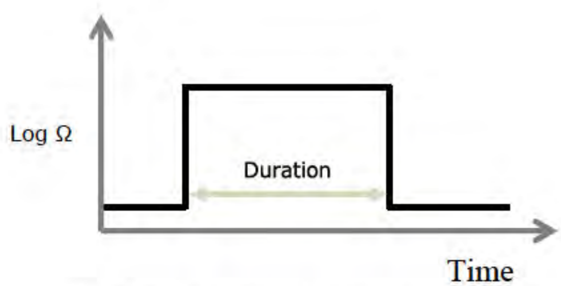


FIGURE 3. Simple pulse.

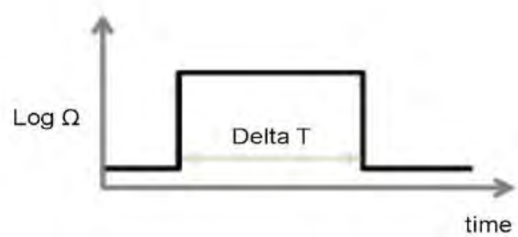


FIGURE 4. Square pulse.

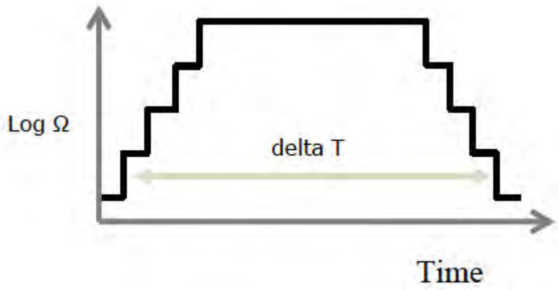


FIGURE 5. Ramped pulse.

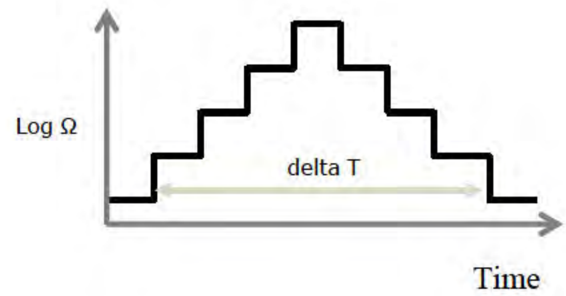


FIGURE 6. Saw-tooth pulse.

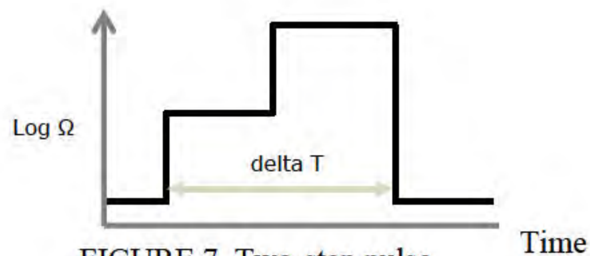


FIGURE 7. Two-step pulse.

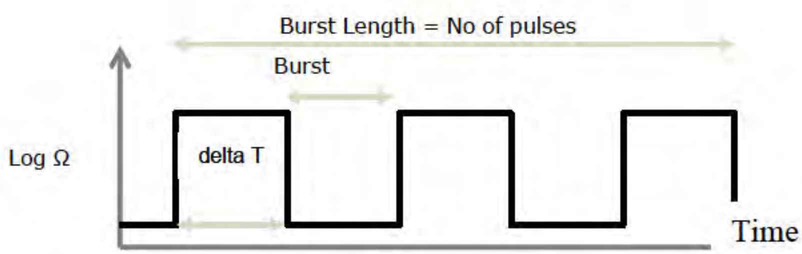


FIGURE 8. Square pulse burst.

5.2 IFE limitations. The IFE was developed for the DoD in order to provide a standardized method of benchmarking diagnostic test equipment with intermittent fault detection capability against MIL-PRF-32516 and may be used to evaluate other diagnostic equipment ability to detect Intermittent Faults. The IFE emulates pseudo-random intermittent faults over 256-channels simulating data bus and nodal architectures, and selectable fault parameters from 4 ohm to 499 ohms, and durations of 100 nanoseconds to 500 milliseconds These faults can be set/saved and replayed as sequences to allow diagnostic equipment to be tested against these sequences and assessed against MIL-PRF-32516. Initial trials of the IFE identified some design constraints that can affect the evaluation of diagnostic equipment that use stimulus voltages and currents in the ranges below 5 V and 30 mA for frequencies from 40 kHz to 10 MHz. The reason for these design constraints is because the IFE was designed to operate across a wide range of stimulus voltages (+15 V to -15 V), have high electrostatic discharge protection and produce simulated faults down to 100 nanoseconds. In order for the IFE to meet its design specification, it was necessary to use an electronic switch as the method of producing a transient break in the circuit for the diagnostic equipment to detect and isolate a fault. Using an electronic switch to simulate this type of failure mode has a degree of limitation because a 'real world' intermittent fault generally results from actual mechanical breaks in a circuit. The IFE's electronic switches exhibit unwanted characteristics that may not exist as part of a mechanical failure, including forward and reverse bias of the internal transistors of the electronic switch, capacitive charge and negative charge induction during switching, and frequency response. Testing of the IFE has found that the IFE functions well at test-stimulus currents of 90 milliamps or greater per test channel and/or above 100 microseconds but may not function outside these parameters.

5.3 User manual. Information necessary to be able to program and interact with the IFE which is controlled by a GUI is located in the user manual (see CTL-229-01). To program the IFE to emulate specific intermittent fault signals, refer to the IFE User Manual as specified in chapter 4.

5.4 Multi-channel detection test procedure.

5.4.1 Tests. This testing requires the IFE, a host Microsoft Windows® computer loaded with the GUI software application loaded on the connected computer. The IFE application is used to set up intermittent event sequences and to manage, save, and download the sequences and corresponding runs or emulations. The primary screens and indications of the application are shown in the User Manual. Using the IFE, perform the sequence of tests listed in table I. Perform Test 1-1 and if the IFE detects the fault on at least 95 percent of the test points, then proceed to Test 1-2 through Test 1-6.

TABLE I. Multi-channel detection tests.

Test No	Number of Test Points Evaluated	MIL-PRF-32516 Category	IFE Fault Duration
1-1	128	Not categorized	500 milliseconds
1-2	128	3	5 milliseconds
1-3	256	3	10 milliseconds
1-4	256	3	501 microseconds
1-5	256	2	250 microseconds
1-6	256	2	25 microseconds

5.4.2 Test results. If the Intermittent Fault Diagnostic Equipment passes all 6 tests, then it can be concluded that the diagnostic equipment is able to test across multiple test points. In addition, these tests also prove that it can detect intermittent faults down to 25 microseconds (40 kHz), which is within the Category 2 range of MIL-PRF-32516. To test the diagnostic equipment's performance below these durations then additional testing is required.

5.4.3 Extended test procedure. After completing the tests of 5.4.1 the following tests determine if the Intermittent Fault Diagnostic Equipment can detect intermittent faults down to 100 nanoseconds (10MHz). This testing assumes that the diagnostic equipment architecture is able to test simultaneously as proven in tests of 5.4.1. The extended test procedure also assumes that IFDE can perform in a simultaneous fault environment at faster frequencies and can pass the extended test procedure tests. Therefore, this Fault Duration Detection Test is designed to ascertain specifically if the diagnostic equipment can detect emulated intermittent faults down to 100 nanoseconds (10MHz).

5.4.3.1 Signal generator (SG). This testing requires the use of an SG with the ability to generate an arbitrary waveform generator output. Set the SG with a square wave with peak to peak voltage set to 1.5V and the frequency set as outlined in the table II, and place the selected test points across the output of the SG's output. The circuit will produce a raw simulated intermittent event each time the SG is triggered and the operator can assess if the diagnostic equipment has detected the simulated fault.

5.4.3.2 Tests. This testing should include the tests listed below as a minimum. Note: for ease of setup and operation it may be more appropriate to use 1 test point on the Intermittent Fault Diagnostic Equipment and carry out each of the frequencies 3 times for each test point.

5.5 Pinouts. Information necessary to develop the interface adapter harness for individual technologies should comply with the pinouts as shown in Appendix A.

TABLE II. Emulator tests.

Test No	**Method**	**MIL-PRF-32516 Category**	**SG Fault Duration**
2-1	Use 5 different test points on the diagnostic equipment and trigger the SG 3 times with a gap of 1 second between triggers. Record how many of the 15 faults are detected by the diagnostic equipment.	2	25 microseconds (40kHz)
2-2		2	5 microseconds (200kHz)
2-3		2	1 microseconds (1MHz)
2-4		2	500 nanoseconds (2MHz)
2-5		2	125 nanoseconds (8MHz)
2-6		1	95 nanoseconds (10.5MHz)

6. NOTES

6.1 Intended use. This handbook provides guidance for using the IFE to demonstrate the capabilities of IFDI technologies, methods, and devices capability to detect and isolate intermittent faults.

6.2 Subject term (key word) listing.

Electronic Test Equipment

INTERMITTENT FAULT EMULATOR TEST CHANNELS

A.1 SCOPE

A.1.1 Scope. This appendix provides information on the configuration of the IFE's test channels to assist in determining how to connect the diagnostic equipment to the IFE.

Note: Figures A-1 to A-4 and tables A-II to A-V courtesy of Copernicus Technology Ltd.

A.2 Test channels. The IFE has 256 test channels each with the following switchable resistances (see figure A-1): Figure A-2 shows examples of the 66 way electrical connector, the pin and channel layout for IFE input connectors.

4 ohms Represents a Closed Circuit condition (default on all channels)

56 ohms

1.1k ohms

10.1k ohms

499k ohms (Represents an open circuit condition)

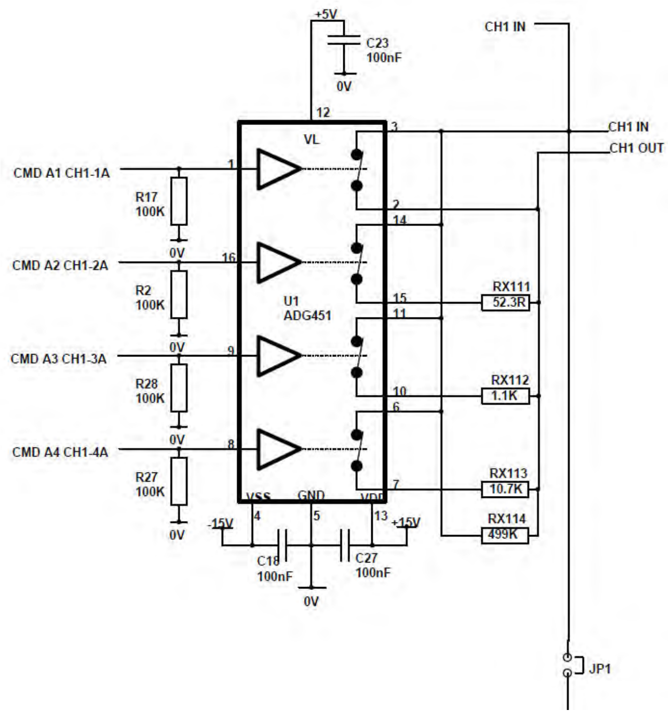


FIGURE A-1. Channel schematic.

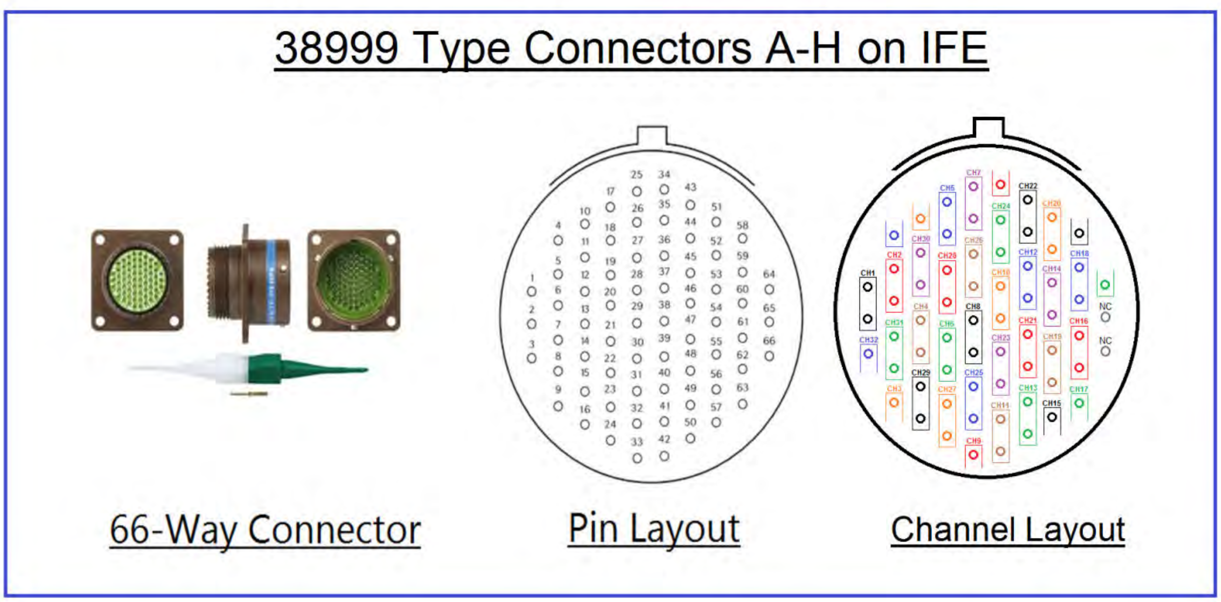


FIGURE A-2. IFE Input connectors.

A.2.1 Test connectivity architecture. To represent the connectivity architectures found in LRU/WRA components, the IFE's 256 channels are configured in either a databus (see figure A-3 (i.e., point-to-point)), or nodal (see figure A-4 (i.e., more than one channel interconnected)) arrangement. These configuration concepts are illustrated below:

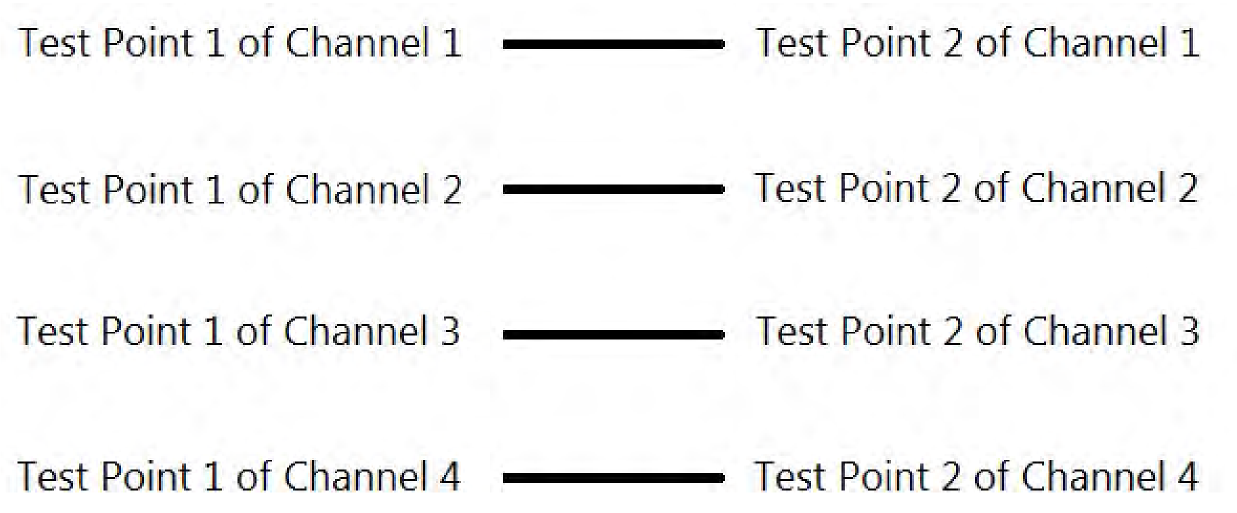


FIGURE A-3. Databus configuration.

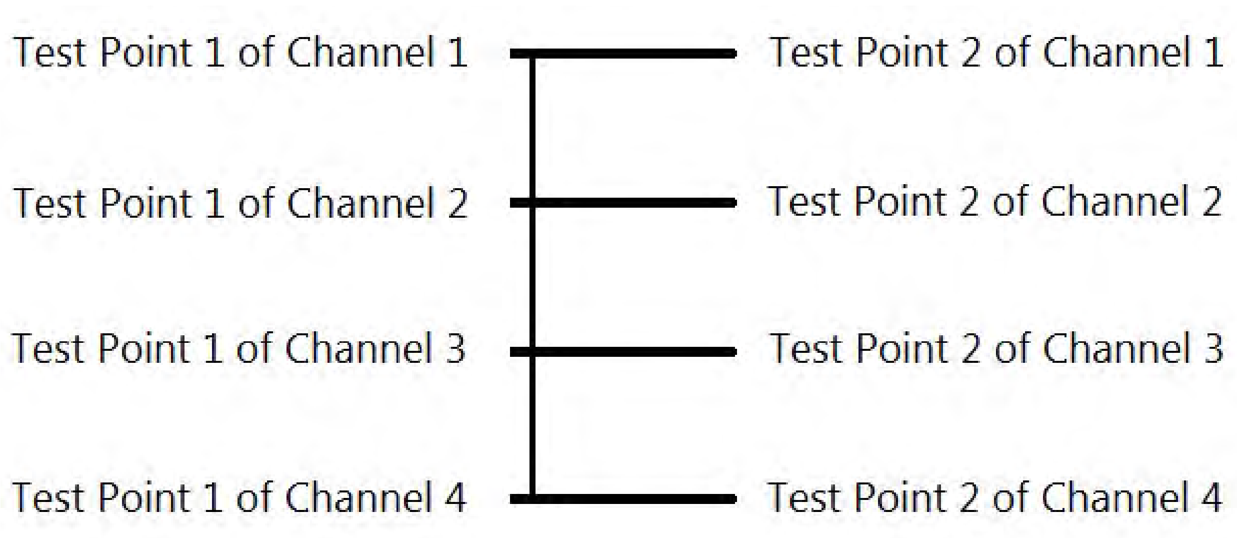


FIGURE A-4. Nodal configuration.

A.2.1.1 Test channel architecture. The 256 IFE test channels' architecture is specifically configured as per the following list, with channel-specific details shown in tables A-II through A-V:

128 channels consist of 1 channel each in databus configuration - all annotated with a 'D'

8 nodes consist of 4 channels each - Nodes: N1, N2, N3, N4, N5, N6, N7, N8

4 nodes consist of 8 channels each – Nodes: N9, N10, N11, N12

2 nodes consist of 16 channels each - Nodes N13, N14

1 node consists of 32 channels - Node: N15

A.2.1.2 Test channel configuration. The specific test channel configuration details are illustrated for each connector in tables A-II to A-V.

TABLE A-I. Connector plug key for tables.

D	Denotes that a channel is in a databus configuration and that the channels In/Out are not interconnected with any other channel.
N	Denotes a nodal configuration, with each separate node annotated with the requisite number, e.g., N5 means that all channels annotated against N5 will be on that same node.

TABLE A-II. Channel and databus/nodal configuration vs connector pins: plugs A through D.

Plug A		
Channel	Pin Out	D/N
CH1	1,2	D
CH32	3,4	D
CH2	5,6	D
CH31	7,8	D
CH3	9,10	D
CH30	11,12	D
CH4	13,14	D
CH29	15,16	D
CH5	17,18	D
CH28	19,20	D
CH6	21,22	D
CH27	23,24	D
CH7	25,26	D
CH26	27,28	D
CH8	29,30	D
CH25	31,32	D
CH9	33,34	D
CH24	35,36	D
CH10	37,38	D
CH23	39,40	D
CH11	41,42	D
CH22	43,44	D
CH12	45,46	D
CH21	47,48	D
CH13	49,50	D
CH20	51,52	D
CH14	53,54	D
CH19	55,56	D
CH15	57,58	D
CH18	59,60	D
CH16	61,62	D
CH17	63,64	D

Plug B		
Channel	Pin Out	D/N
CH1	1,2	D
CH32	3,4	D
CH2	5,6	D
CH31	7,8	D
CH3	9,10	D
CH30	11,12	D
CH4	13,14	D
CH29	15,16	D
CH5	17,18	D
CH28	19,20	D
CH6	21,22	D
CH27	23,24	D
CH7	25,26	D
CH26	27,28	D
CH8	29,30	D
CH25	31,32	D
CH9	33,34	D
CH24	35,36	D
CH10	37,38	D
CH23	39,40	D
CH11	41,42	D
CH22	43,44	D
CH12	45,46	D
CH21	47,48	D
CH13	49,50	D
CH20	51,52	D
CH14	53,54	D
CH19	55,56	D
CH15	57,58	D
CH18	59,60	D
CH16	61,62	D
CH17	63,64	D

Plug C		
Channel	Pin Out	D/N
CH1	1,2	D
CH32	3,4	N4
CH2	5,6	D
CH31	7,8	N4
CH3	9,10	D
CH30	11,12	N4
CH4	13,14	D
CH29	15,16	N4
CH5	17,18	N1
CH28	19,20	D
CH6	21,22	N1
CH27	23,24	D
CH7	25,26	N1
CH26	27,28	D
CH8	29,30	N1
CH25	31,32	D
CH9	33,34	D
CH24	35,36	N3
CH10	37,38	D
CH23	39,40	N3
CH11	41,42	D
CH22	43,44	N3
CH12	45,46	D
CH21	47,48	N3
CH13	49,50	N2
CH20	51,52	D
CH14	53,54	N2
CH19	55,56	D
CH15	57,58	N2
CH18	59,60	D
CH16	61,62	N2
CH17	63,64	D

Plug D		
Channel	Pin Out	D/N
CH1	1,2	D
CH32	3,4	N8
CH2	5,6	D
CH31	7,8	N8
CH3	9,10	D
CH30	11,12	N8
CH4	13,14	D
CH29	15,16	N8
CH5	17,18	N5
CH28	19,20	D
CH6	21,22	N5
CH27	23,24	D
CH7	25,26	N5
CH26	27,28	D
CH8	29,30	N5
CH25	31,32	D
CH9	33,34	D
CH24	35,36	N7
CH10	37,38	D
CH23	39,40	N7
CH11	41,42	D
CH22	43,44	N7
CH12	45,46	D
CH21	47,48	N7
CH13	49,50	N6
CH20	51,52	D
CH14	53,54	N6
CH19	55,56	D
CH15	57,58	N6
CH18	59,60	D
CH16	61,62	N6
CH17	63,64	D

TABLE A-III. Channel and databus/nodal configuration vs connector pins: plugs E through H.

Plug E

Channel	Pin Out	D/N
CH1	1,2	D
CH32	3,4	D
CH2	5,6	D
CH31	7,8	D
CH3	9,10	D
CH30	11,12	N11
CH4	13,14	D
CH29	15,16	N11
CH5	17,18	N9
CH28	19,20	N11
CH6	21,22	N9
CH27	23,24	N11
CH7	25,26	N9
CH26	27,28	N11
CH8	29,30	N9
CH25	31,32	N11
CH9	33,34	N9
CH24	35,36	N11
CH10	37,38	N9
CH23	39,40	N11
CH11	41,42	N9
CH22	43,44	N11
CH12	45,46	N9
CH21	47,48	N11
CH13	49,50	N10
CH20	51,52	N10
CH14	53,54	N10
CH19	55,56	N10
CH15	57,58	N10
CH18	59,60	N10
CH16	61,62	N10
CH17	63,64	N10

Plug F

Channel	Pin Out	D/N
CH1	1,2	N12
CH32	3,4	D
CH2	5,6	N12
CH31	7,8	D
CH3	9,10	N12
CH30	11,12	D
CH4	13,14	N12
CH29	15,16	D
CH5	17,18	N12
CH28	19,20	D
CH6	21,22	N12
CH27	23,24	D
CH7	25,26	N12
CH26	27,28	D
CH8	29,30	N12
CH25	31,32	D
CH9	33,34	N13
CH24	35,36	N13
CH10	37,38	N13
CH23	39,40	N13
CH11	41,42	N13
CH22	43,44	N13
CH12	45,46	N13
CH21	47,48	N13
CH13	49,50	N13
CH20	51,52	N13
CH14	53,54	N13
CH19	55,56	N13
CH15	57,58	N13
CH18	59,60	N13
CH16	61,62	N13
CH17	63,64	N13

Plug G

Channel	Pin Out	D/N
CH1	1,2	N14
CH32	3,4	D
CH2	5,6	N14
CH31	7,8	D
CH3	9,10	N14
CH30	11,12	D
CH4	13,14	N14
CH29	15,16	D
CH5	17,18	N14
CH28	19,20	D
CH6	21,22	N14
CH27	23,24	D
CH7	25,26	N14
CH26	27,28	D
CH8	29,30	N14
CH25	31,32	D
CH9	33,34	N14
CH24	35,36	D
CH10	37,38	N14
CH23	39,40	D
CH11	41,42	N14
CH22	43,44	D
CH12	45,46	N14
CH21	47,48	D
CH13	49,50	N14
CH20	51,52	D
CH14	53,54	N14
CH19	55,56	D
CH15	57,58	N14
CH18	59,60	D
CH16	61,62	N14
CH17	63,64	D

Plug H

Channel	Pin Out	D/N
CH1	1,2	N15
CH32	3,4	N15
CH2	5,6	N15
CH31	7,8	N15
CH3	9,10	N15
CH30	11,12	N15
CH4	13,14	N15
CH29	15,16	N15
CH5	17,18	N15
CH28	19,20	N15
CH6	21,22	N15
CH27	23,24	N15
CH7	25,26	N15
CH26	27,28	N15
CH8	29,30	N15
CH25	31,32	N15
CH9	33,34	N15
CH24	35,36	N15
CH10	37,38	N15
CH23	39,40	N15
CH11	41,42	N15
CH22	43,44	N15
CH12	45,46	N15
CH21	47,48	N15
CH13	49,50	N15
CH20	51,52	N15
CH14	53,54	N15
CH19	55,56	N15
CH15	57,58	N15
CH18	59,60	N15
CH16	61,62	N15
CH17	63,64	N15

TABLE A-IV. Channel configuration vs IFE channels 1 through 256: plugs A through D.

Plug A			Plug B			Plug C			Plug D		
Channel	Ref Ch	D/N	Channel	Ref Ch	D/N	Channel	Ref Ch	D/N	Channel	Ref Ch	D/N
CH1	1	D	CH1	33	D	CH1	65	D	CH1	97	D
CH2	2	D	CH2	34	D	CH2	66	D	CH2	98	D
CH3	3	D	CH3	35	D	CH3	67	D	CH3	99	D
CH4	4	D	CH4	36	D	CH4	68	D	CH4	100	D
CH5	5	D	CH5	37	D	CH5	69	N1	CH5	101	N5
CH6	6	D	CH6	38	D	CH6	70	N1	CH6	102	N5
CH7	7	D	CH7	39	D	CH7	71	N1	CH7	103	N5
CH8	8	D	CH8	40	D	CH8	72	N1	CH8	104	N5
CH9	9	D	CH9	41	D	CH9	73	D	CH9	105	D
CH10	10	D	CH10	42	D	CH10	74	D	CH10	106	D
CH11	11	D	CH11	43	D	CH11	75	D	CH11	107	D
CH12	12	D	CH12	44	D	CH12	76	D	CH12	108	D
CH13	13	D	CH13	45	D	CH13	77	N2	CH13	109	N6
CH14	14	D	CH14	46	D	CH14	78	N2	CH14	110	N6
CH15	15	D	CH15	47	D	CH15	79	N2	CH15	111	N6
CH16	16	D	CH16	48	D	CH16	80	N2	CH16	112	N6
CH17	17	D	CH17	49	D	CH17	81	D	CH17	113	D
CH18	18	D	CH18	50	D	CH18	82	D	CH18	114	D
CH19	19	D	CH19	51	D	CH19	83	D	CH19	115	D
CH20	20	D	CH20	52	D	CH20	84	D	CH20	116	D
CH21	21	D	CH21	53	D	CH21	85	N3	CH21	117	N7
CH22	22	D	CH22	54	D	CH22	86	N3	CH22	118	N7
CH23	23	D	CH23	55	D	CH23	87	N3	CH23	119	N7
CH24	24	D	CH24	56	D	CH24	88	N3	CH24	120	N7
CH25	25	D	CH25	57	D	CH25	89	D	CH25	121	D
CH26	26	D	CH26	58	D	CH26	90	D	CH26	122	D
CH27	27	D	CH27	59	D	CH27	91	D	CH27	123	D
CH28	28	D	CH28	60	D	CH28	92	D	CH28	124	D
CH29	29	D	CH29	61	D	CH29	93	N4	CH29	125	N8
CH30	30	D	CH30	62	D	CH30	94	N4	CH30	126	N8
CH31	31	D	CH31	63	D	CH31	95	N4	CH31	127	N8
CH32	32	D	CH32	64	D	CH32	96	N4	CH32	128	N8

TABLE A-V. Channel configuration vs IFE channels 1 through 256: plugs E through H.

Plug E		
Channel	Ref Ch	D/N
CH1	129	N9
CH2	130	N9
CH3	131	N9
CH4	132	N9
CH5	133	N9
CH6	134	N9
CH7	135	N9
CH8	136	N9
CH9	137	D
CH10	138	D
CH11	139	N10
CH12	140	N10
CH13	141	N10
CH14	142	N10
CH15	143	N10
CH16	144	N10
CH17	145	N10
CH18	146	N10
CH19	147	D
CH20	148	D
CH21	149	N11
CH22	150	N11
CH23	151	N11
CH24	152	N11
CH25	153	N11
CH26	154	N11
CH27	155	N11
CH28	156	N11
CH29	157	D
CH30	158	D
CH31	159	D
CH32	160	D

Plug F		
Channel	Ref Ch	D/N
CH1	161	N12
CH2	162	N12
CH3	163	N12
CH4	164	N12
CH5	165	N12
CH6	166	N12
CH7	167	N12
CH8	168	N12
CH9	169	D
CH10	170	D
CH11	171	D
CH12	172	D
CH13	173	D
CH14	174	D
CH15	175	D
CH16	176	D
CH17	177	N13
CH18	178	N13
CH19	179	N13
CH20	180	N13
CH21	181	N13
CH22	182	N13
CH23	183	N13
CH24	184	N13
CH25	185	N13
CH26	186	N13
CH27	187	N13
CH28	188	N13
CH29	189	N13
CH30	190	N13
CH31	191	N13
CH32	192	N13

Plug G		
Channel	Ref Ch	D/N
CH1	193	N14
CH2	194	N14
CH3	195	N14
CH4	196	N14
CH5	197	N14
CH6	198	N14
CH7	199	N14
CH8	200	N14
CH9	201	N14
CH10	202	N14
CH11	203	N14
CH12	204	N14
CH13	205	N14
CH14	206	N14
CH15	207	N14
CH16	208	N14
CH17	209	D
CH18	210	D
CH19	211	D
CH20	212	D
CH21	213	D
CH22	214	D
CH23	215	D
CH24	216	D
CH25	217	D
CH26	218	D
CH27	219	D
CH28	220	D
CH29	221	D
CH30	222	D
CH31	223	D
CH32	224	D

Plug H		
Channel	Ref Ch	D/N
CH1	225	N15
CH2	226	N15
CH3	227	N15
CH4	228	N15
CH5	229	N15
CH6	230	N15
CH7	231	N15
CH8	232	N15
CH9	233	N15
CH10	234	N15
CH11	235	N15
CH12	236	N15
CH13	237	N15
CH14	238	N15
CH15	239	N15
CH16	240	N15
CH17	241	N15
CH18	242	N15
CH19	243	N15
CH20	244	N15
CH21	245	N15
CH22	246	N15
CH23	247	N15
CH24	248	N15
CH25	249	N15
CH26	250	N15
CH27	251	N15
CH28	252	N15
CH29	253	N15
CH30	254	N15
CH31	255	N15
CH32	256	N15

INTERMITTENT FAULT EMULATOR WAVEFORMS

B.1 SCOPE

B.1.1 Scope. The appendix provides examples of intermittent fault waveforms that can be generated using flexible profile codes that are built into the IFE.

B.2 Background. The IFE is a useful tool in evaluating intermittent diagnostic equipment that is very easy to set up and operate. The IFE has the ability to quickly validate diagnostic equipment capabilities. The IFE does an excellent job categorizing test equipment and gauging intermittence detection performance when testing a single wire (databus) or interconnected (nodal) circuitry.

An independent evaluation of the IFE found that the IFE works extremely well on the slow-duration end of the testing spectrum (ranging from one hundred microseconds to seconds) regardless of the test stimulus (current) applied. Unfortunately, this evaluation also found that the IFE struggles to perform as necessary on the fast-duration (nanoseconds [ns]) end when low-power test stimulus is applied.

Intermittence is a complex failure mode that typically begins in the nanosecond to microsecond realm. The physical root causes of intermittence are often only evident under a microscope.

Simulating this low-level, complex environment is difficult, especially when a broad range of testing stimulus is considered.

Solid state switches used in the IFE were the only option for providing the speed of switching required for short duration intermittent fault emulation, but there are a number of performance trade-offs. The higher the voltage requirement, the slower the speed of switching and as speed increases in the same voltage range, the amount of charge injected into the channel from these switches also increases. This unwanted injected charge changes the voltage in the switched circuit for a period that depends on the amount of current flowing in the circuit. The lower the current, the longer the voltage is not at the expected level. Therefore, a switch capable of generating a 100ns pulse-width with a voltage of up to plus or minus 15 volts will have enough charge injection as to require a current of several tens of milliamps to overcome the effects of the charge injection.

Due to inherent limitations in the electronic switches used in the IFE, it will not properly gauge the ability to detect intermittence below 15 microseconds on a databus if the diagnostic equipment test stimulus is below 40 milliamps. At low-power stimulus, pulse-widths greater than 15 microseconds are more accurate, and the accuracy increases as the test current increases from 40 to 90 milliamps.

The IFE performs well for simulated intermittent events employing 90 milliamps of stimulus and above, but may not provide validation of diagnostic equipment, which have test stimulus currents less than 90 milliamps, especially in nodal circuit configurations.

The example waveforms shown in this appendix illustrate the limitations of the solid state switches and are provided to give the user a reference point in regard to waveforms that can be generated with various levels of test voltage, current, and time durations.

B.3 Flexible profile codes (see B.1.1) Table B-I gives the flexible profile codes for the intermittent fault waveforms that can be generated by the IFE.

TABLE B-I. Flexible profile codes.

Code Letter	Event Characteristic
Q	**Square -** A simple pulse changing to its maximum ohmic variance.
R	**Ramped** – the event starts and ends with ohmic variance stepping through the values available to the defined maximum. One eighth of the event duration is ramping up, one eighth ramping down with six eights at the required resistance.
S	**Saw-tooth** – The event steps through each resistance for an equal time up and down.
T	**Two-step** – The event spends half its time at half the required resistance and the other half at the full value.

Notes:

1. Each event will have the duration in microseconds set by its deltaT parameter. There is a small overhead in the generation of these events so that each event is always 300 nanoseconds longer than the deltaT value set.

2. Events that step through resistance values are limited by the four steps available. Therefore, if a T profile (see code letter T in table B-I) is set with a code number of 3, the first part will be at level 1 (as 1.5 is not feasible).

3. All durations and sub-parts thereof are carried out for whole microsecond durations. Therefore if a T profile is set with a delta T of 3 microseconds, the first part will be 1 microsecond not 1.5 microseconds.

4. Due to the calculations involved, profiles R and S do not create accurate ‘shapes’ if shorter than 10 microseconds.

B.3.1 Profile code numbers. The emulator has built-in waveform profiles that are identified by a single code letter and number. The number identifies the resistance variance (see table B-II).

TABLE B-II. Profile code numbers.

Code Number	Variance (Ω)
1	53
2	1,000
3	10,000
4	500,000

B.4 Example waveforms. The following waveforms on figures B-2 through B-15 were generated using the flexible profile codes built into the IFE.

B.4.1 Test setup. Figure B-1 is a picture of the test setup used to generate the waveforms shown on figures B-2 through B-15. A decade resistance box and power supply were used to generate the 3 and 30 milliamperes input across one of the IFE channels. Once the IFE input was established, the profile code was programmed into the IFE and the intermittent event was triggered. The resultant waveform was captured on a PicoScope® and laptop computer shown on figure B-1.

FIGURE B-1. IFE waveform test setup.

B.4.2 Waveform figures. Figures B-2 to B-15 illustrate waveforms that can be generated by using the IFE flexible profile codes and show the limitations of the IFE's ability to generate various waveforms. The input and output of a channel are normally a closed circuit, which resistive values (see table B-II) can be individually turned on or any combination can be turned on. The resistance in any given channel can vary from the inherent resistance of the closed circuit to approximately 511K ohms. The following is an explanation of the waveforms:

Figure B-2 Single pulse square wave formed by switching from a closed circuit to 500K ohms for 100 ns duration using a 30 mA source.

Figure B-3 Single pulse square wave formed by switching from a closed circuit to 500K ohms for 1 ms duration using a 3 mA source.

Figure B-4 Single pulse square wave formed by switching from a closed circuit to 500K ohms for 1 ms duration using a 30 mA source.

Figure B-5 Single pulse square wave formed by switching from a closed circuit to 500K ohms for 1 µs duration using a 30 mA source.

Figure B-6 Burst of five square waves formed by switching from a closed circuit to 500K Ohms for 10 µs duration using a 30 mA source.

Figure B-7 Single pulse square wave formed by switching from a closed circuit to 500K ohms for 10 µs duration using a 30 mA source.

Figure B-8 Single pulse square wave formed by switching from a closed circuit to 500K ohms for 100 µs duration using a 30 mA source.

Figure B-9 Ramped square waves formed by switching from a closed circuit to 53, 1K, 10K and 500K ohms and back to the closed circuit for 1 ms duration using a 3 mA source.

Figure B-10 Ramped square waves formed by switching from a closed circuit to 53, 1K, 10K and 500K ohms and back to the closed circuit for 100 µs duration using a 30 mA source. Ramping up is 12.5 µs, ramping down is 12.5 µs and 75 µs at 500K ohms.

Figure B-11 Saw-tooth square waves formed by switching from a closed circuit to 53, 1K, 10K and 500K ohms and back to the closed circuit for 1ms duration using a 3 mA source. Each resistance duration is equal time up and down.

Figure B-12 Saw-tooth square waves formed by switching from a closed circuit to 53, 1K, 10K and 500K ohms and back to the closed circuit for a total 100 µs duration using a 30 mA source. Each resistance duration is equal in time during both the up and down cycles.

Figure B-13 Two-step square wave formed by switching from a closed circuit in two steps at half 500K and 500K ohms for 1 ms duration using a 3 mA source. Half of the duration is spent at each resistance.

Figure B-14 Burst of five two step square wave formed by switching from a closed circuit in two steps at half 500K and 500K ohms for 10 µs duration using a 30 mA source. In the two step square wave, half of the duration is spent at each resistance.

Figure B-15 Two-step square wave formed by switching from a closed circuit in two steps at half 500K and 500K ohms for 100 µs duration using a 30 mA source. Half of the duration is spent at each resistance.

B.4.3 Waveform summary. There are several conclusions that can be made based on the waveforms shown on figures B-2 through B-15.

a. As illustrated on figure B-2 the IFE is not able to fully create the required waveform in very short durations such as 100 ns on figure B-2.

b. The IFE generates a significant positive and negative spike during both the opening and closing of the resistance in the channel path. This spike is due to charge injection characteristics inherent in the IFE electronic switches. The waveforms generated and spike reduction by the IFE improve as the stimulus current of the diagnostic equipment increases above 40 mA.

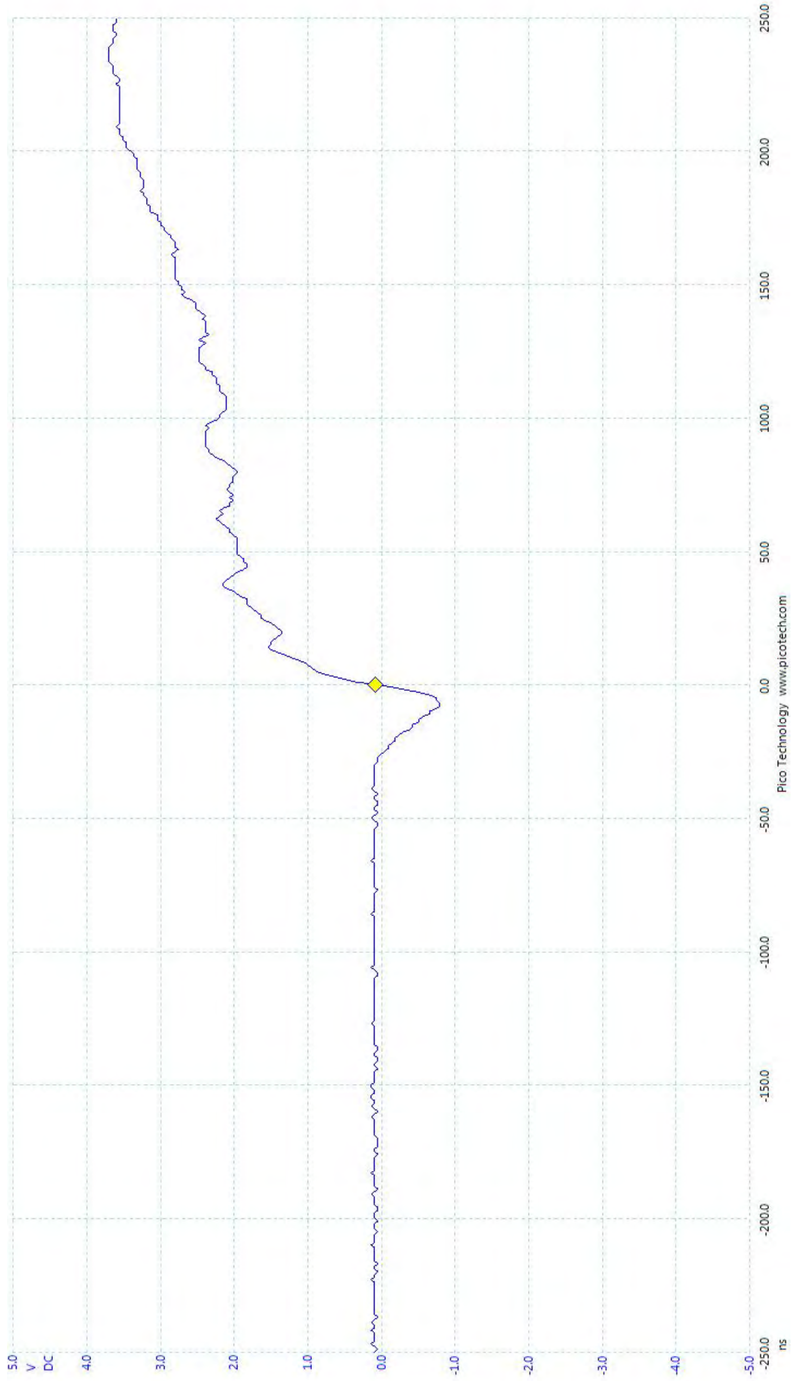


FIGURE B-2. Waveform A4 30 mA 100 ns.

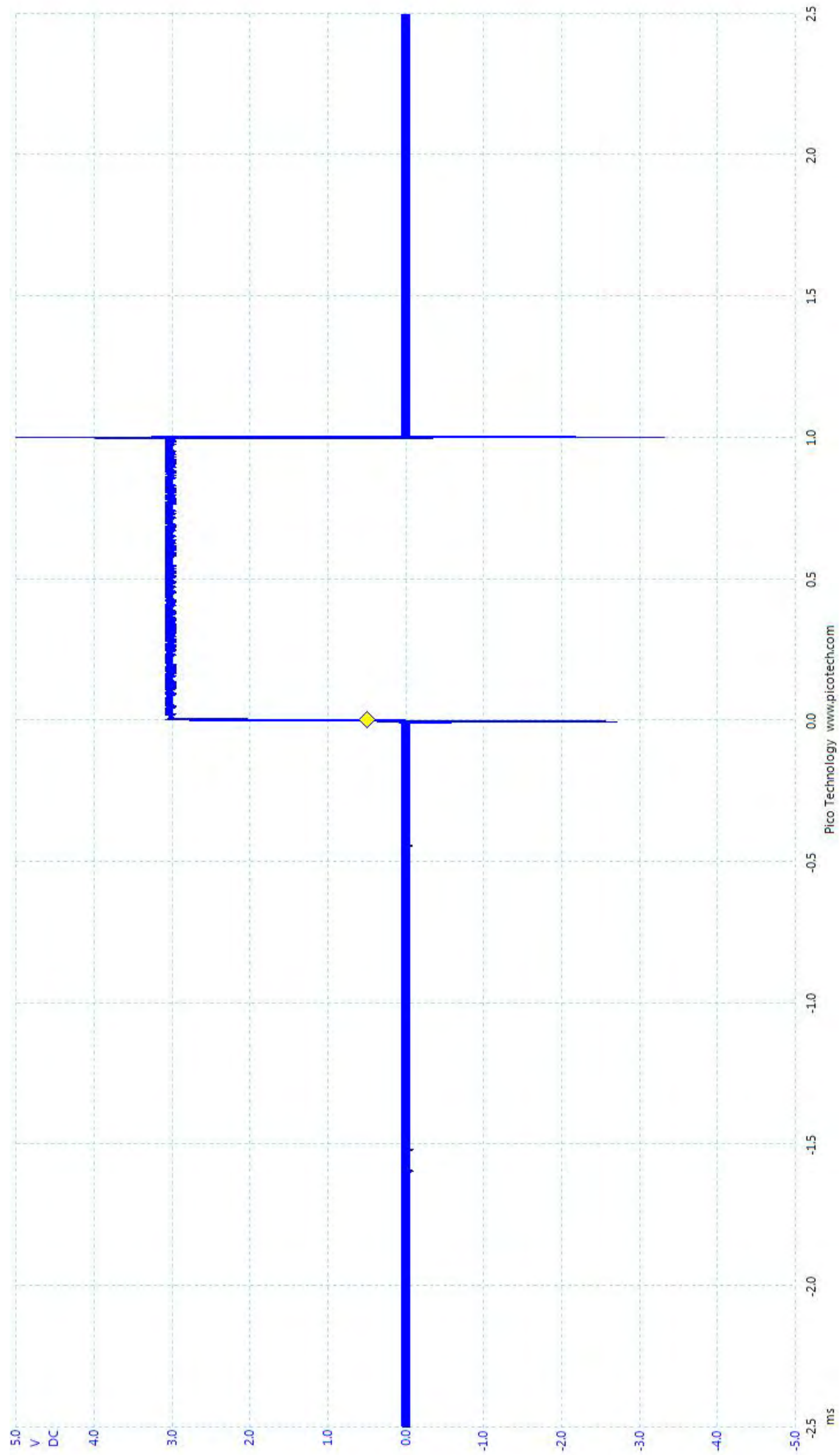


FIGURE B-3. Waveform Q4 3 mA 1 ms.

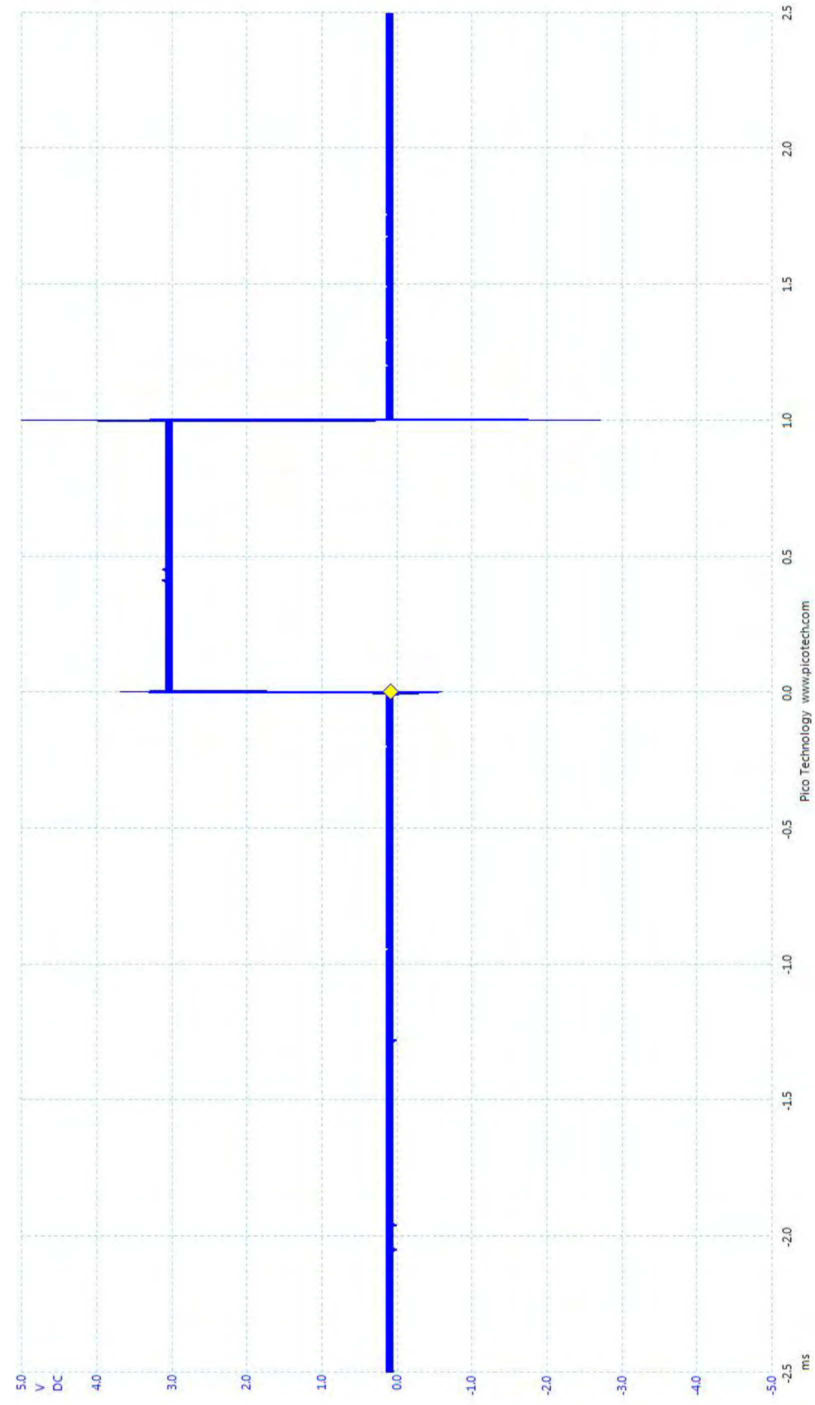


FIGURE B-4. Waveform Q4 30 mA 1 ms.

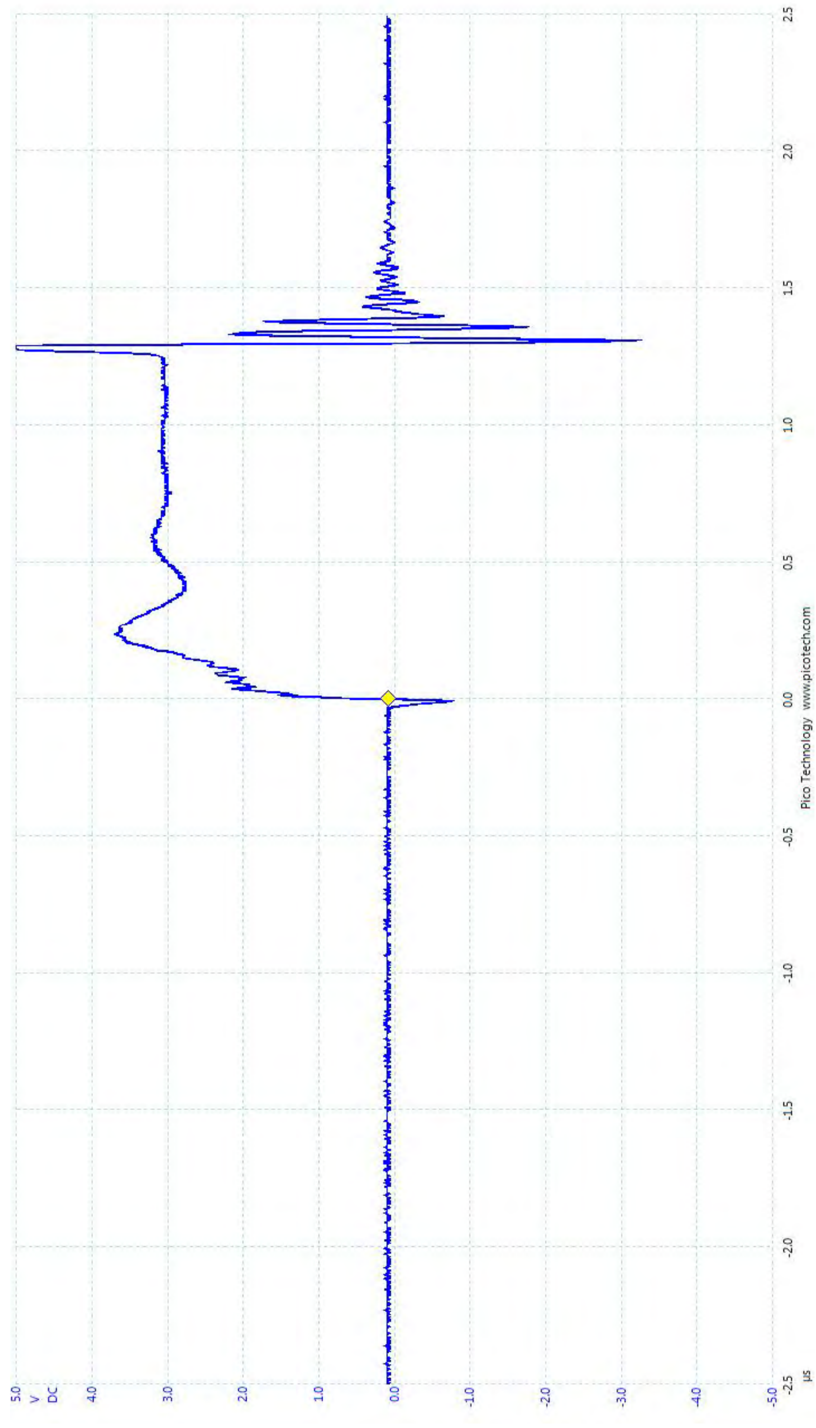


FIGURE B-5. Waveform Q4 30 mA 1 µs.

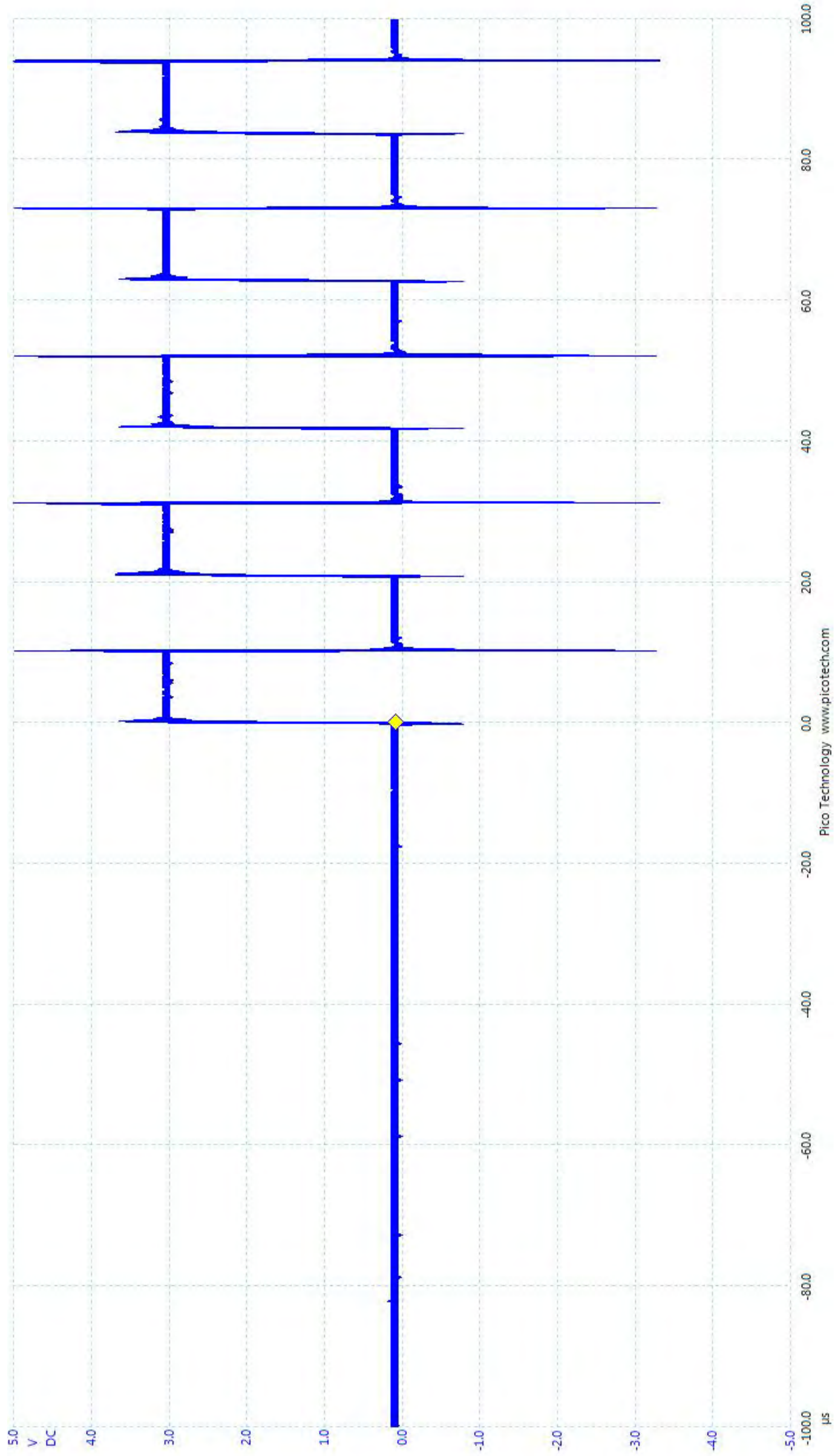


FIGURE B-6. Waveform Q4 30 mA 10 µs 5B.

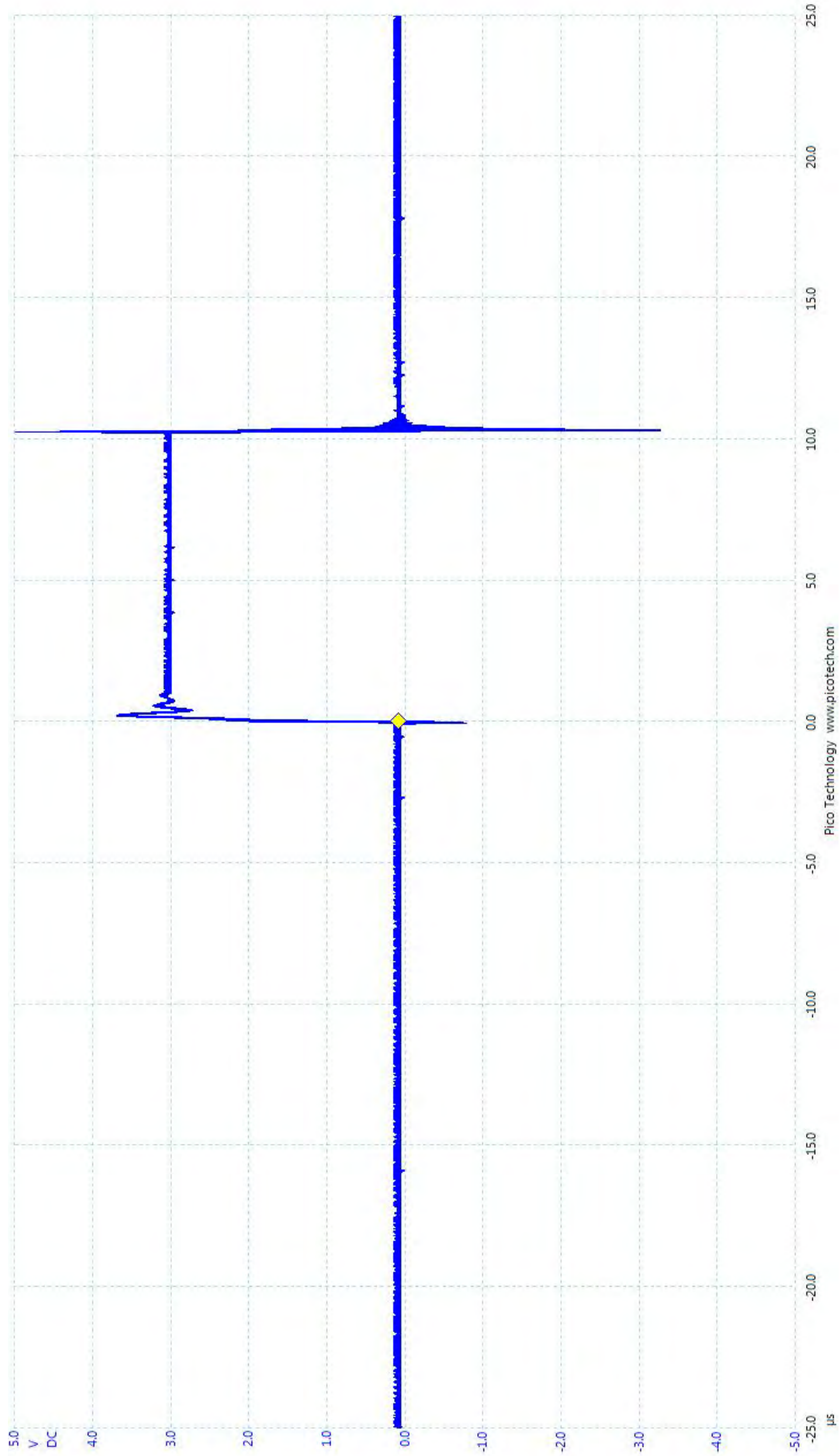


FIGURE B-7. Waveform Q4 30 mA 10 µs.

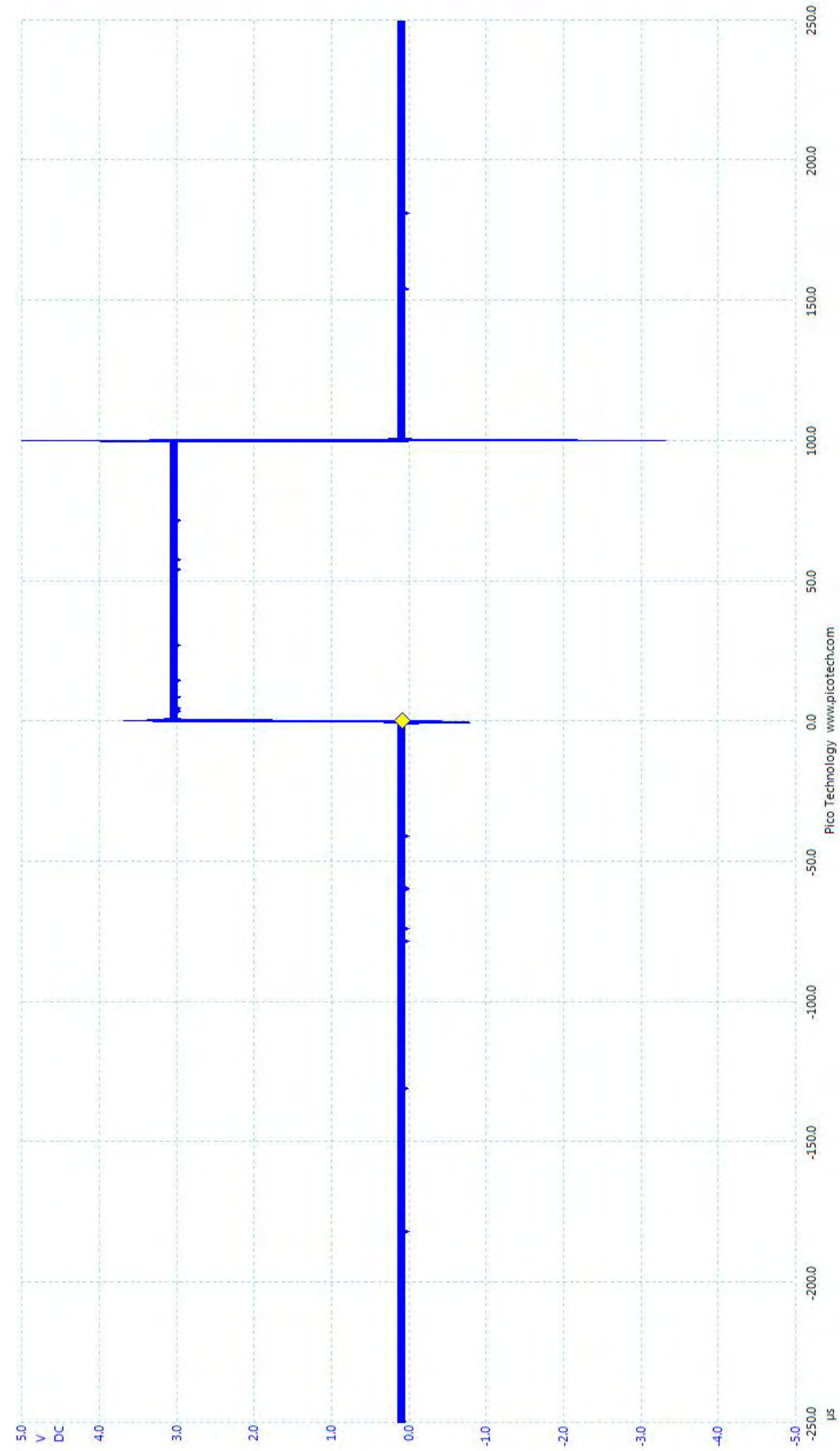


FIGURE B-8. Waveform Q4 30 mA 100 µs.

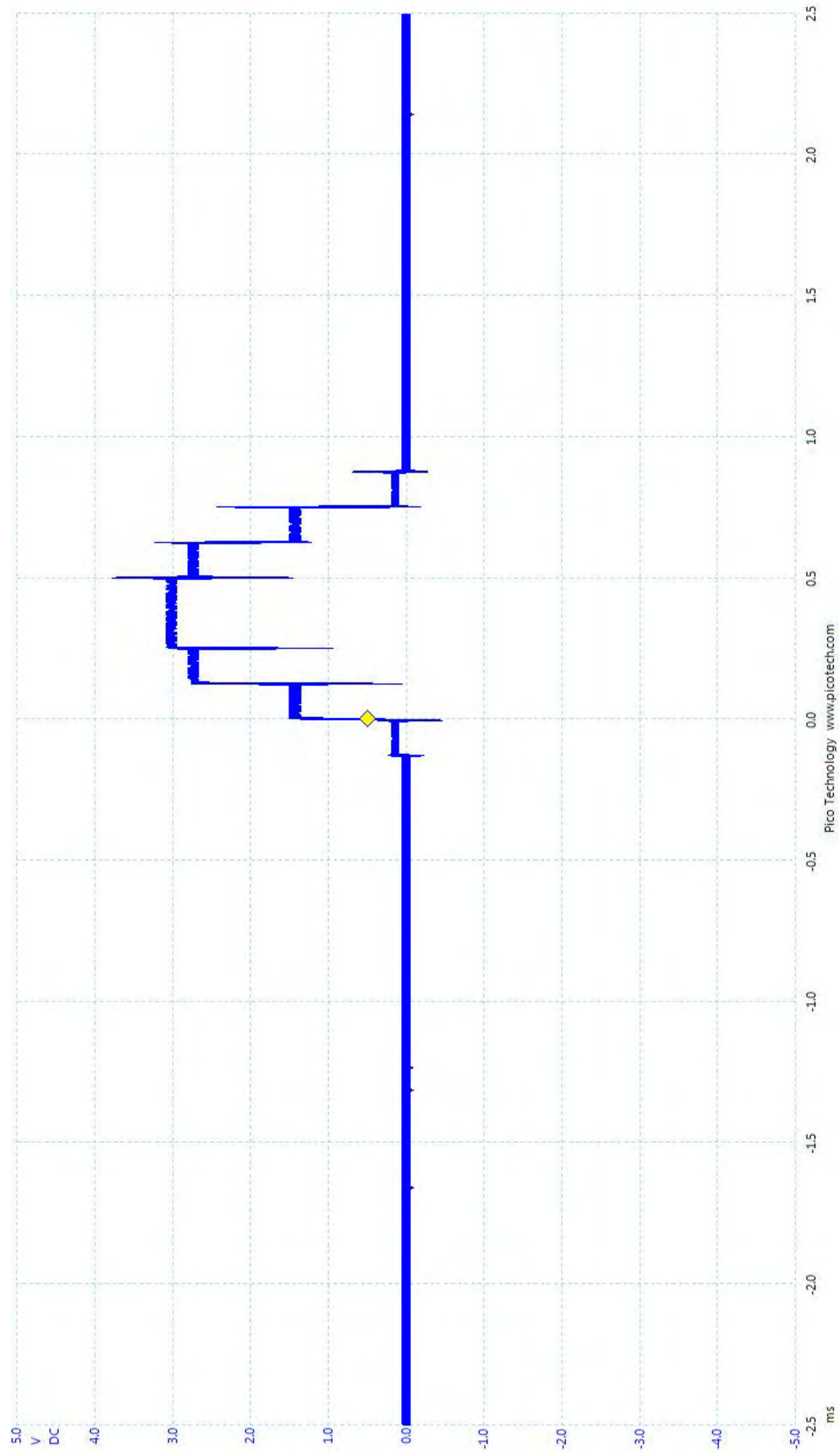


FIGURE B-9. Waveform R4 3 mA 1 ms.

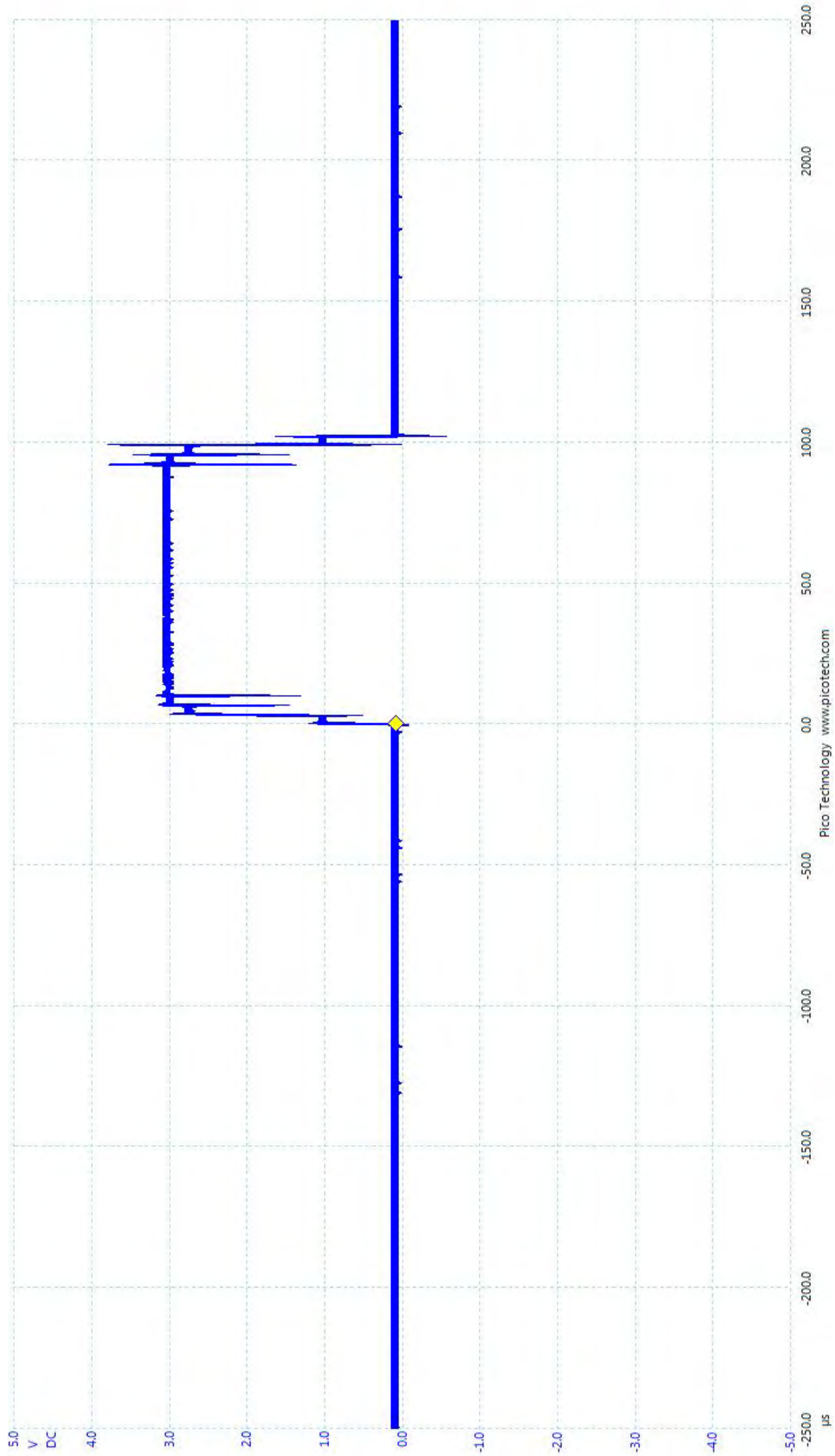


FIGURE B-10. Waveform R4 30 mA 100 µs.

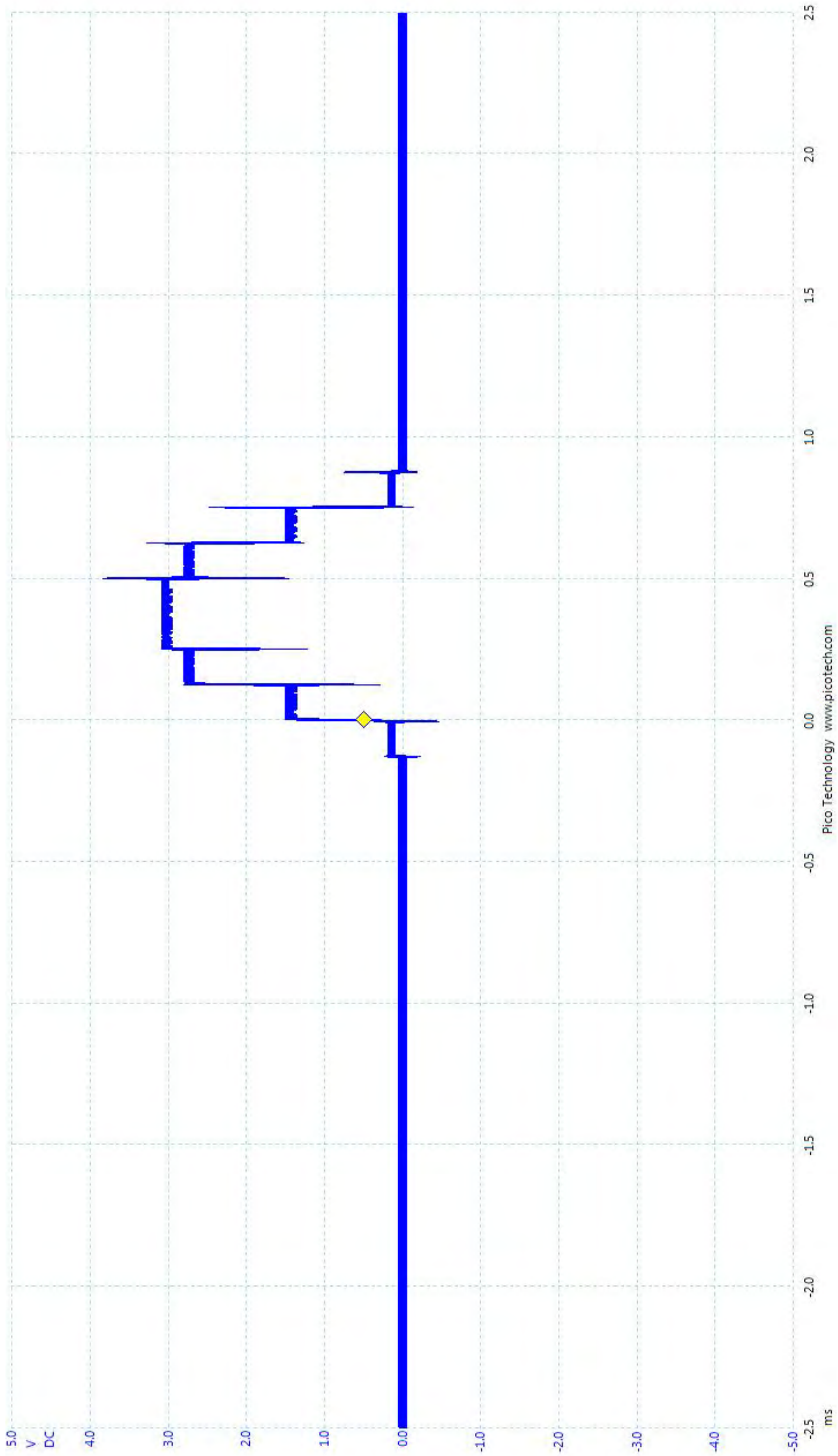


FIGURE B-11. Waveform S4 3 mA 1 ms.

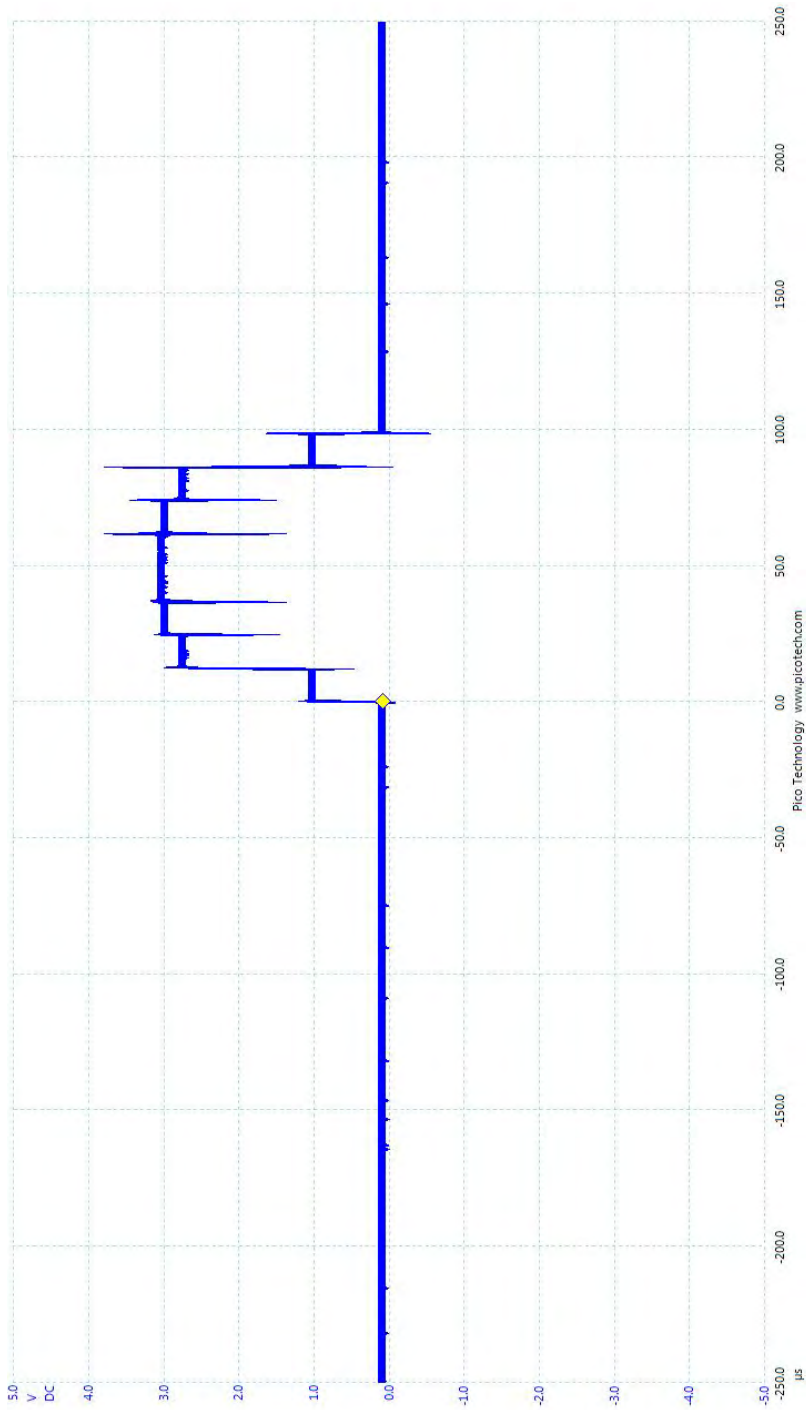


FIGURE B-12. Waveform S4 30 mA 100 µs.

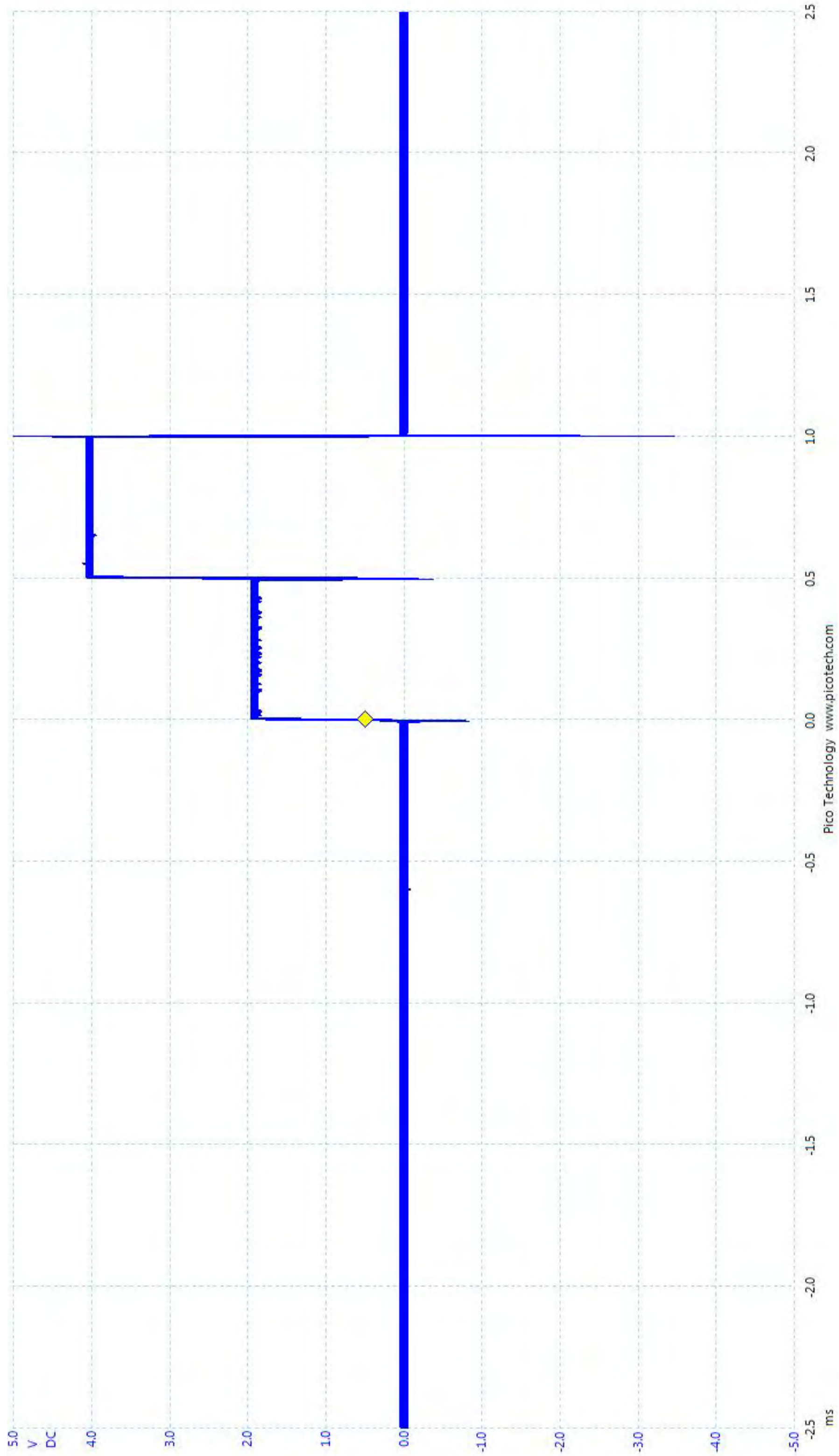


FIGURE B-13. Waveform T4 3 mA 1 ms.

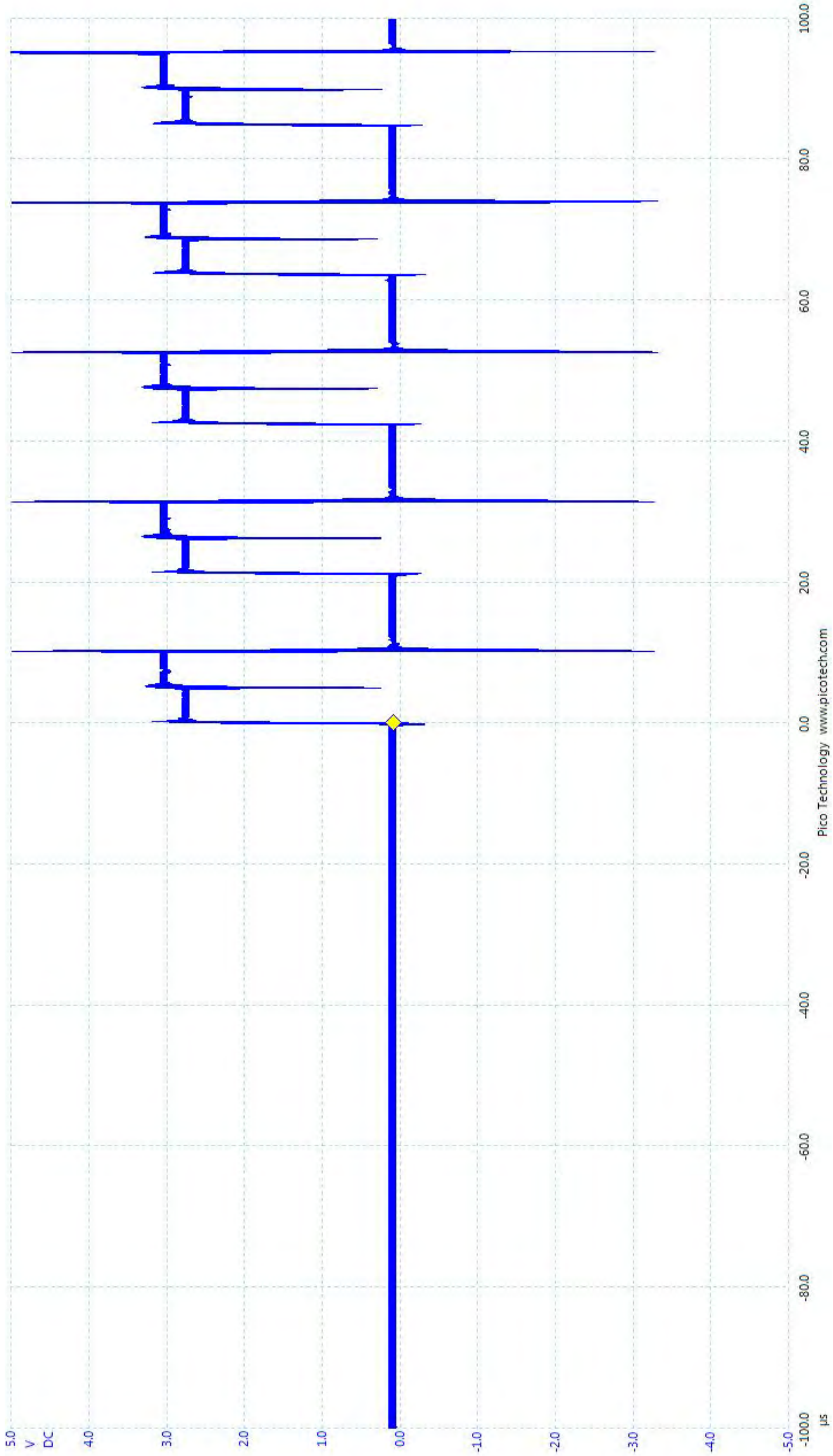


FIGURE B-14. Waveform T4 30 mA 10 µs 5B.

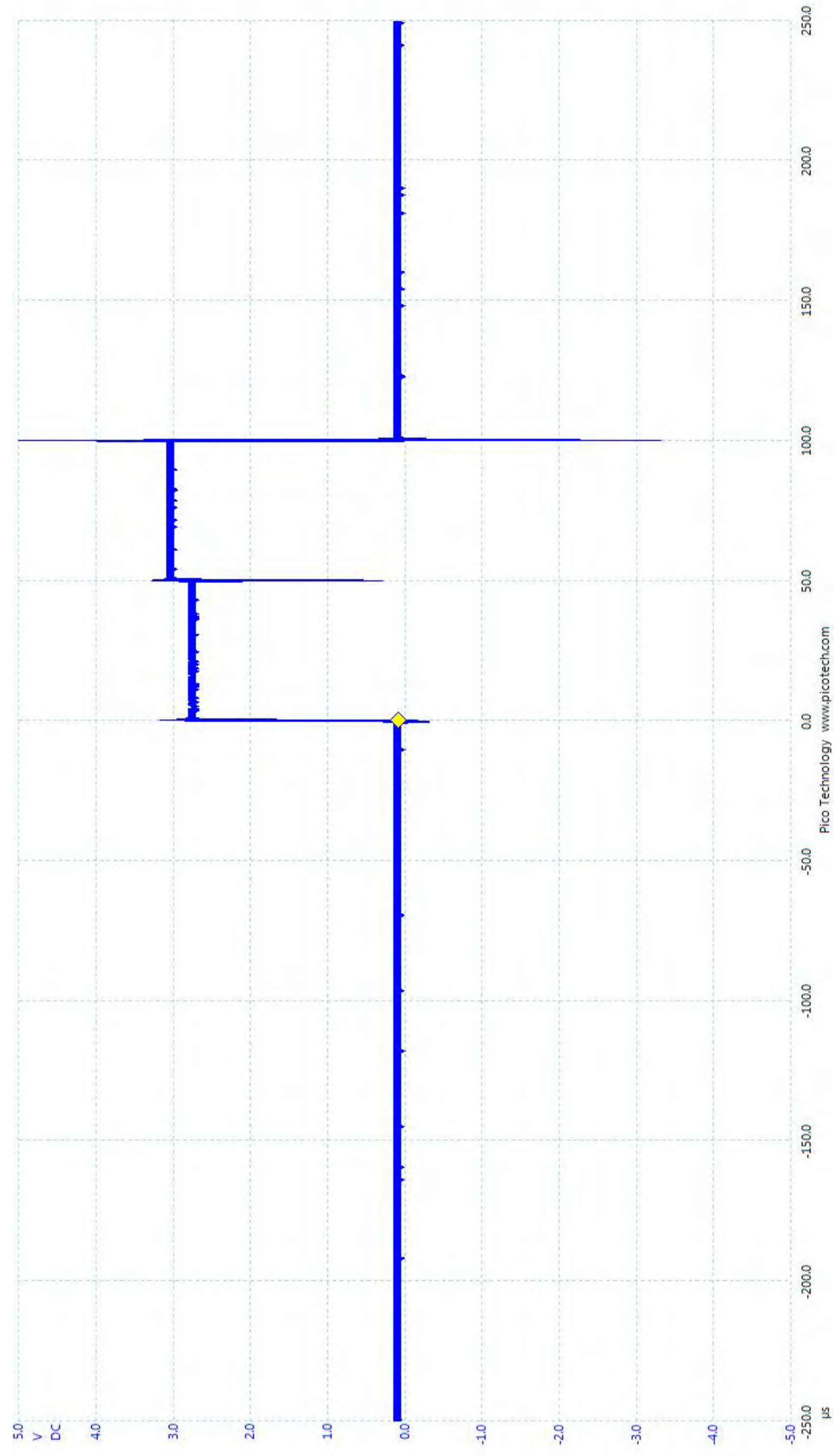


FIGURE B-15. Waveform T4 30 mA 100 µs.

B.5 F/A-18 generator converter unit waveform examples. Figures B-16 through B-21 are examples of waveforms taken from an F/A -18 Generator Converter Unit (GCU). These intermittent faults were detected by Intermittent Fault Diagnostic Equipment and the waveforms were captured on an oscilloscope. All of the waveforms are of different amplitudes and durations, but coming from the same test point. These examples illustrate the importance of testing all circuits simultaneously. Figures B-16 through B-21 also show that intermittent faults do not follow a specific pattern from minute to minute during testing, which is one reason that intermittent faults are difficult to capture and detect. These waveforms are provided only as examples. Waveform duration, amplitude, and shape will vary depending on the piece of equipment and the nature of the intermittent fault (fatigue fracture, cold solder joint, poor crimp, etc.).

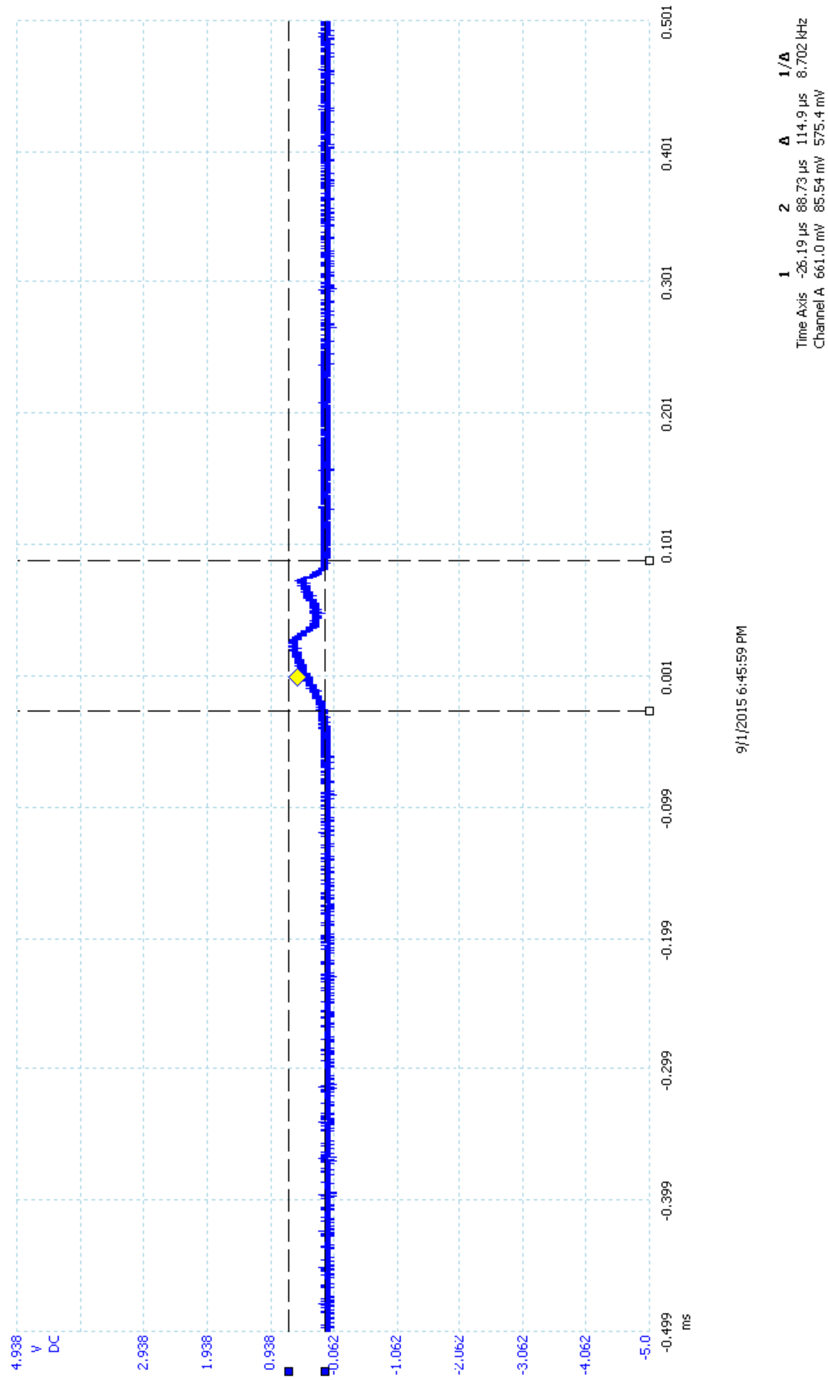


FIGURE B-16. GCU waveform example 1.

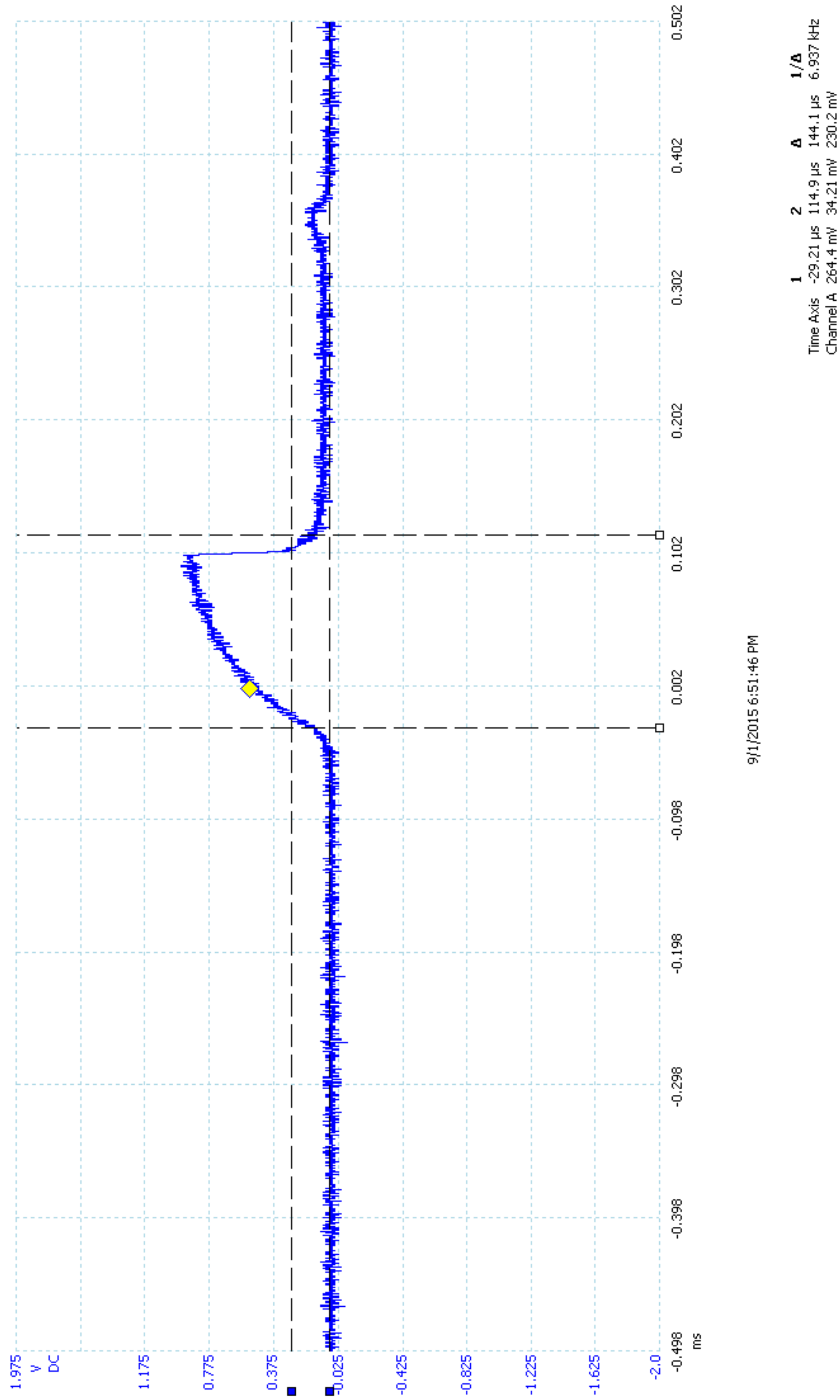


FIGURE B-17. GCU waveform example 2.

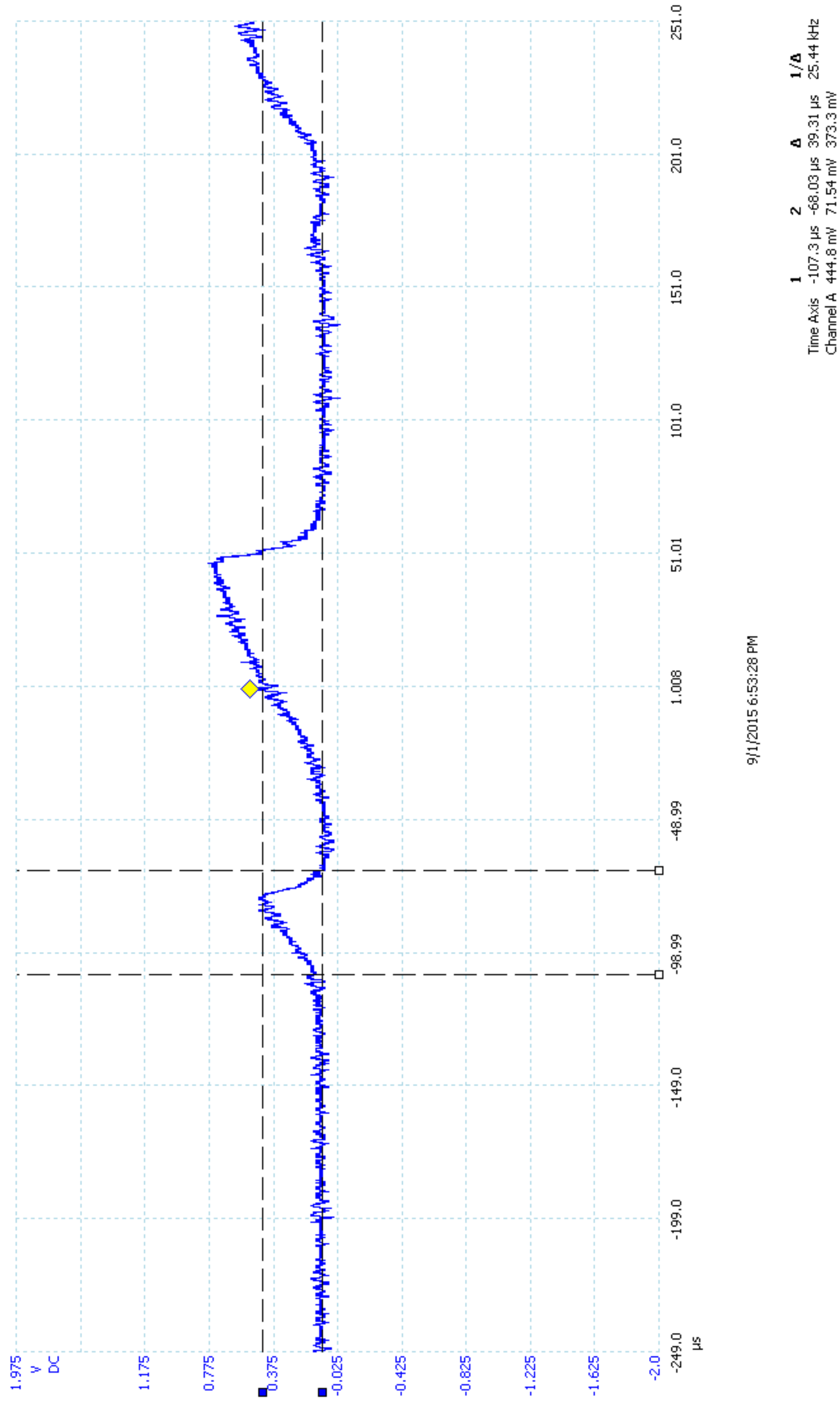


FIGURE B-18. GCU waveform example 3.

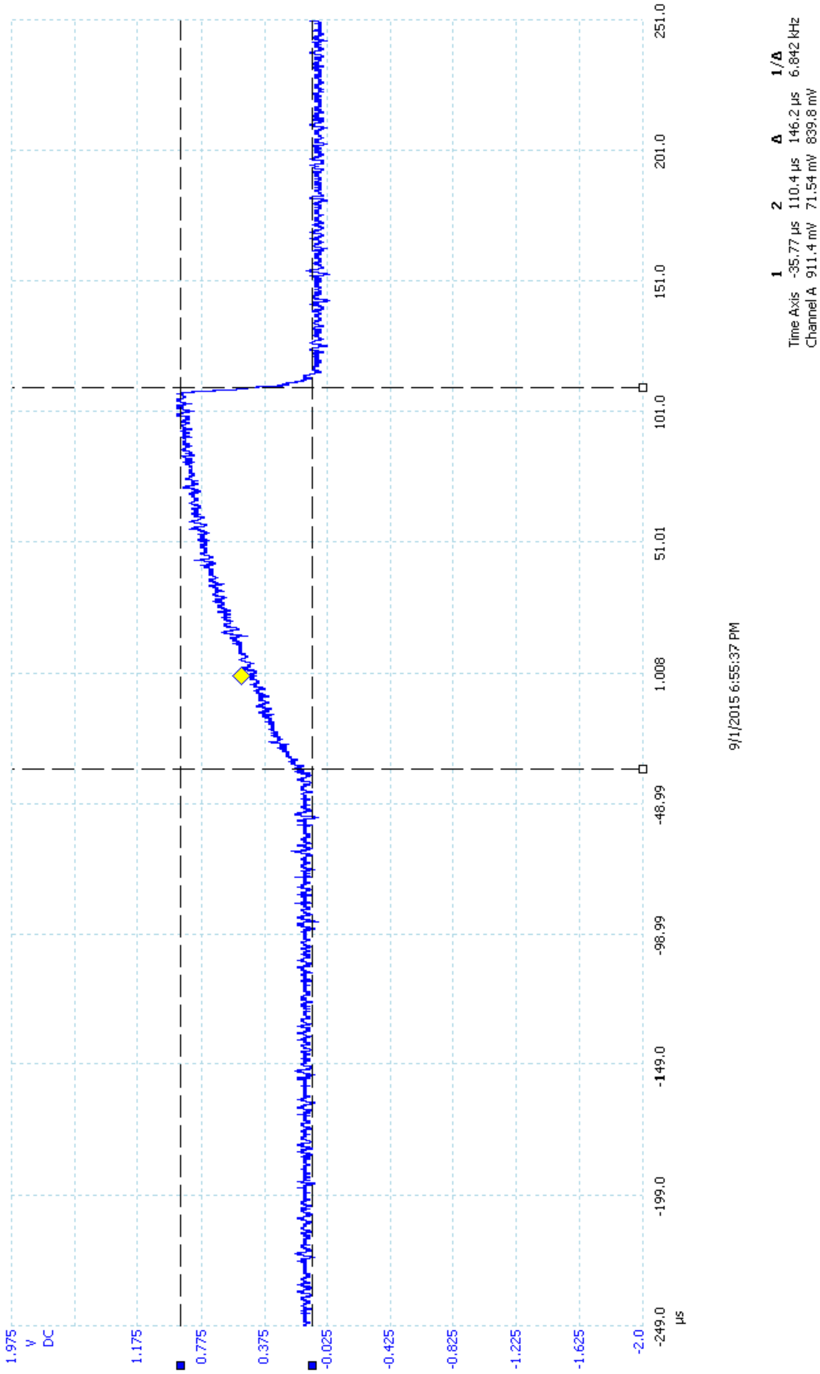


FIGURE B-19. GCU waveform example 4.

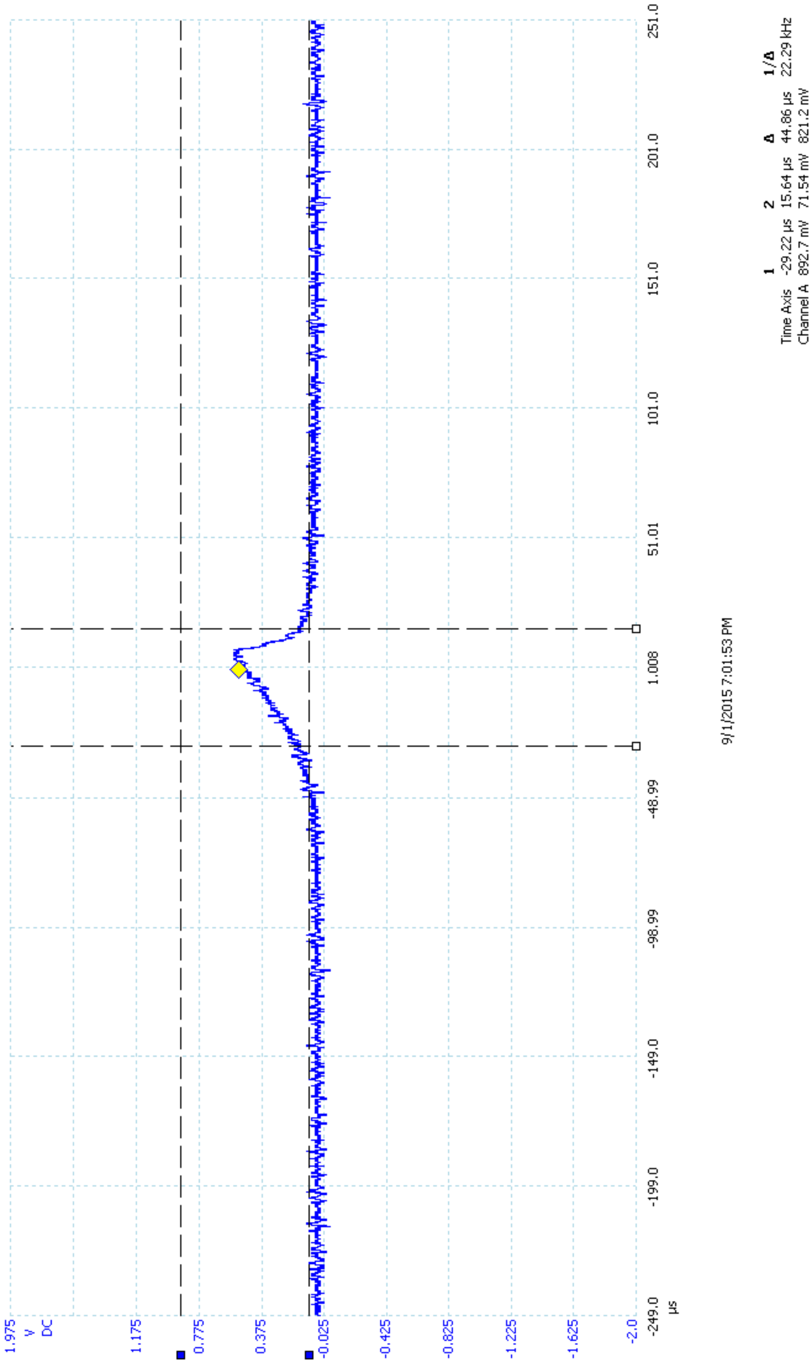


FIGURE B-20. GCU waveform example 5.

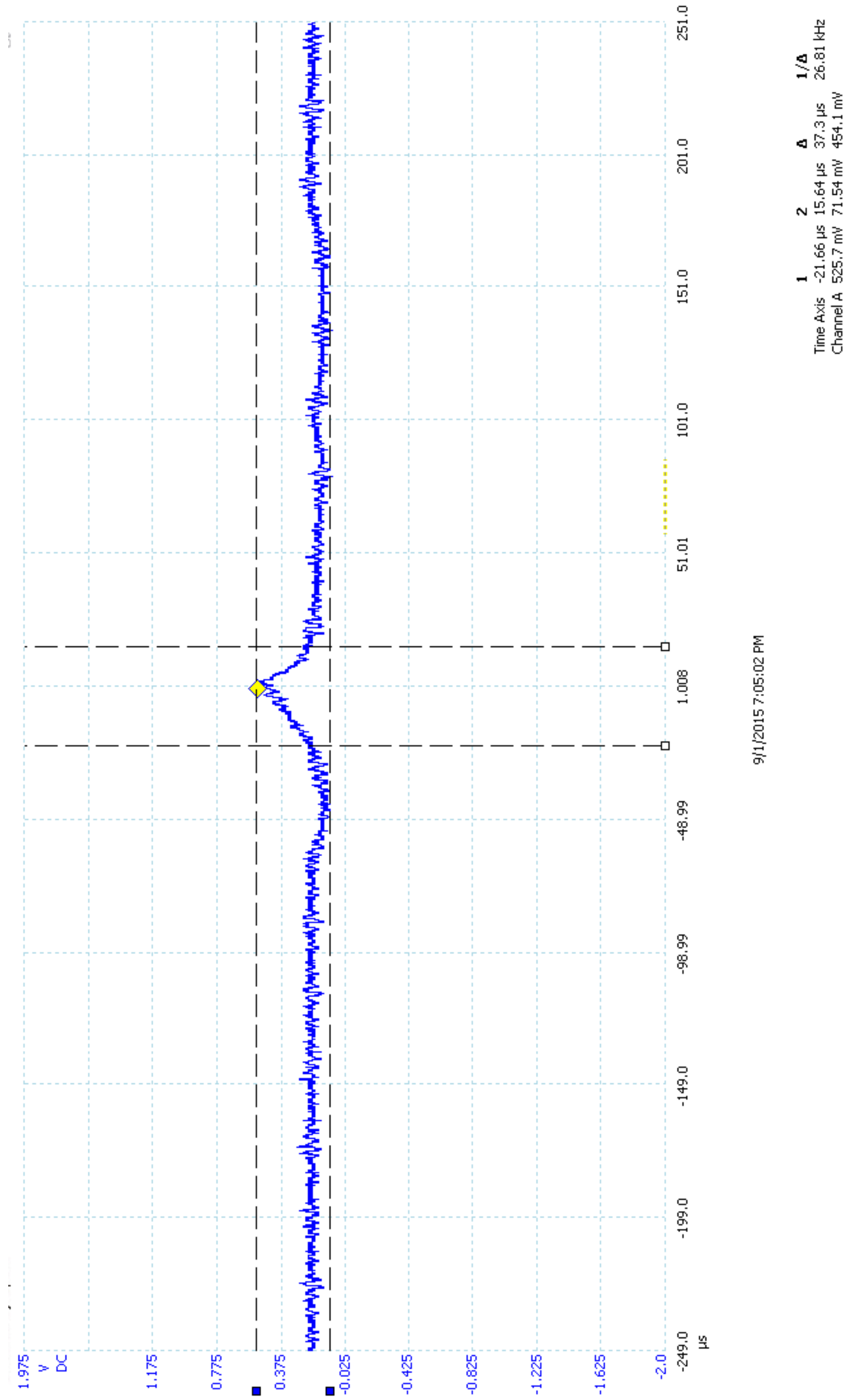


FIGURE B-21. GCU waveform example 6.

B.6 AN/APG-68 radar system programmable signal processor (PSP) waveform examples. Figures B-22 through B-26 are examples of waveforms taken from an AN/APG-68 Radar PSP. These intermittent faults were detected by Intermittent Fault Diagnostic Equipment and the waveforms were captured on an oscilloscope. All of the waveforms were detected on the same pin within the PSP and demonstrate the same intermittent event at different durations. Again as was seen in F/A-18 GCU (see B.5) example, this illustrates the importance of testing all circuits simultaneously. Figures B-22 through B-26 also demonstrate that intermittent faults do not follow a specific pattern from minute to minute during testing, which is one reason that intermittent faults again are difficult to capture and detect. These waveforms are provided only as examples. Waveform duration, amplitude and shape will vary depending on the piece of equipment and the nature of the intermittent fault (fatigue fracture, cold solder joint, poor crimp, etc.).

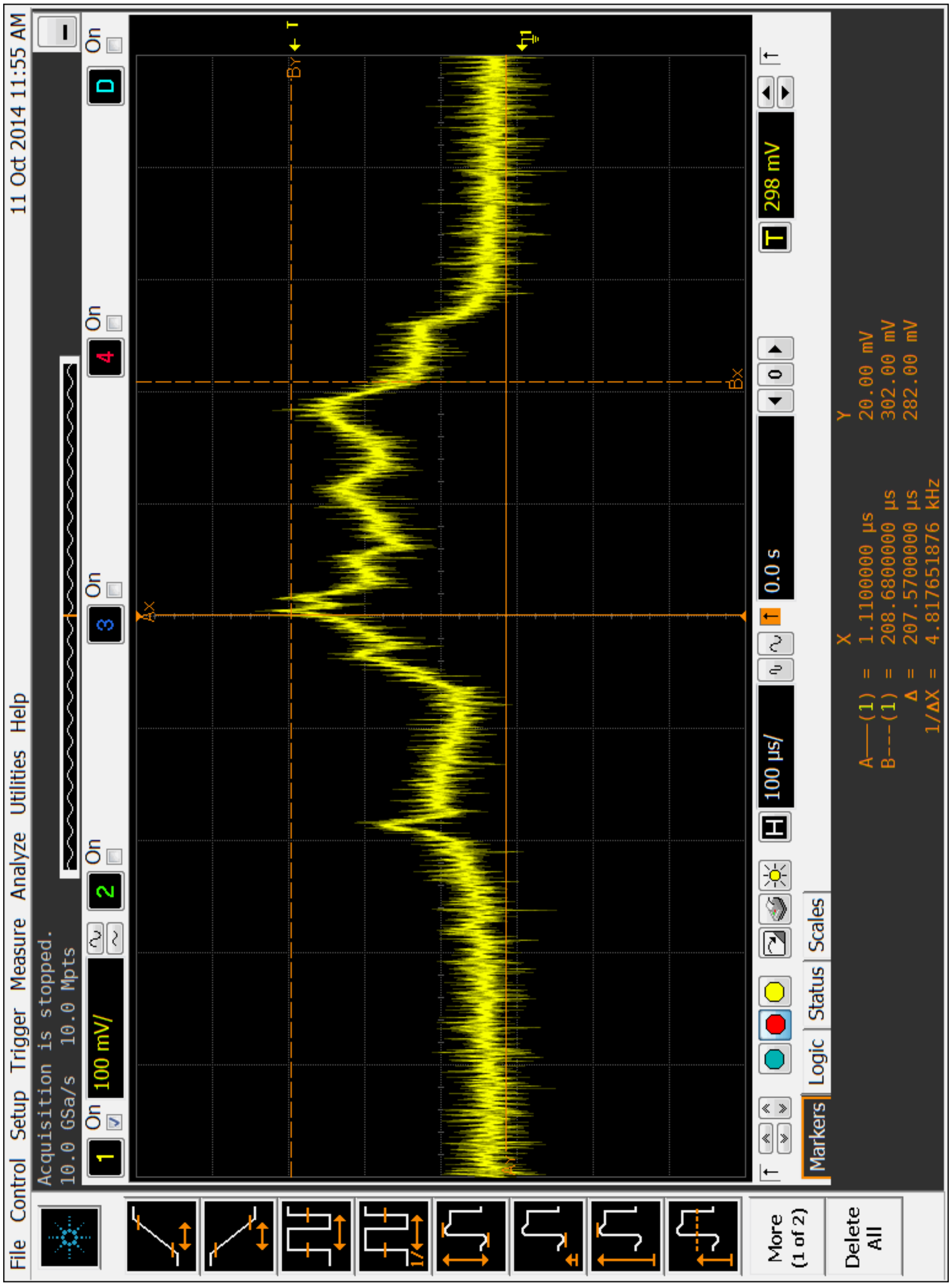


FIGURE B-22. PSP intermittent.
Duration approximately 207 microseconds

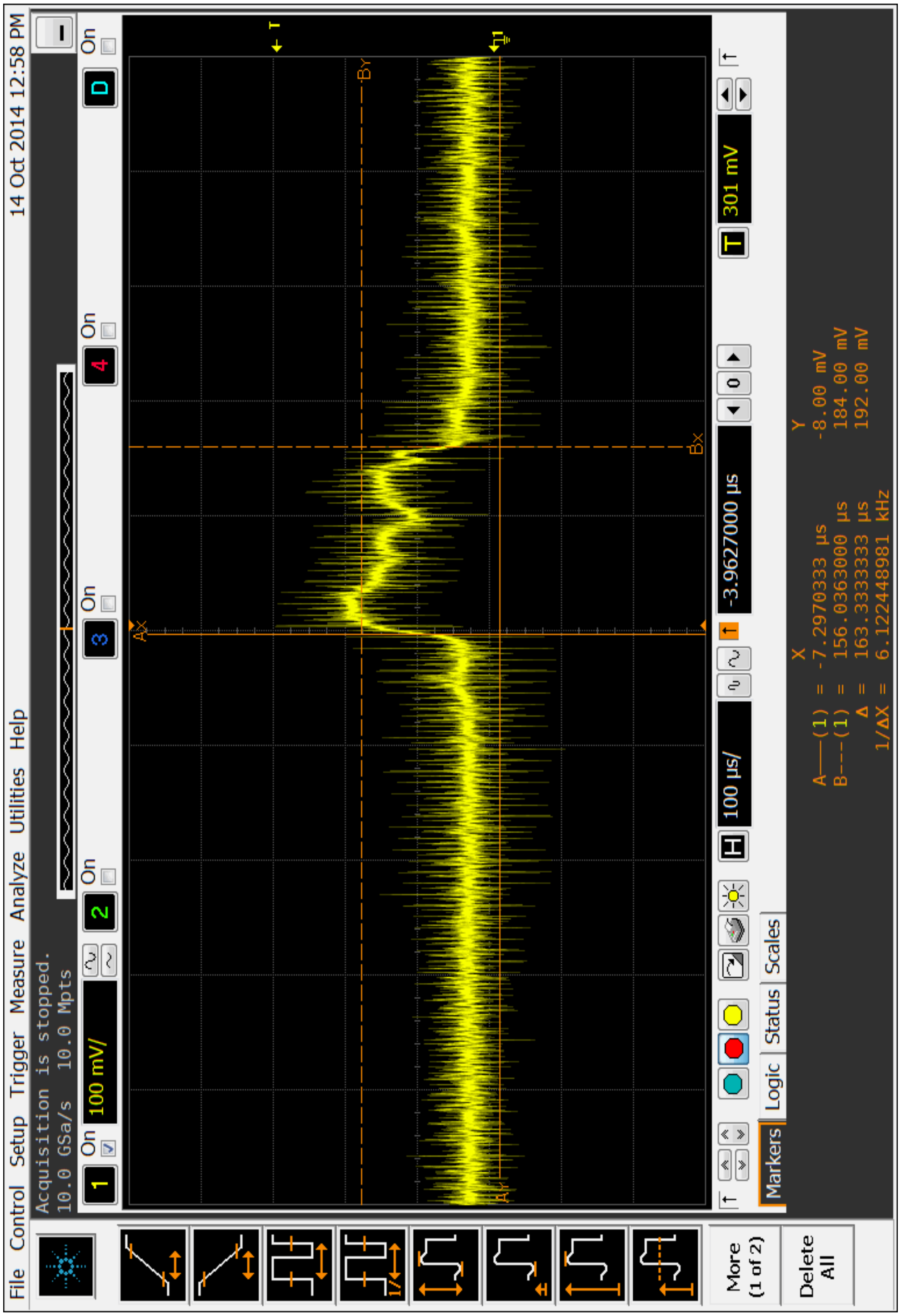


FIGURE B-23. PSP intermittent.
Duration approximately 163 microseconds

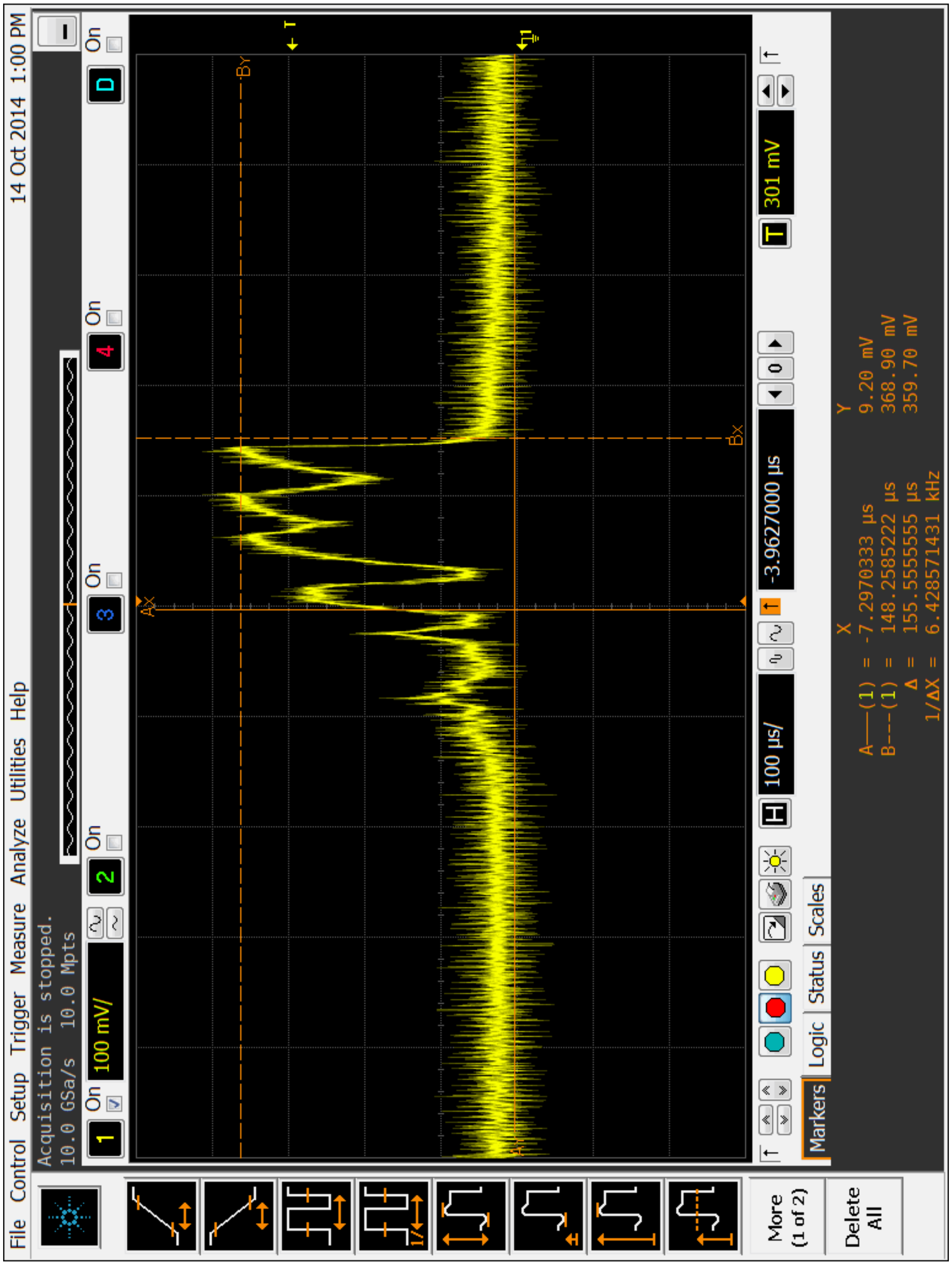


FIGURE B-24. PSP intermittent.
Duration approximately 155 microseconds

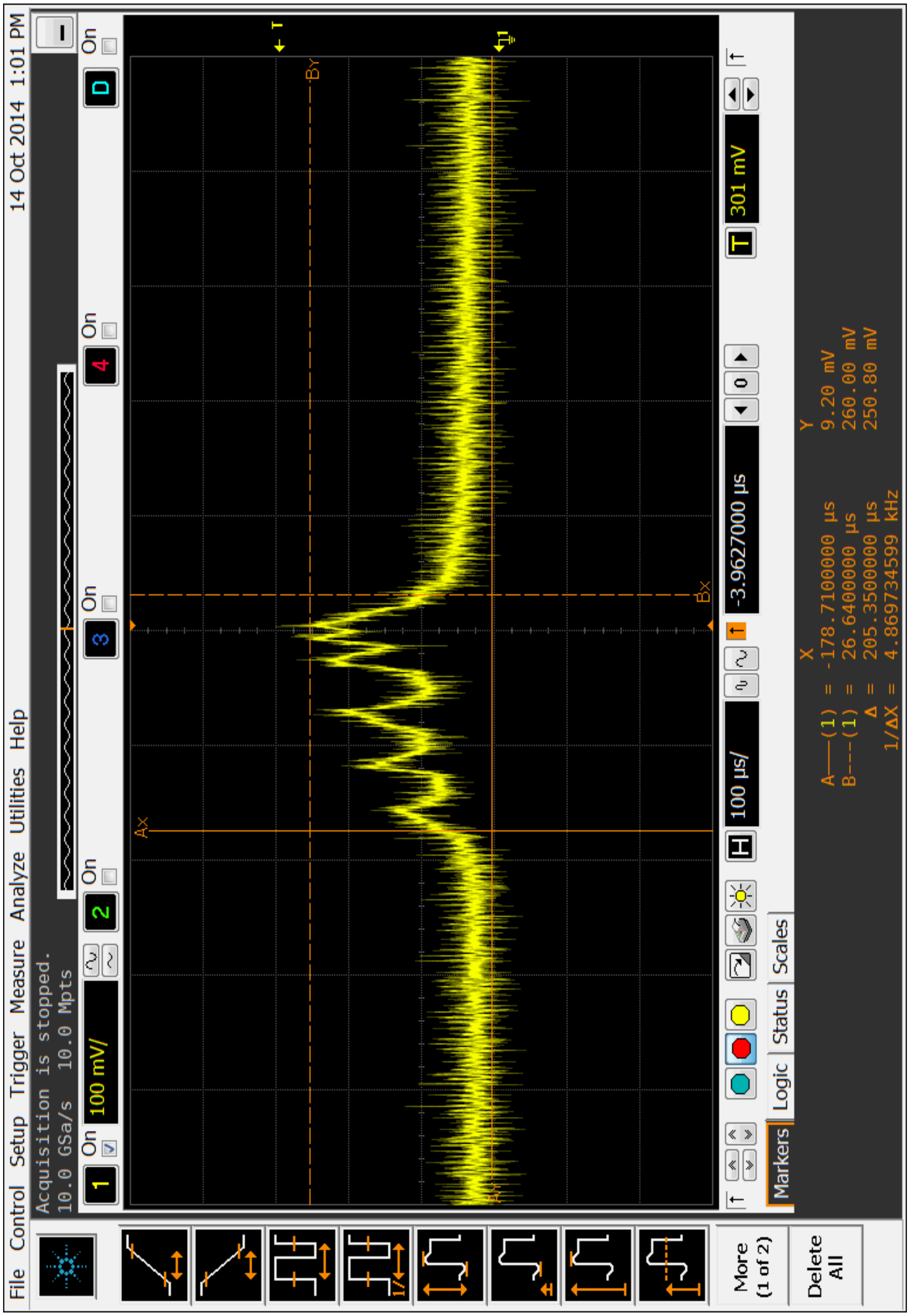


FIGURE B-25. PSP intermittent.
Duration approximately 205 microseconds

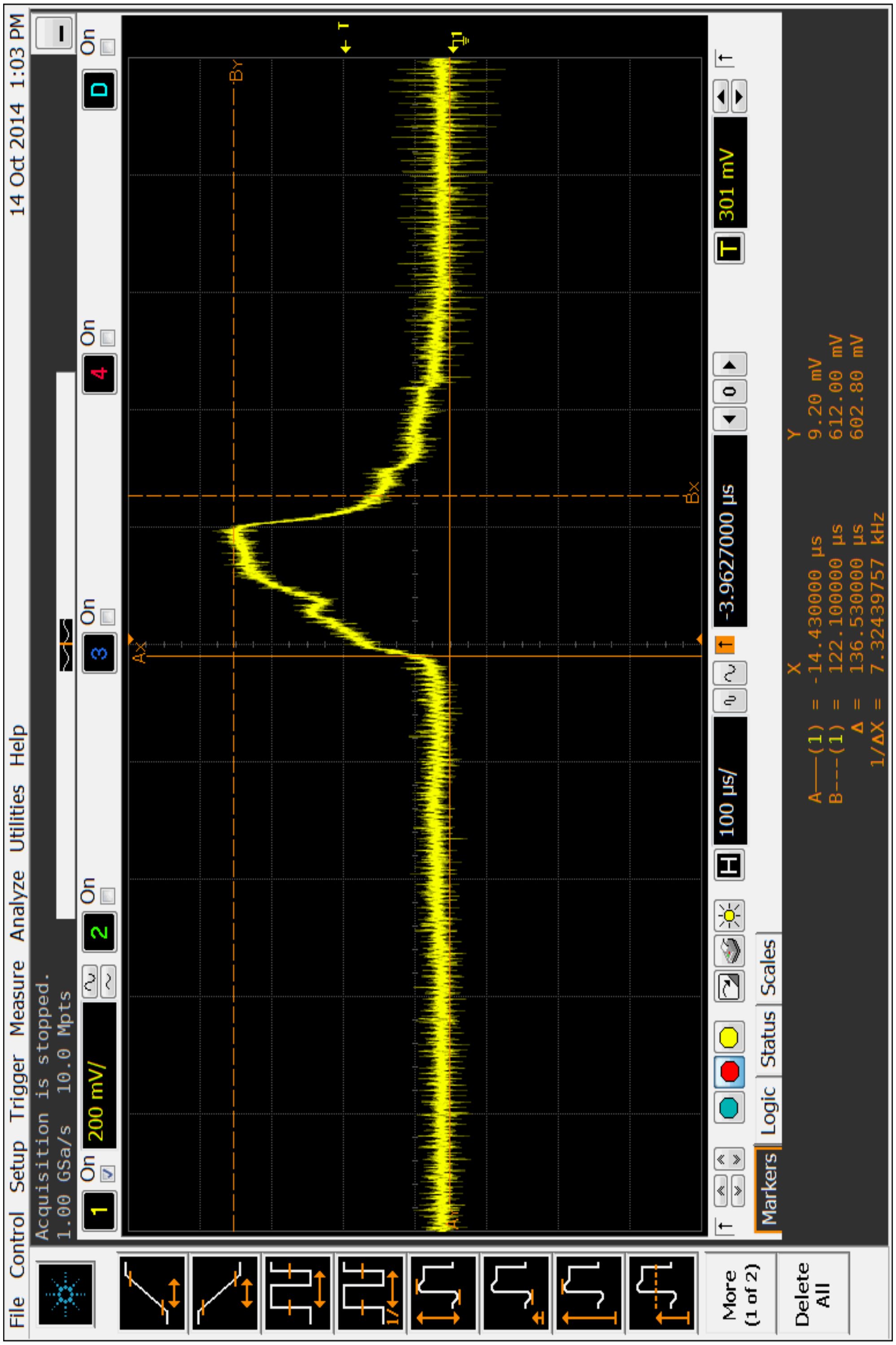


FIGURE B-26 .PSP intermittent.
Duration approximately 136 microseconds

CONCLUDING MATERIAL

Custodians:
Army - MI
Navy - AS
Air Force - 85

Review activities:
Army - AV
Air Force - 99

Preparing activity:
Navy – AS
Project 6625-2017-002

NOTE: The activities listed above were interested in this document as of the date of this document. Since organizations and responsibilities can change, you should verify the currency of the information above using the ASSIST Online database at https://assist.dla.mil.

Determining the Potential for IFDIS

Briefing to the Joint Intermittence Tester (JIT) Team

Greg Kilchenstein and Eric Herzberg

August 2, 2017

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Cleared For Public Release

Purpose

- Update the JIT on use of the Maintenance and Availability Data Warehouse (MADW) to determine potential candidates for the Intermittent Fault Detection and Isolation System (IFDIS)
- Update JIT on methodology used to determine potential savings by industrializing IFDIS process for all possible electronics components.

Maintenance and Availability Data Warehouse

- Started in FY2005 as a result of Congressional interest in reducing impact of corrosion on DoD weapons systems, infrastructure and facilities
- Involves obtaining all maintenance records, costs and non-availability results.
- Cost data back to FY04, availability data to FY08.
- Includes value added data elements such as:
  1) Object – solved through machine learning
  2) Action – solved through machine learning
  3) Standard work breakdown structure (WBS)
  4) Corrective and preventive work classifications
  5) Parts verses structure classifications
  6) Availability and cost results embedded together
  7) Environmental severity index (ESI)
  8) All cost and availability results reconciled to authoritative top-down totals

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MADW – Sample of Data Record

(10 of the approximately 40 labor data fields showing)

ENDITEMUNIQUEID	AVAILCD	Maint NMC	Maint Operation	Maint Object	LMIWBS	UNITCD	Maintenance Cost	MAINTDLH	ESI
163989	Z	0.11	Adjust	Launcher	FM353	N39787	$3,751.84	8	1
160107	Z	0.14	Strip	Door	RC020	M09383	$6,285.91	18	7
166365	Z	0.07	Replace	Hydraulic hose	RR062	NF9823	$414.25	1.2	12
166291	Z	0.11	Clean	Locking pin	RC034	N09822	$681.00	2	3
166388	Z	0.13	Check	Track	RI351	M53923	$3,300.35	3	5
164075	Z	0.09	Replace	Hydraulic hose	RR062	N09299	$62.60	0.2	12
164075	Z	0.15	Replace	Hydraulic hose	RR062	N09299	$62.60	0.2	18
164075	Z	0.14	Replace	Hydraulic hose	RR062	N09299	$214.32	0.8	3
160825		0	Weld	Airframe	RF020	M09202	$543.59	2	5
156438		0	Repair	Gearbox	RF053	M09793	$3,164.43	5.8	6
154853		0	Repair	Gearbox	RF053	M52790	$3,215.00	6	8
165910		0	Install	Computer	FL116	M09439	$158.80	1	2
165931		0	Repair	Drive Unit	FF062	N09678	$1,016.37	1	4
166407		0	Install	Alarm	FL194	N09355	$257.80	1.2	11
166532		0	Install	Alarm	FL194	N4544A	$257.80	0.2	10
166533		0	Configure	Controller	FM095	N55138	$407.79	0.1	9
166532		0	Configure	Alarm	FM194	N55138	$74.34	0.1	9

Approximately 800 million maintenance records for weapon systems for all services

All weapon systems studies now being executed on a yearly basis – soon to be quarterly

All yearly maintenance costs accounted for relative to these systems

Standardized data structure across DoD

Availability results for ground, ships and aviation systems since FY2008.

The NMC totals equal the reported totals for each Service by weapon system.

Contains both labor (task) and materials (parts) detail. Parts are linked to labor through the job control number.

Results can be determined to the action and object level of detail

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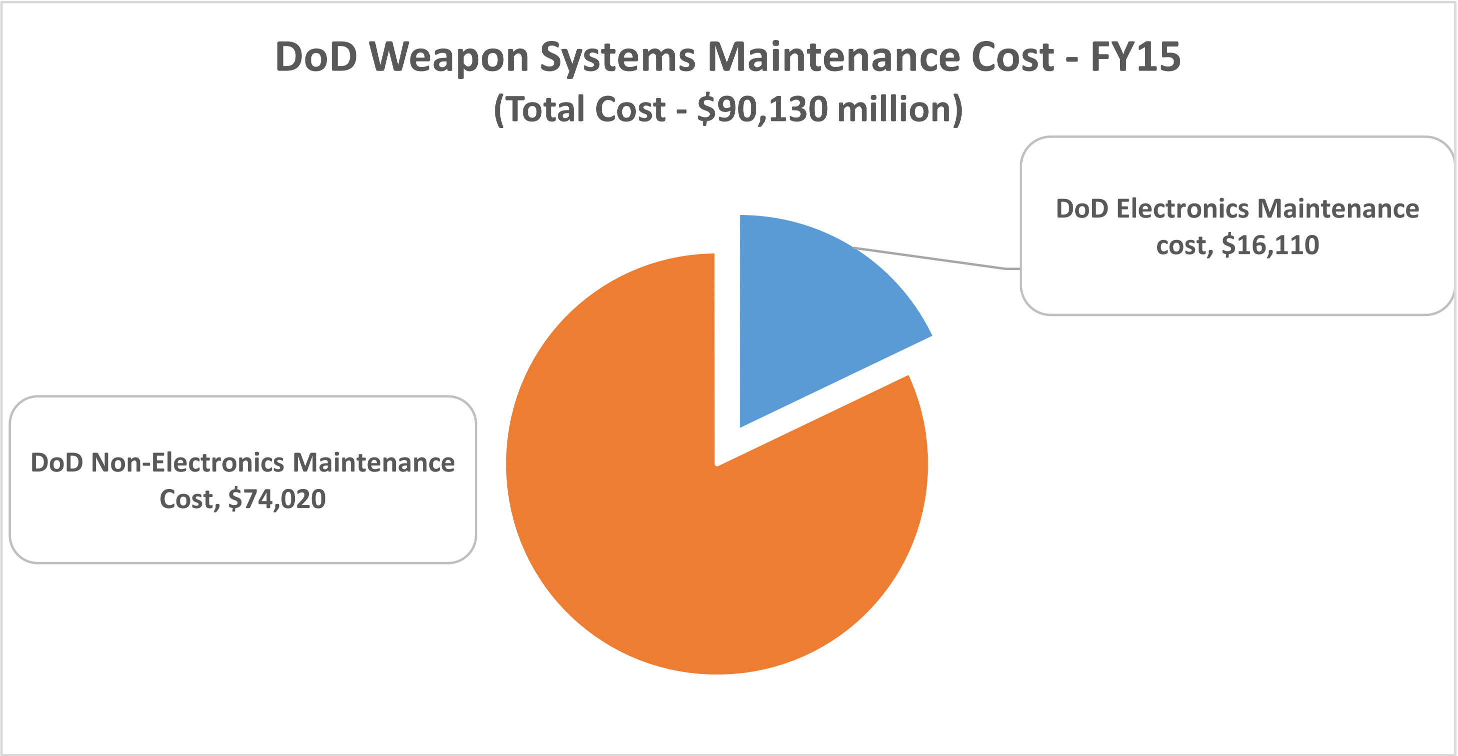
Electronics Cost as a Subset of Weapons Systems Maintenance Costs



Electronics maintenance ($16,110 million) includes all electronics, not just LRU's and WRA's

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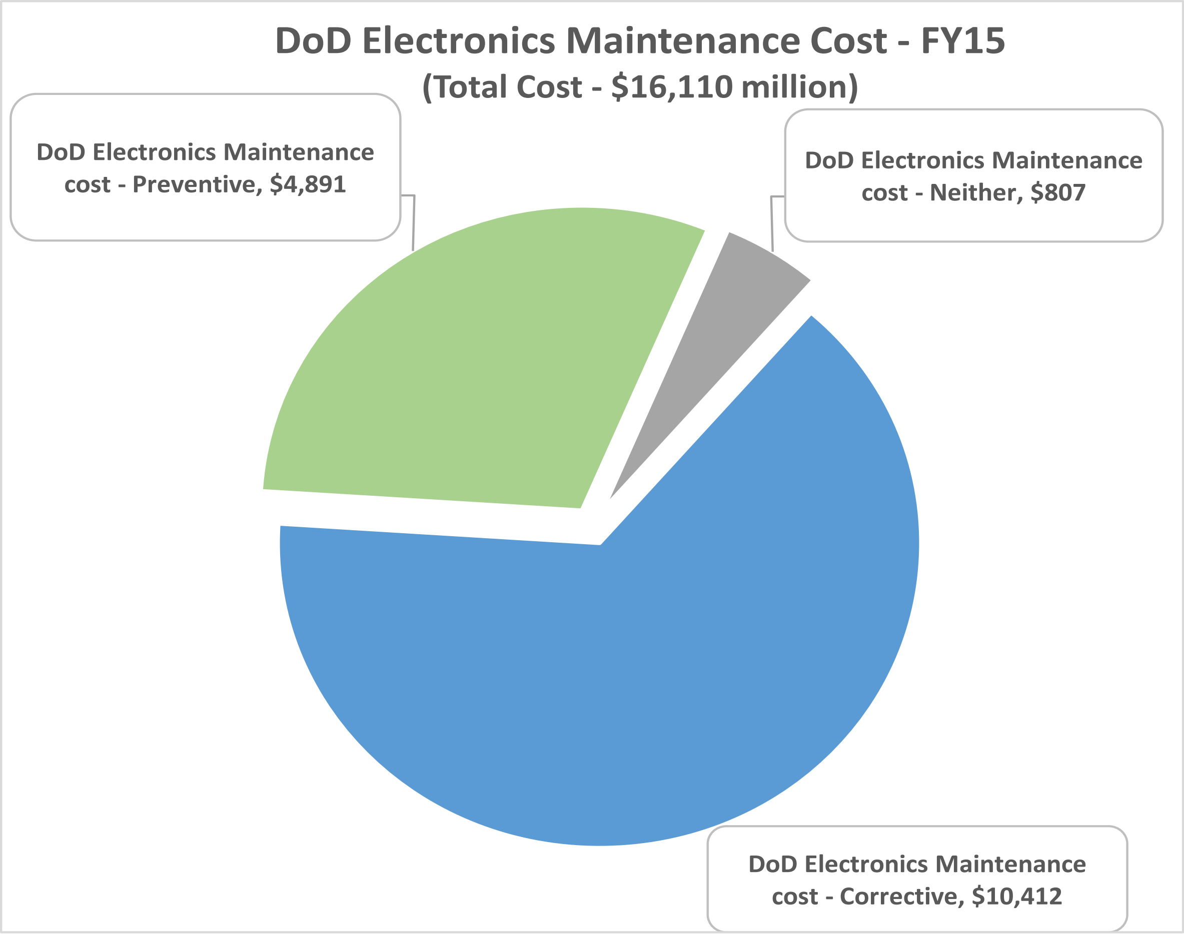
Electronics Cost By Nature of Work



We will focus on only the corrective maintenance portion ($10,412 million)

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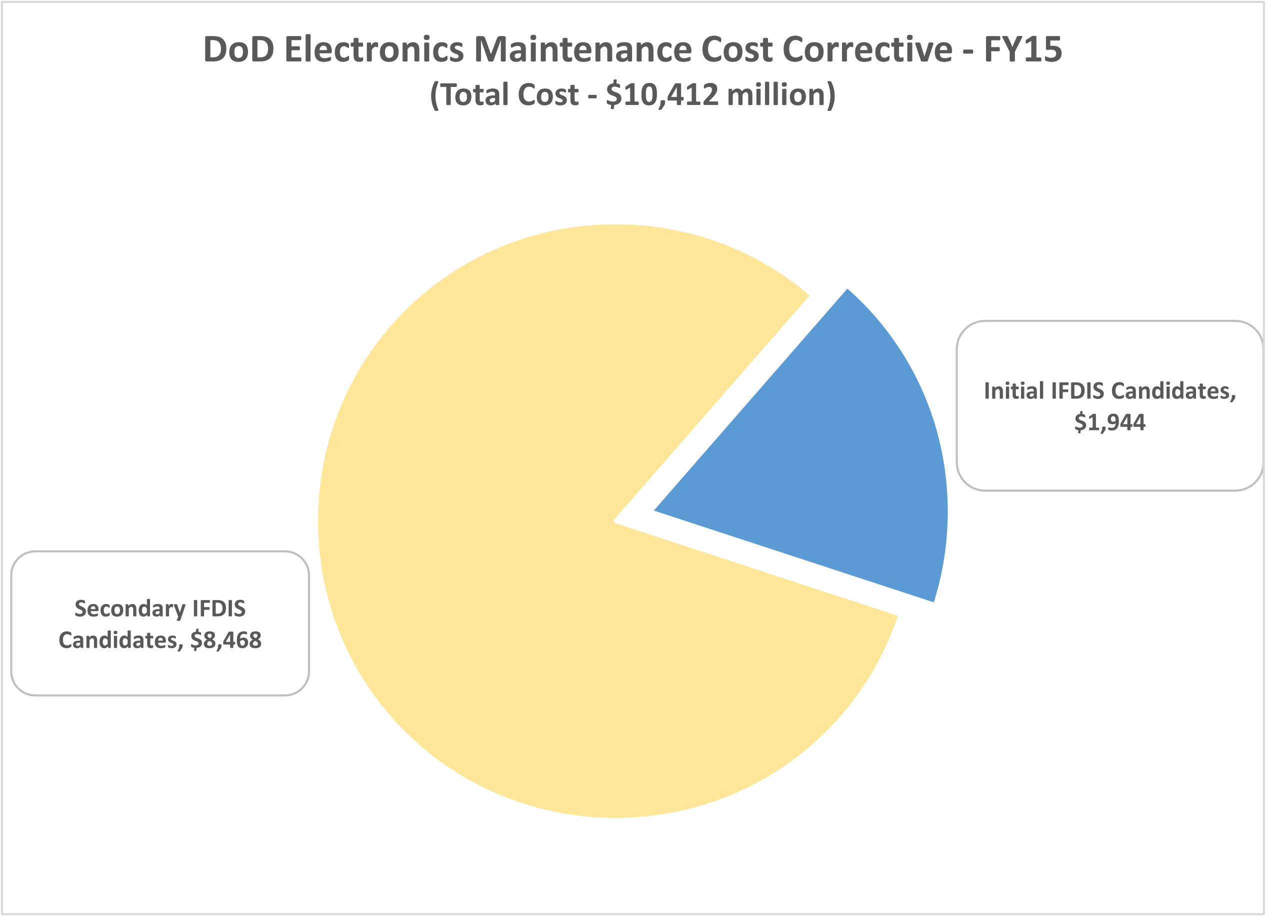
Corrective Electronics Cost IFDIS Potential



We can isolate initial IFDIS candidates (LRU's, WRA's) and secondary IFDIS candidates (non LRU's and WRA's)

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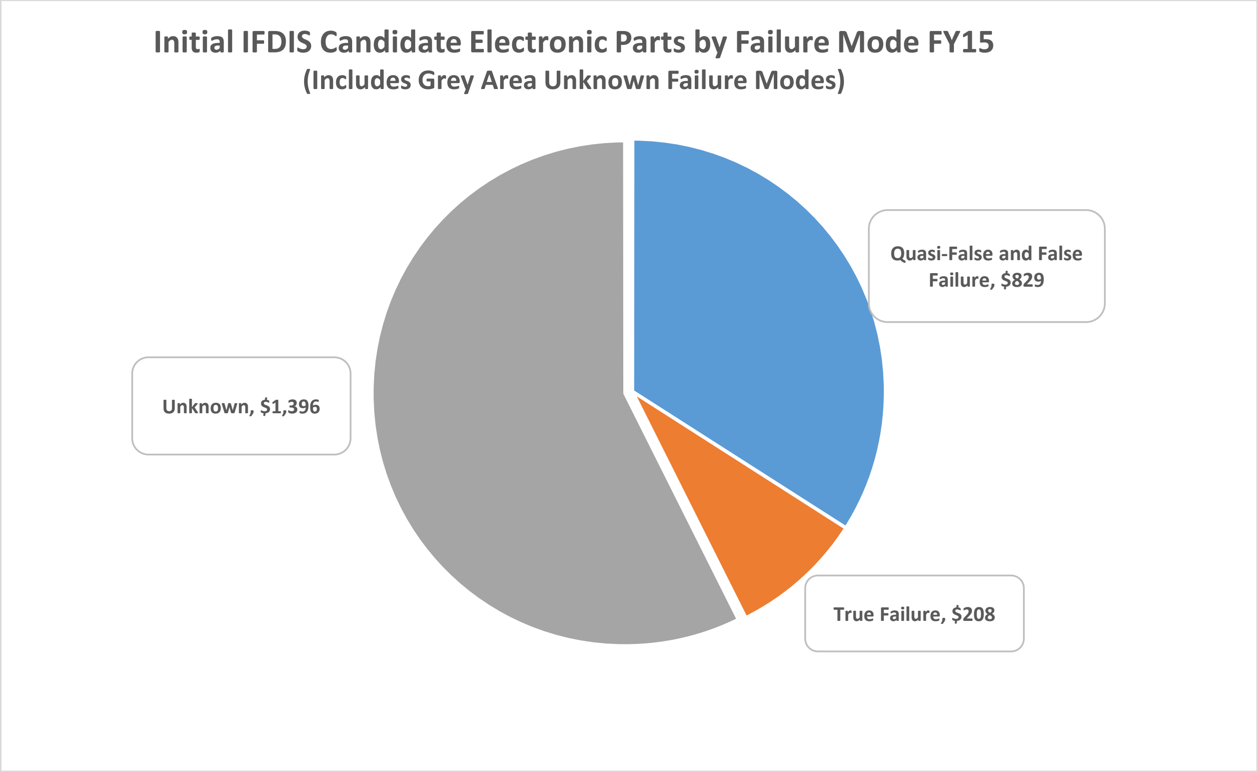
Determining Initial IFDIS Candidates



Using FY15 data and isolating potential LRU, WRA type objects and NIINs, the failure recipe tagged $829 million costs as quasi-false and false failures and $208 million in cost as true failures.

There was another $1,396 million of the same objects and NIINs, which had corrective maintenance actions but not tagged by the failure recipes. We apportioned this population into the blue and orange by ratio.

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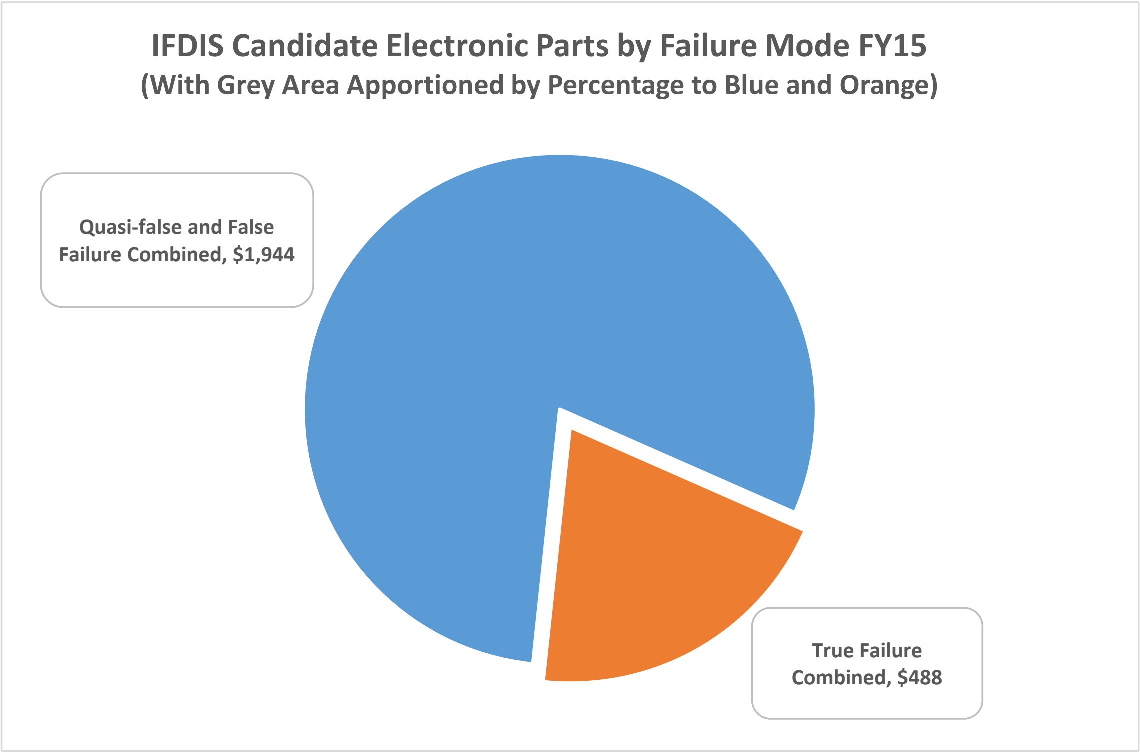
Determining Initial IFDIS Candidates



The resulting true failure (orange area) and quasi-false and false failure (blue area) totals are as depicted above after the “Unknown” (grey area from previous slide) is apportioned into orange and blue areas.

The annual total for the true failure (orange area) is $488 million. The annual total for the quasi-false and false failures (blue area) is **$1,944 million**. This is the initial IFDIS candidate total.

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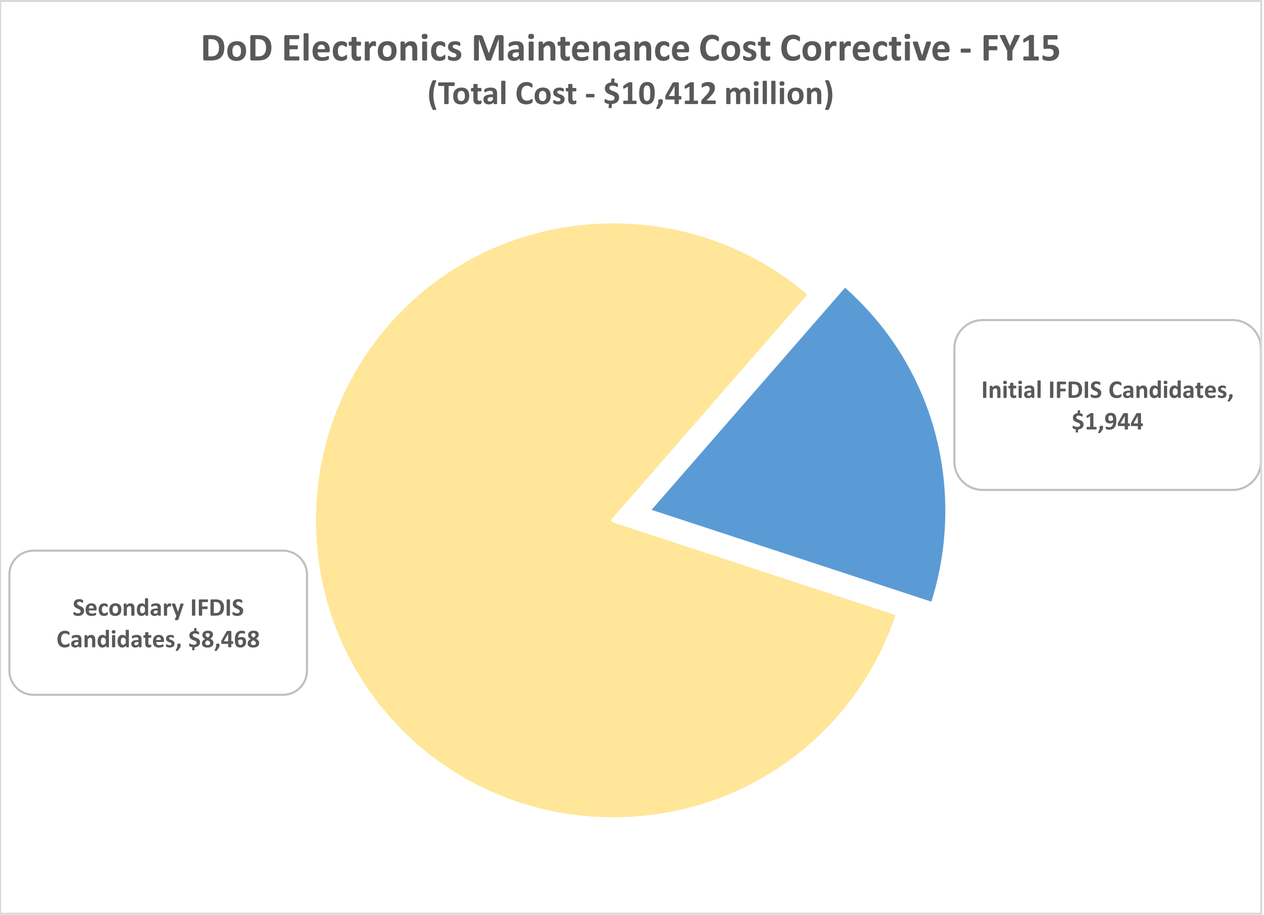
Determining Secondary IFDIS Candidates



The secondary IFDIS candidates are electronics components that have experienced corrective maintenance work that are not initial IFDIS candidates

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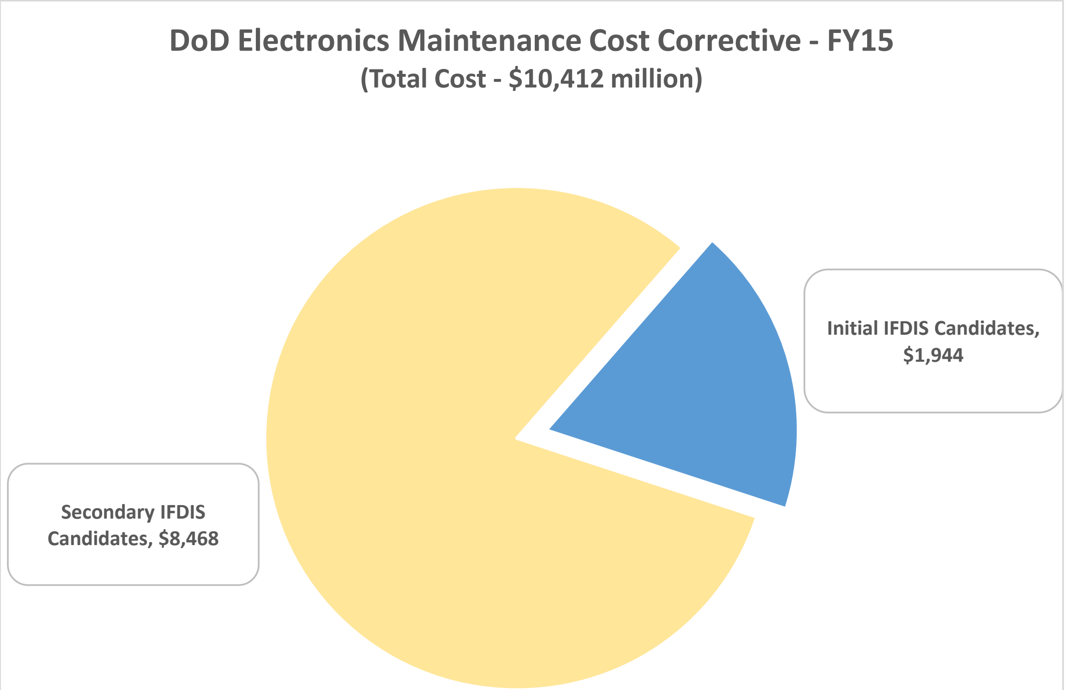
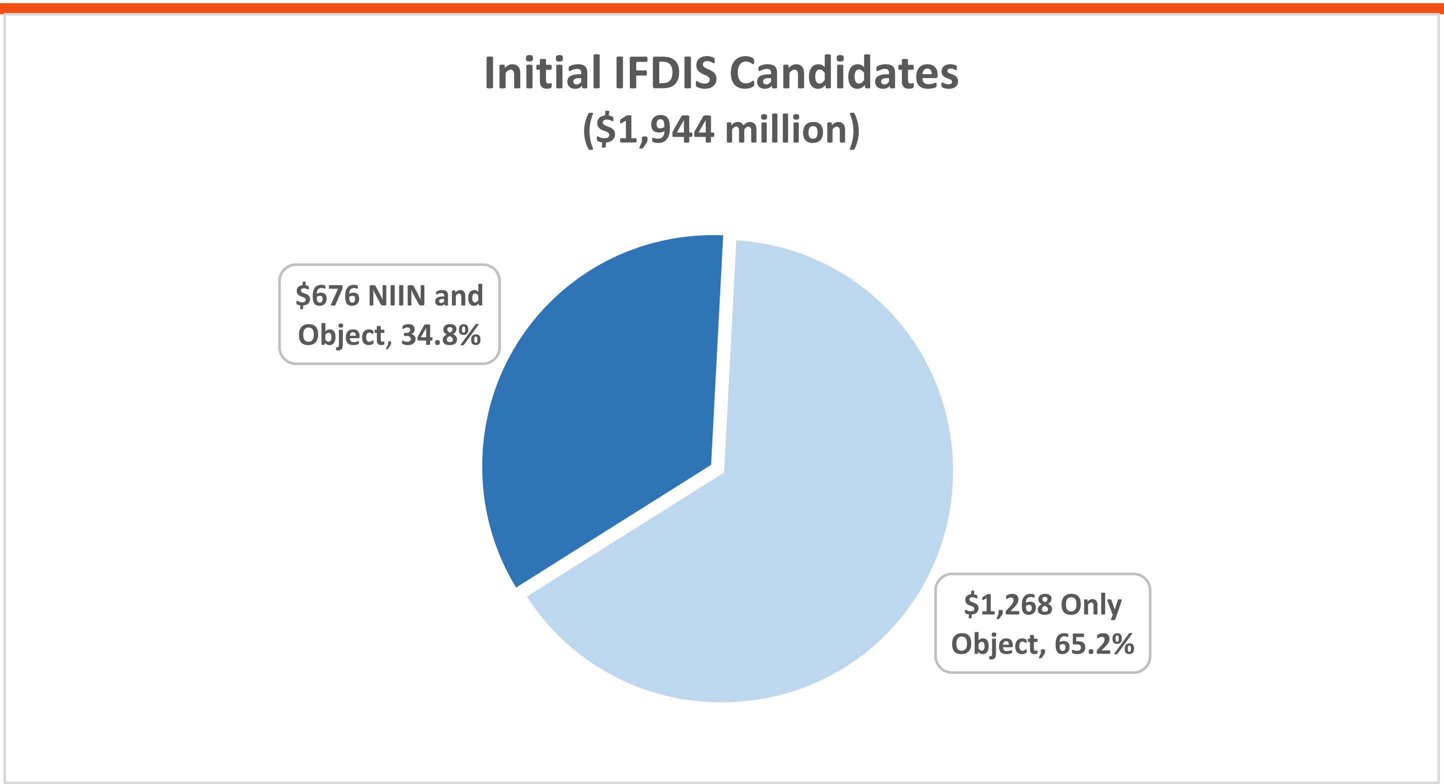
Total IFDIS Potential Savings



Category	Annual Costs ($ millions)	Total potential annual gains ($ millions)
IFDIS gains from Quasi-false and false failure remedy (Initial IFDIS candidates)	$1,944	$1,944
Potential secondary IFDIS electronic component gains with 10% improvement	$847	$2,791
Potential secondary IFDIS electronic component gains with 20% improvement	$1,694	$3,638
Potential secondary IFDIS electronic component gains with 30% improvement	$2,541	$4,485
Potential secondary IFDIS electronic component gains with 40% improvement	$3,387	$5,331
Potential secondary IFDIS electronic component gains with 50% improvement	$4,234	$6,178

Initial IFDIS Candidate ID by NIINs and Objects



Of the data records which comprise the $1,944 million worth of initial IFDIS candidates cost, 34.8% percent of these records identified the item being worked on by NIIN. All of the records identified the item being worked on by object. We therefore present two lists of initial IFDIS candidates for each service – one by NIIN and the other by object and type/model series of the end item.

Initial IFDIS Candidate ID by NIIN

(Navy example – costs and non-availability are two year totals for FY14-15)

Service	Criticality Code	Safety Critical?	NIIN	Maintenance Cost	Non-available days	Nomenclature
Navy	Y	No	013042152	$15,370,010	754	CONVERTER UNIT,GENE
Navy	Y	No	015911354	$15,050,678	33	SENSOR UNIT,ELECTRO
Navy	Y	No	014950012	$14,818,493	0	INERTIAL MEASURING
Navy	Y	No	015518187	$6,448,118	0	TRANSFORMER,POWER
Navy	X	No	014554501	$5,773,131	477	DISPLAY UNIT,HEAD-UP
Navy	Y	No	015340697	$5,652,936	0	CIRCUIT CARD ASSEMBLY
Navy	S	Yes	010595889	$5,392,032	0	CIRCUIT CARD ASSEMBLY
Navy	0	No	010874423	$4,525,048	72	RECEIVER-TRANSMITTER,RADAR
Navy	V	No	008157282	$4,500,733	13	INDICATOR
Navy	X	No	014814599	$4,239,823	0	MODEM ASSEMBLY,COMMUNICATIONS
Navy	Y	No	015507849	$4,200,337	31	CONVERTER FREQUENCY
Navy	F	Yes	015087987	$4,030,519	370	COMPUTER,FLIGHT CONTROL
Navy	N	No	012168124	$3,988,943	57	PROCESSOR,RADAR TARGET DATA
Navy	X	No	010121938	$3,940,351	40	NAVIGATION SET,TACTICAL AIR NAVIGATION SYSTEM
Navy	N	No	013336621	$3,742,916	193	DISPLAY UNIT,HEAD-UP
Navy	Y	No	015221457	$3,733,621	197	COMPUTER,FLIGHT CONTROL
Navy	X	No	013726234	$3,452,113	0	REGULATOR,VOLTAGE
Navy	Y	No	013755187	$3,405,498	13	COMPUTER,RADAR DATA
Navy	F	Yes	015486318	$3,380,616	108	COMPUTER,FLIGHT CONTROL
Navy	0	No	007196882	$3,245,462	21	TRANSMITTER,ANGLE OF ATTACK

Initial IFDIS Candidate ID by Object/TMS

(Air Force example - costs and non-availability are two year totals for FY14-15)

Service	Object	TMS	Maintenance cost	Non-available days
Air Force	DATA DISPLAY UNIT	F-16C	$48,293,131	1,235
Air Force	TARGET ACQUISITION SYSTEM	F-16C	$44,843,636	2,972
Air Force	IFF SYSTEM	F-16C	$25,614,521	916
Air Force	NAVIGATION SYSTEM	F-16C	$14,310,433	1,013
Air Force	NAVIGATION SYSTEM	C-130H	$12,402,740	628
Air Force	INDICATING, ORDER AND METERING	KC-135R	$11,324,172	206
Air Force	DATA DISPLAY UNIT	MQ-9A	$10,377,094	48
Air Force	TARGET ACQUISITION SYSTEM	A-10C	$9,299,788	647
Air Force	WIRING	C-17A	$9,297,600	101
Air Force	RADAR WARNING SYSTEM	F-15E	$8,548,591	35
Air Force	SENSOR	U-2S	$8,374,846	4
Air Force	TRAFFIC ADVISORY SYSTEM	B-52H	$8,310,182	22
Air Force	INDICATING, ORDER AND METERING	F-15E	$8,269,354	113
Air Force	WIRING	B-1B	$8,243,270	47
Air Force	TARGET ACQUISITION SYSTEM	F-16D	$8,141,758	568
Air Force	TRANSMITTER	KC-135R	$7,381,988	168
Air Force	NAVIGATION SYSTEM	KC-135R	$7,184,340	220
Air Force	RADAR WARNING SYSTEM	F-16C	$7,128,060	190
Air Force	WIRING	KC-135R	$7,024,458	118
Air Force	AUTOMATIC FLIGHT CONTROL	F-16C	$6,937,634	235

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IFDIS Candidate Analysis - Summary

Spreadsheets are available for each service that identifies their top IFDIS candidates by NIIN and objects/TMS along with the corrective costs and availability loss totals

The failure recipe is available as well and can be modified for future use. The new results can determined based on the new recipe fairly quickly.

Followup analysis of IFDIS implementation to determine the impact can be made available as well.

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Intermittent Fault Detection and Isolation System (IFDIS) Assessment History

Intermittent Fault Detection Project

Contract # IDIQ GSA ITSS ID05140071011/ Task Order 12

Prepared for:

Air Force Life Cycle Management Center/ Product Support Engineering Division

Submitted by

University of Dayton Research Institute

17 May 18

SECURITY CLASSIFICATION: UNCLASSIFIED

Executive Summary

Problem Statement

In 2009, through a Small Business Innovative Research contract, the depot at Hill AFB purchased an Intermittent Fault Detection and Isolation System (IFDIS) from Universal Synaptics to use on the F-16 Modular Low Power Radio Frequency (MLPRF) unit.

There is concern that the purchase of IFDIS by Hill AFB did not follow the DoD acquisition process and as such, IFDIS may not have been the optimal solution.

Since IFDIS is a Commerical off the Shelf (COTS) acquired solution, it was not developed under a traditional DoD Acquisition Process. All the decisions related to bringing IFDIS to market were commercial decisions by the manufacturer. This report examines the decision points the government makes when procuring a COTS solution:

- Was there an identified need?
- Were requirements established?
- Was an Analysis of Alternatives considered?
- Does the select solution satisfy the requirements?

The objective of this paper is to review reports and briefings related to IFDIS and determine if the decision points for COTS solutions were met or otherwise satisfied. Even though IFDIS is in use by both military and civilian organizations, this report focuses only on DoD related documents.

Project Objective

The Air Force Lifecycle Management Center, Product Support Division (AFLCMC/EZP) is committed to technology insertion across the Air Force (AF) sustainment community in an effort to modernize depot operations. This particular project addresses the AF's inability to accurately identify, isolate, and repair intermittent faults of aircraft avionics Line Replaceable Units (LRUs). One such device to identify intermittent faults is a commercially available Intermittent Fault Detection and Isolation System (IFDIS). Although IFDIS is able to identify intermittent faults, the AF Enterprise has not adopted this technology. ALFCMC/EZP is championing this effort to determine why this technology is not used in the AF, address those concerns, and if desired, implement the intermittent fault detection capability.

Results

There is no doubt that IFDIS was originally procured by Hill AFB with the desire to improve readiness and deliver a better product to the warfighter. It is also clear that traditional acquisition processes were not followed however procurement gates were met in a combination of government and contractor actions.

Was there an identified need?

Yes - The briefing by Mr. John Johns, Deputy Assistant Secretary of Defense for Maintenance established the monetary cost of the No Fault Found (NFF) problem[1]. A significant portion of the maintenance budget is spent on removing, shipping, testing, reshipping, and reinstalling components for issues that cannot be duplicated. In addition, the Navy, as the lead agency on the Joint Intermittent Tester working group, identified several components that have a high rate of NFF[2].

Were requirements established?

Yes - Military Performance Specification 32516[3] defines the functional requirements for an intermittent fault detection and isolation system, the environment in which it must operate, and interface and interchangeability characteristics.

Was an Analysis of Alternatives considered?

Yes –An Analysis of Alternatives was conducted in two ways. From a capabilities perspective, several vendors that claimed to have a solution that meets the requirements were evaluated[4]. From a Return on Investment and Cost Benefit Analysis documents[5] [6], the use of IFDIS was shown to be the more economical solution.

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[1] Giles Huby, "*US Defence Dept targets billion dollar NFF savings*", Copernicus Technology,05 November 2015, para 3, http://www.copernicustechnology.com/index.php/about-copernicus-technology/news/158-usdod-billion-dollar-nff-savings-target

[2] Troy Bayer. *JIT (Joint Intermittence Tester) Naval Aviation Enterprise (NAE) Future Readiness Initiative POM17 Return on Investment (ROI) Analysis*. Report. 4.2 Cost Analyst, 4 August 2014, 10

[3] United States. *MIL-PRF-32516 Performance Specification Electronic Test Equipment, Intermittent Fault Detection and Isolation for Chassis and Backplane Conductive Paths*. By Naval Air Warfare Center Aircraft Division, 23 March 2015, 3-7

[4] National Center for Manufacturing Sciences, *Joint Intermittence Testing (JIT) Capability – Phase II Final Report*. Report. December 2016, 14-16

[5] Ogden Air Logistics Complex Acquisition Cost Division, *G3TL12 F-16 Programmable Signal Processor (PSP) Intermittent Fault Detection and Isolation CIP Economic Analysis,* Report, December 2012, 18

[6] Troy Bayer, *JIT (Joint Intermittence Tester) Business Case Analysis (BCA) Analysis of Alternatives (AOA)*. Report. 4.2 Cost Analyst. 19 September 2013, 9

Does the select solution satisfy the requirements?

Yes – The National Center for Manufacturing Sciences, on contract to NAVAIR evaluated several vendor offerings against MIL-PRF 32516 and IFDIS "was the most capable tester of all the systems showcased" and passed all IFE testing[7].

Conclusion

The review of the literature shows that there was an identified need for an intermittent fault detection and isolation system in the Air Force as well as in the Navy. Requirements were established, an Analysis of Alternatives conducted, and IFDIS from Universal Synaptics met those requirements. There is no indication that further evaluations would invalidate the findings.

[7] National Center for Manufacturing Sciences, *Joint Intermittence Testing,* 15

Table of Contents

1.0 Introduction/Background

1.1 Problem Statement

In 2009, through a Small Business Innovative Research contract, the depot at Hill AFB purchased an Intermittent Fault Detection and Isolation System (IFDIS) from Universal Synaptics to use on the F-16 Modular Low Power Radio Frequency (MLPRF) unit. IFDIS continuously monitors all electrical connections while at the same time, subjecting the unit under test to the same thermal and vibration environment as in operation. IFDIS is discounted by some because of the belief that the Hill AFB purchase of the system did not adhere to the traditional DoD acquisition process as shown in Figure 1

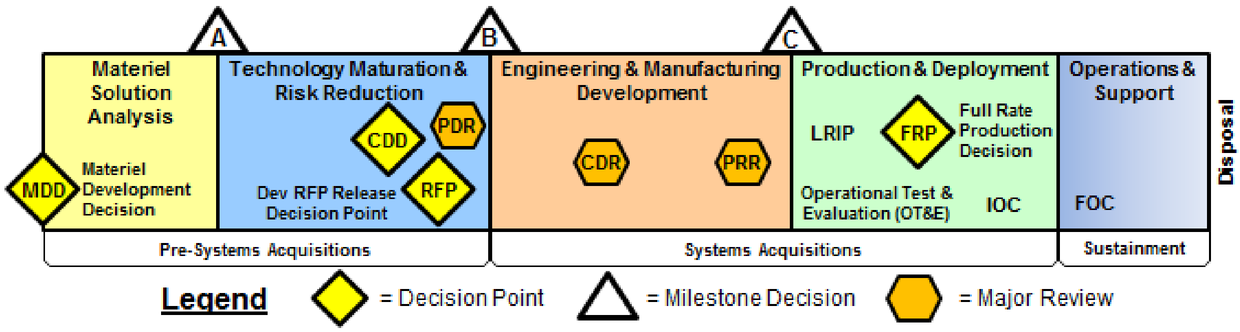

Figure 1 DoD Acquisition Process

The process begins with a stated need and initial capabilities document in the Material Solution Analysis Phase, through fielding in the Operations and Support Phase. Criticism focuses on the early phases of the acquisition process where requirements are established, analysis of alternatives generated, and an evaluation of the solution against those requirements is conducted.

Since IFDIS is a COTS solution, it was not developed under a traditional DoD Acquisition Process. Consequently, all the decisions related to bringing IFDIS to market were made for commercial reasons by the manufacturer. This report examines the decision points the government makes when procuring a COTS solution.

Note: Universal Synaptics has two products; Intermittent Fault Detection and Isolation System (IFDIS) and NCompass Voyager™. The fault detection technology is identical with the difference being that IFDIS includes an environmental chamber.

1.1 Questions Considered

Was there an identified need? A need may be directed from senior leaders or generated from the user community. Is there a need for this technology and what issue is being addressed?

Were requirements established? Once a need has been identified, the government must establish specific requirement in order to proceed. These requirements guide the evaluation of solutions.

Was an Analysis of Alternatives considered? When procuring a COTS solution, it is rare that there is only a single vendor for that solution. An analysis of alternatives evaluates not only different solution providers, but also different courses of action.

Does select solution satisfy the requirements? Has the selected solution been measured against the requirements and if so, how well does the solution meet those requirements? This step evaluates the effectiveness of the solution against the requirements.

The objective of this paper is to review published works related to IFDIS and determine if the acquisition process gates were met or otherwise satisfied. Even though IFDIS is in use by both military and civilian organizations, this report focuses only on DoD related documents.

1.2 Project Description

The Air Force Lifecycle Management Center, Product Support Division (AFLCMC/EZP) is committed to technology insertion across the Air Force (AF) sustainment community in an effort to modernize depot operations. The aircraft maintenance community is faced with situations where avionics Line Replaceable Units (LRU) fail while onboard an aircraft but subsequently pass all standard bench tests when removed from the aircraft. This No Fault Found (NFF) problem costs the DoD between $2 to $10 billion dollars annually and adversely impacts Air Force mission readiness. The majority of NFF issues are attributed to intermittent faults that manifest for extremely short periods (micro- or nano-seconds) and often only occur when the LRU is subjected to the extreme temperature and vibration environments of operational aircraft.

The AF does not have an effective way of accurately identifying and isolating intermittent faults in avionic LRU. NFF due to intermittent faults is a long standing problem that plagues avionics LRU repair. Intermittent faults are frequently caused by cracked solder joints, loose crimp connections, loose wire wraps, corroded contacts, sprung connector receptacles, non-soldered/cold soldered connections and the like on backplane, connectors and/or LRU junction boxes. These LRUs frequently exhibit built in test failures and performance degradation while in flight, however in a back shop or Depot environment, these units often pass all standard tests, resulting in a NFF. The impact of non-resolved intermittent faults is wasted man-hours troubleshooting LRUs, increased aircraft maintenance cost due to continually removing and replacing LRUs. There is also increased cost to procure and sustain greater number of LRUs in order for the supply chain to compensate for low mean time between failures (MTBF), etc. NFF is a $2B - $10B annual non-value added expense to the DoD each year.[8]

In light of an intermittent fault problem on the F-16 Modular Low Power Radio Frequency (MLPRF) LRU, in 2008 Hill AFB procured an IFDIS test platform[9], manufactured by Universal

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[8] OSD/OUSD ATL, Director, Enterprise Maintenance Technology OSD Maintenance Policy and Programs, 24 Oct 17.

[9] Intermittent Fault Detection & Isolation System (IFDIS™) *Neil Starling* - http://www.usynaptics.com/index.php/products/ifdis accessed 15 Mar 18.

Synaptics. IFDIS combines continuous high-resolution monitoring of every electrical path in an LRU chassis and features an environmental enclosure that heats, cools, and vibrates the LRU under test, thereby mimicking the in-flight conditions that manifest the intermittent faults.

However, the IFDIS is not included in the standard maintenance test procedures for the depot. That along with isolated skepticism of IFDIS effectiveness has resulted in resistance to adopt this new technology.

IFDIS is a commercial system that has been evaluated numerous times for the Department of Defense. This document reviews those evaluations, identifies who conducted them, provides a summary, and, in the end, draws a conclusion as to the completeness of the documentation against the project objective to determine if the acquisition process gates were met or otherwise satisfied.

2.0 Establishing Need

Was there a need identified for this system.

2.1 Cost of No fault Found

2.1.1 Reference Information

Title: AUTOTESTCON 2015 Military Keynote Speaker

Date: November 2015

Author: Mr. John Johns, Deputy Assistant Secretary of Defense for Maintenance

2.1.2 Summary

This reference establishes the cost of intermittent faults.

As Deputy Assistant Secretary of Defense for Maintenance, Mr. Johns oversaw the DoD $80 billion equipment and weapons maintenance program. In a presentation at AutoTestCon in 2015, Mr. Johns stated "[the US government] spend[s] $2 billion annually on removing and processing subsystems with 'No Fault Found'"[10].

2.1.3 Conclusion

Establishes the need. The reference establishes the need for an intermittent fault detection system by quantifying the cost of the No Fault Found problem within the US Government. This establishes the economic need to address the No Fault Found problem.

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[10] Huby, "*US Defence Dept targets*", para 3

3.0 Establishing Requirements

3.1 Document: MIL-PRF-32516 Performance Specification[11]

3.1.1 Document Information

Title: MIL-PRF-32516 Electronic Test Equipment, Intermittent Fault Detection and Isolation for Chassis and Backplane Conductive Paths

Date: March 2015

Author: Naval Air Warfare Center Aircraft Division

3.1.2 Summary

This Performance Specification indicates a classification for diagnostic equipment based on the category of intermittent faults that it detects. The following categories are defined:

- Category 1. Short duration intermittent faults that are under 100 nanosecond duration across all LRU/WRA backplane circuits and associated wire harnesses.
- Category 2. Intermediate duration intermittent faults that are 101 nanosecond to 500 microsecond duration across all LRU/WRA backplane circuits and associated wire harnesses.
- Category 3. Long duration intermittent faults that are 501 microsecond to 5 millisecond duration across all LRU/WRA backplane circuits and associated wire harnesses.

The specification defines the environment in terms temperature, humidity, altitude, vibration, etc. that the test equipment must endure and still operate correctly. This specification contains testing guidance in the following appendices:

- Appendix A Vibration Stimulation
- Appendix B Temperature Stimulation
- Appendix C Temperature/Vibration Stimulation

3.1.3 Conclusion

Establishes the requirements. This document establishes the performance specification for an intermittent fault detection and isolation electronic test equipment. This establishes the requirements that a test unit must meet.

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[11] United States. *MIL-PRF-32516 Performance Specification*

4.0 Establishes Analysis OF Alternatives

4.1 Hill AFB Economic Analysis[12]

4.1.1 Document Information

Title: Hill AFB, Utah G3TL12 F-16 Programmable Signal Processor (PSP) Intermittent Fault Detection and Isolation System (IFDIS)

Date: December 2012

Author: Ogden Air Logistics Complex Acquisition Cost Division, OO-ALC/FZC

4.1.2 Summary

This document provides an economic analysis of the IFDIS as a test mechanism for the F-16 Programmable Signal Processor (PSP). Based on the results of using IFDIS on the MLPRF LRU, Hill AFB wanted to quantify the expected results of IFDIS use on the PSP.

Specifically, it explores three alternatives:

- Alternative 1 – Continue status quo testing the PSP utilizing the existing equipment.
- Alternative 2 – Procure a new IFDIS system capable of use on the PSP.
- Alternative 3 – Use the MLPRF IFDIS system.

Alternative 3 was dismissed since the number of test connections required to test the PSP is 8,265 and the MLPRF IFDIS is limited to 1,024.

The document concluded that alternative 2 would provide the lower cost to benefit ratio and results in a savings of $2.25 for each $1 invested with a payback period of just under 8 years.

The analysis is based on the opinion of the Hill AFB Avionics Director that IFDIS detects intermittent faults in 70% of the units tested.[13]

4.1.3 Conclusion

Establishes analysis of alternatives. This document provide a source of IFDIS performance along with the project cost savings of using IFDIS on the PSP. This is the earliest evaluation on the cost benefit of IFDIS for the PSP.

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[12] Ogden Air Logistics Complex, *G3TL12 F-16 Programmable Signal Processor (PSP)*

[13] No additional information provided on the source of the 70% figure.

4.2 JIT (Joint Intermittence Tester) Business Case Analysis (BCA) Analysis of Alternatives (AOA)[14]

4.2.1 Document Information

Title: JIT (Joint Intermittence Tester) Business Case Analysis (BCA) Analysis of Alternatives (AOA)

Date: September 2013

Author: Troy Bayer, Naval Air Warfare Center Aircraft Division Lakehurst Competency 4.2

4.2.2 Summary

Establishes analysis of alternatives. The Joint Intermittence Tester Wiring Product Team (WIPT) commissioned this analysis of alternatives with regard to adopting different IFDIS configurations. This study did not look at a specific Weapons Replaceable Assemblies (WRA)/LRU but analyzed the cost of the top fifteen "bad actor" WRA/LRUs for the F/A-18A-F, EA-18G, HH-60H, MH-60R, MH-60S, and the MV-22. A "bad actor" is defined as a WRA/LRU with a high rate of no fault found when testing. The five alternatives considered were:

- Alternative 1 – Continue with status quo, no change
- Alternative 2 – Invest in core Intermittent Fault Detector (IFD) technology (attempt to induce fault with slight tapping on side of WRA)
- Alternative 3 – Invest in core IFD technology plus Vibration Stand (dynamic testing)
- Alternative 4 – Invest in core IFD technology plus Thermal Chamber (dynamic testing)
- Alternative 5 – Invest in core IFD technology plus Vibration Stand plus Thermal Chamber (dynamic testing)

The analysis concluded that alternative 3 (Intermittent Fault Detection system combined with the vibration) had the highest return on investment factor of 12.3. This is a savings of $152.4 million against a cost $12.4 million through FY35.

Alternative 5 (Intermittent Fault Detection system with vibration and thermal chamber) had the second greatest return on investment factor of 11.2, but provided the greatest life cycle savings of $189.9 million against a cost of $17.2 million.

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[14] Bayer, *JIT (Joint Intermittence Tester) Business Case Analysis (BCA)*

The analysis was based on “USAF reduced [units declared beyond economical repair] attributed to [no fault found] by 68% by the fielding [depot level] IFD.”[15]

4.2.3 Conclusion

Establishes analysis of alternatives. This document analyzes the return on investment between the various configurations of IFDIS (with/without vibration stand and with/without thermal chamber). The conclusion of the evaluation is that while more expensive, the ability to test thermal and vibration while at the same time continuously monitor all the circuit paths yields the greatest life cycle cost savings.

4.3 JIT (Joint Intermittence Tester) Business Case Analysis (BCA) Analysis of Alternatives (AOA)[16]

4.3.1 Document Information

Title: JIT (Joint Intermittence Tester) Naval Aviation Enterprise (NAE) Future Readiness Initiative POM17 Return on Investment (ROI) Analysis

Date: August 2014

Author: Troy Bayer, Naval Air Warfare Center Aircraft Division Lakehurst Competency 4.2

4.3.2 Summary

This document reports the ROI analysis used to determine whether investing in Common Support Equipment (CSE) that allows for diagnosis and repairs of intermittent failures at the D-level (with potential application at the I-level) will be cost effective to the USN/USMC. This analysis is based on 11 known “bad actors” for the F/A-18.

The document shows that for the 11 WRA/LRUs in question, the USN/USMC will spend $203.84 million on operation and sustainment through FY39. However, investing $10.71 million to procure two IFD systems and 1 portable system, the return on investment would yield a reduction in operations and sustainment cost to $81.49 million through FY39.

This analysis is based, in part, to “applied cost reduction rate of 68% to mirror USAF’s performance data” using IFDIS.

4.3.3 Conclusion

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[15] No additional information provided on the source of the 68% figure.

[16] Bayer, *JIT (Joint Intermittence Tester) Naval Aviation Enterprise (NAE)*

Establishes analysis of alternatives. This is the third cost benefit analysis of using IFDIS for testing. In this case, this analysis involved the application of 3 systems to the NFF issues across 11 LRUs.

4.4 Document: Navy's First Intermittent Fault Detection & Isolation System (IFDIS)[17]

4.4.1 Document Information

Title: Navy's First Intermittent Fault Detection & Isolation System (IFDIS)

Date: October 2015

Author: Brett Gardner, Advanced Aircraft Technologies (AAT) Fleet Readiness Center Southwest

4.4.2 Summary

This document reviews an evaluation of the Universal Synaptics IFDIS conducted by the US Navy. As a result of a high NFF rate of the F/A-18 Generator Convertor Unit (GCU), an AAT team visited Hill AFB to observe the MLPRF IFDIS unit. Following that visit, a NAVSUP funded a demonstration test of the IFDIS targeted against the GCU.

The Navy conducted the test at the TQS facility at Ogden and brought five Ready For Use (RFU) GCUs. RFU is a designation given to a WRA/LRU deemed serviceable and ready to install on an aircraft. The IFDIS system detected and isolated one or more intermittent circuits in four of the five (80% GCU failure rate).

As a result of the test, Navy funded the purchase an IFDIS and three separate interface test adapters for the GCU.

4.4.3 Conclusion

Establishes meeting requirements. This documents a deliberate test of the effectiveness of IFDIS against the F-18 GCU. The result that the IFDIS discovered intermittent faults in 80% demonstrates the effectiveness of IFDIS.

5.0 Establish Meeting Requirements

5.1 Joint Intermittence Testing (JIT) Capability – Phase II Final Report[18]

[17] Brett Gardner, *Navy's First Intermittent Fault Detection & Isolation System (IFDIS)*. Report. Advanced Aircraft Technologies (AAT) FRCSW, 27 October 2015

[18] National Center for Manufacturing Sciences, *Joint Intermittence Testing (JIT),* 16

5.1.1 Document Information

Title: Joint Intermittence Testing (JIT) Capability – Phase II Final Report

Date: December 2016

Author: National Center for Manufacturing Sciences

5.1.2 Summary

This report covers a technology demonstration of intermittent fault detection test equipment during the week of 4 January 2017 at NAVAIR Lakehurst. The Department of the Navy issued a Request-For-Information N68335-15-RFI-0505 and six companies responded:

- Dragoon ITCN
- Trimble Sustainment Engineering, Inc.
- Eclypse International
- Universal Synaptics Corporation
- Williams RDM
- Solavitek

Of the six companies, Eclypse International, Universal Synaptics Corporation, and Solavitek, Inc. and a fourth, Ridgetop Group, identified in a previous RFI, accepted the invitation to a demonstration week. The demonstration involved the vendors employing their respective intermittent test systems to identify intermittent fails generated by the Government Furnished Equipment Intermittent Fault Emulator (IFE). The IFE induces conductive path faults that emulate intermittent LRUs/WRAs faults.

Of the four products evaluated, the Universal Synaptics IFDIS (called the NCompass Voyager) "appeared to be the best product and Universal Synaptics performed, by far, the best during the Industry Week demonstrations."

It should be noted that the NCompass Voyager is the portable version of the IFDIS that does not include an environmental chamber to stimulate vibration, heat and cold.

5.1.3 Conclusion

Establishes meeting the requirements. This report is another evaluation of IFDIS but against the standard MIL-PRF-32516 and using the Intermittent Fault Emulator. The result of this testing highlights that IFDIS meets the standard.

6.0 Assessment

The following is an assessment of the documents referenced in this report, and how they align with system development practices.

6.1 Need

As stated during Mr. Johns' keynote address at AutoTestCon November 2015, the Department of Defense spends $2 billion annually on No Fault Found issues. These are LRU/WRAs that exhibit problems during employment, but otherwise pass all bench testing regimens. The standard reasoning for this is that these faults are intermittent are environmentally induced. Without the ability to test for thermally or vibrational induced intermittent faults, defective WRA/LRU are put back in to the supply systems.

6.2 Requirement

The MIL-PRF-32516 Performance Specification establishes the standard for an intermittent fault tester. This specification establishes classifications for faults, and references an intermittent fault emulator available to test equipment manufactures. This specification defines the standard that intermittent test platforms must meet in order to satisfy the requirement. This requirement covers the magnitude and duration of the fault as well as the ability to monitor multiple test points at the same time.

6.3 Analysis of Alternatives

IFDIS was the subject of several economic analysis documents comparing the cost of acquiring the solution to the status quo. Various configurations of IFDIS were evaluated to determine the return on investment when including the thermal and vibration environmental chamber. And finally, IFDIS was compared to products from competing vendors.

6.4 Meeting the Requirement

The Universal Synaptics system, NCompass Voyager™, was evaluated against the performance specification MIL-PRF-32516 by the Joint Intermittence Testing Group and they determined that the system "appeared to be the best product and Universal Synaptics performed, by far, the best during the Industry Week demonstrations."[19] In addition, the IFDIS testing of the F-18 GCU performed under the supervision of the US Navy demonstrated the ability of the system to detect issues that current testing procedures missed.

6.5 Conclusion

The Air Force can proceed with implementation decisions related to IFDIS confident that the procurement questions were asked and answered. There is a defined need, requirements

[19] National Center for Manufacturing Sciences, *Joint Intermittence Testing (JIT),* 16

established, analysis of alternatives conducted and positive evaluation that the technology met the requirements.

Appendix A Source Documents

Reference	Document
Brett Gardner, *Navy's First Intermittent Fault Detection & Isolation System (IFDIS)*. Report. Advanced Aircraft Technologies (AAT) FRCSW, 27 October 2015	201510_Navy IFDIS JTEG for public relea
Ogden Air Logistics Complex Acquisition Cost Division, *G3TL12 F-16 Programmable Signal Processor (PSP) Intermittent Fault Detection and Isolation CIP Economic Analysis,* Report, December 2012	201212_G3TL12_Hill _AFB_PSP_IFDIS_CIP_
National Center for Manufacturing Sciences, *Joint Intermittence Testing (JIT) Capability – Phase II Final Report*. Report. December 2016	201612_JIT II Final Report.pdf
Troy Bayer, *JIT (Joint Intermittence Tester) Business Case Analysis (BCA) Analysis of Alternatives (AOA)*. Report. 4.2 Cost Analyst. 19 September 2013	201309_JIT BCA AOA Brief.pdf
Troy Bayer. *JIT (Joint Intermittence Tester) Naval Aviation Enterprise (NAE) Future Readiness Initiative POM17 Return on Investment (ROI) Analysis*. Report. 4.2 Cost Analyst, 4 August 2014	201408_JIT ROI Analysis.pdf
United States. *MIL-PRF-32516 Performance Specification Electronic Test Equipment, Intermittent Fault Detection and Isolation for Chassis and Backplane Conductive Paths*. By Naval Air Warfare Center Aircraft Division, 23 March 2015	201503_MIL-PRF-32 516.pdf

F-16 Modular Low Power Radio Frequency (MLPRF) Performance Analysis

Intermittent Fault Detection Project

Contract # IDIQ GSA ITSS ID05140071011/ Task Order 12

Prepared for:

Air Force Life Cycle Management Center/ Product Support Engineering Division

Submitted by

University of Dayton Research Institute

17 May 18

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Executive Summary

Problem Statement

A significant problem in the aircraft maintenance community are situations where avionics Line Replaceable Units (LRU) fail while onboard an aircraft but then subsequently pass all standard bench tests when removed from the aircraft. This No Fault Found (NFF) problem costs the DoD between $2 to $10 billion dollars annually[1] and adversely impacts Air Force mission readiness. The majority of NFF issues are attributed to intermittent faults that manifest for extremely short periods (micro- or nano-seconds) and often only occur when the LRU is subjected to the extreme temperature and vibration environments of operational aircraft.

In 2009, through a Small Business Innovative Research contract, the depot at Hill AFB purchased an Intermittent Fault Detection and Isolation System (IFDIS) from the Universal Synaptics Corporation, to resolve NFF issues with the F-16 Modular Low Power Radio Frequency (MLPRF) unit.

Unlike conventional automated testing systems, IFDIS continuously monitors all electrical connections while subjecting the LRU under test to the same thermal and vibration environments the LRU experiences during normal flying operation. Despite the success of IFDIS in resolving the MLPRF NFF issues, there is isolated skepticism of IFDIS effectiveness. To date, the use of IFDIS is only at Hill AFB and not part of the standard test procedures at the Depot.

Project Objective

The objective of this effort is to confirm/refute the suitability of the IFDIS to resolve the LRU NFF problem by analyzing the MLPRF data in the Reliability and Maintainability Information System (REMIS) to determine if IFDIS has a measurable impact on MLPRF Mean Time Between Failure (MTBF).

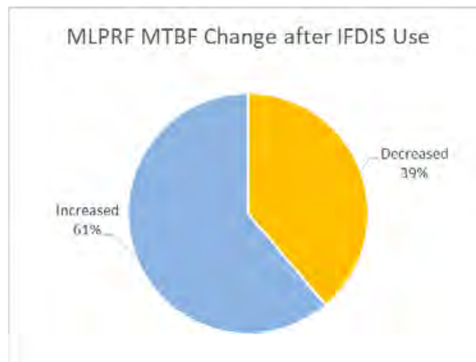

Figure 1 Change in MTBF after IFDIS Testing

[1] Giles Huby, "*US Defence Dept targets billion dollar NFF savings*", Copernicus Technology,05 November 2015, para 3, http://www.copernicustechnology.com/index.php/about-copernicus-technology/news/158-usdod-billion-dollar-nff-savings-target

Results

While the data in REMIS is partially incomplete and contains some errors, there is sufficient data to perform the analysis. This report contains the reviewed maintenance histories of 67 MLPRF units; 17 of which are presented in Universal Synaptics briefings and 50 others that were randomly selected from the REMIS data.

Out of the population of 67 MLPRFs, 41 (61%) showed an improvement in MTBF after IFDIS testing while 26 (39%) did not.

In the case of the 41 MLPRFs with a positive MTBF change, the analysis showed that the average MTBF before utilizing IFDIS was 124 hours. After testing with IFDIS, the average MTBF improved to 406 hours as shown in Figure 2. The average improvement percentage is approximately 410%.

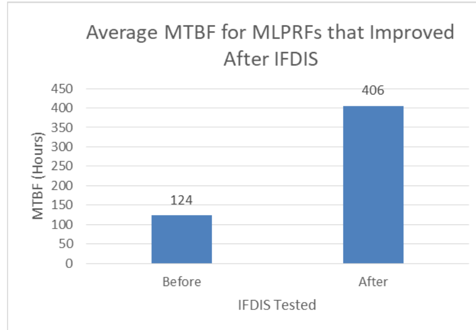

Figure 2 MTBF of MLPRFs that Improved with IFDIS

Inclusion of all 67 MLPRFs analyzed reveals that after IFDIS testing, the overall MTBF of the MLPRFs improved from 165 hours to 285 hours as shown in Figure 3. The average improvement percentage is approximately 230%.

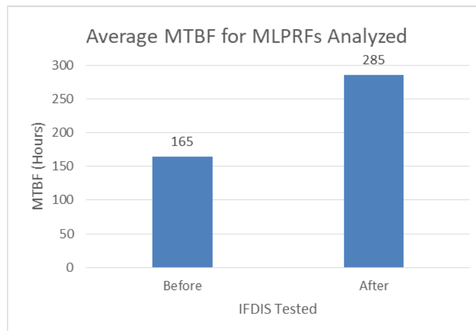

Figure 3 MTBF of All MLPRFs Analyzed

Conclusion

The use of IFDIS demonstrated a substantial positive impact on the majority of MLPRFs that it was used to diagnose and that impact was a dramatic increase in the MTBF of the MLPRF.

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1. Project Description

The Air Force Lifecycle Management Center, Product Support Division (AFLCMC/EZP) is committed to sustainment technology insertion across the U.S. Air Force (AF) sustainment community in an effort to automate Depot operations. This particular project addresses AF's inability to accurately identify intermittent faults of aircraft Line Replaceable Units (LRUs). One sustainment technology with the ability to identify, and isolate intermittent faults is the commercially available Intermittent Fault Detection and Isolation System (IFDIS), manufactured by the Universal Synaptics Corporation. Although IFDIS is able to identify intermittent faults, the AF Enterprise has not adopted this technology at all the Air Logistics Complexes. ALFCMC/EZP is championing the effort to determine why this IFDIS technology is not used in the AF, to resolve IFDIS-related concerns, and if warranted, to implement an intermittent Fault Detection capability.

1.2. Problem Statement

The AF does not have an effective method to accurately identifying and isolate intermittent faults in LRUs. No Fault Found (NFF) due to intermittent faults is a long standing problem that plagues avionics LRU repair. Intermittent faults are frequently caused by cracked solder joints, loose crimp connections, loose wire wraps, corroded contacts, sprung connector receptacles, non-soldered/cold soldered backplane connections, etc.

1.3. Background

These LRUs frequently exhibit built in test (BIT) failures and performance degradation while in flight, however, while in a back shop or Depot environment, these units often pass all standard tests, resulting in a NFF. The impact of non-resolved intermittent faults is wasted man-hours associated with ineffective LRU troubleshooting procedures, increased aircraft maintenance cost due to frequent removal and replacement of LRUs, and the increased cost to procure and sustain greater quantities of a given LRUs in order for the for the supply chain simply to compensate for low mean time between failures (MTBF), etc. NFF is a $2B - $10B non-value added expense to the DoD each year.[2]

In an attempt to resolve an intermittent fault problem with the F-16 Modular Low Power Radio Frequency (MLPRF) LRU, in 2008 Hill AFB procured an IFDIS test platform, manufactured by the Universal Synaptics Corporation. The IFDIS system combines continuous high-resolution monitoring of every electrical path within an LRU chassis and features an environmental enclosure that heats, cools, and vibrates the LRU under test, thereby mimicking the in-flight conditions associated with manifestation of intermittent faults.

[2] Huby, "*US Defence Dept targets*", para 3

The IFDIS is not included in the standard maintenance test procedures for the Depot. That fact combined with isolated skepticism of IFDIS effectiveness has resulted in resistance to adopt this new technology.

1.4. Project Scope

In order to assess the effectiveness of IFDIS, UDRI conducted an in-depth analysis of MLPRF data from the AF Reliability and Maintainability Information System (REMIS). REMIS is the AF Maintenance enterprise system providing operational authoritative information for validating, standardizing and equipment maintenance data, including reliability and maintainability data, on a global level. REMIS is the repository of maintenance records from both the base level maintenance system, Integrated Maintenance Data System (IMDS), and the Depot maintenance system Defense Repair Information Logistics System (DRILS). UDRI examined REMIS to determine the time between failure of an LRU before testing with IFDIS and the Time Between Failure after IFDIS is used.

2. REMIS Data

2.1. Data Request

On 20 February 2018, through AFLCMC/EZP, UDRI requested all MLPRF (Work Unit Code 74AN0) data from REMIS for the F-16C and F-16D aircraft. The date range for the data covered is from January 1999 to January 2018. Over the following week, the REMIS program office delivered twenty Excel files totaling nearly 1.4 Gigabytes of relevant data.

These Excel files are comprised of 83 columns of which only the following 26 fields are of interest to this analysis:

Table 1 REMIS Data Fields of Interest

Column Name	Description
Record Type	ON/OFF Maintenance action was either on aircraft or off aircraft (back shop or Depot)
Serial Number	Aircraft Serial number
Current Operating Time	Aircraft Operating Time in hours
Job Control Number	Job Control Number
Geographic Location	Geographic Location that initiated the maintenance action
Organization	Organization that initiated the maintenance action
Discrepancy Narrative	Discrepancy Narrative
Work Unit Code	Identification code unique to a specific component. This is the component that is the cause of the maintenance action.
Type Maintenance Code	Identifies the type of work that is performed. For example B: Unscheduled Maintenance, R: Depot Maintenance, etc. Full list contained in Technical Order 00-20-2.
Action Taken Code	Action taken codes, when used in conjunction with WUCs, How Malfunction codes, and When Discovered codes, identify a complete unit of work, a maintenance task, or action. For example A: Bench Checked and

Column Name	Description
	Repaired, R: Removed and Replaced, S: Remove and Reinstall, etc. Full list contained in Technical Order 00-20-2
When Discovered Code	Indicates when a need for maintenance was discovered. For example A: Before Flight - Abort, D: In-flight - No Abort, etc. Full list contained in Technical Order 00-20-2.
How Malfunction Code	Indicates how or why a piece of equipment malfunctioned. For example 255: Incorrect Output, 799: No Defect, etc. Full list contained in Technical Order 00-20-2.
Transaction Date	Date record was created
Start Time	Work start time
Stop Time	Work stop time
Performing Geographic Location	Geographic Location that entered the maintenance record
Crew Size	Crew size
Units	Labor units
Labor Manhours	Labor man-hours
Install Equipment Designator	Part number of component being installed
Install Serial Number	Serial number of component being installed
Install CAGE Code	Commercial and Government Entity (CAGE) code identifying the supplier of the component being installed
Remove Equipment Designator	Part number of component being removed
Remove Serial Number	Serial number of component being removed
Remove CAGE Code	Commercial and Government Entity (CAGE) code identifying the supplier of the component being removed
Corrective Narrative	Narrative of the corrective maintenance action
Off Component Part Number	Part number of component being worked on
Off Component Serial Number	Serial number of component being worked on

This data was imported into an Access database for analysis and contains over 660,000 maintenance records of over 1,280 F-16 C/D aircraft.

2.2. Data Concerns

There are issues with the data contained in REMIS. This section describes some of the data issues and actions taken to eliminate, mitigate or establish work arounds.

2.2.1. Aircraft Operating Time

In order to calculate the Time Between Failure of the MLPRF, it is necessary to know both the aircraft operating hours when the MLPRF was installed on the aircraft and the aircraft operating hours when the MLPRF was removed from the aircraft. However, approximately 17% of the maintenance records did not contain valid current operating time values. This suggests that when the maintenance record was captured, the technician failed to capture the aircraft operating hours. This problem is shown in Figure 4.

Figure 4 Aircraft Operating Hours with Missing Data

In order to compensate for the missing time data, a simple interpolation was used to calculate the missing hours based on the known good (non-zero) hours occurring before and/or after those records that contain the value zero.

The simple interpolation is shown by examining the first data gap in Figure 4. The event with the missing data is the target event, a valid data point prior to that is Event 0, and the valid data point after is Event 1. Around that data gap is the following data:

- Event 0: Date (D0) 27 Mar 01, reported aircraft hours (H0) is 2591
- Event T: Date (DT) 17 Jan 02, reported aircraft hours (HT) is 0
- Event 1: Date (D1) 11 Oct 02, reported aircraft hours (H1) is 2835

To calculate the estimated hours at Event T, we use the following formula:

$$HT = H0 + \left(\frac{H1 - H0}{D1 - D0}\right) * (DT - D0)$$

In this case, the resulting calculate hours for the aircraft on 17 Jan 02 is 2719. After the linear interpolation, the resulting operating hours for this specific aircraft is shown in Figure 5.

Figure 5 Aircraft Operating Hours after Interpolation

The records where the missing hours are interpolated are noted by the field "Derived" set to true and the statement "AC Hours Estimated" appended to the field "Derived_Notes".

2.2.2. Missing Install/Removal Records

Analysis of maintenance data, specifically install and removal actions, also shows missing records. It is expected that for every removal of a specific MLPRF serial number, there should be a previous maintenance record that shows the installation of that same MLPRF serial number. In addition, if there is a job control number showing off aircraft maintenance of a MLPRF, it is expected that for that job control number, there should be a maintenance record showing the removal of the MLPRF. Where possible and where needed, a missing record is added only if there is a high degree of confidence based on analysis of related records.

For example, in Table 2, analysis of the maintenance actions related to MLPRF Serial # 11437 shows that on Job Control Number 122277253, on the 15-Aug-12 there is off aircraft maintenance but the removal action was not captured.

Table 2 Sample of Missing Removal Record for MLPRF S/N 11437

Date	Action	Aircraft #	AC Hrs	JCN	Org	Discrepancy	Corrective Action
[missing record]							
14-Aug-12	2 Install	9200003890	4570	122277253	0057 WGH WG	RADAR WOULD NOT DISPLAY ROR CONTACTS. ALL OPS WERE NORM, NO TRACKS OR CONTACTS. NO MFL OR PFL.	R2 MLPRF IAW 94-62-04
15-Aug-12	3 Maintenance			122277253	0057 WGH WG	RADAR WOULD NOT DISPLAY ROR CONTACTS. ALL OPS WERE NORM, NO TRACKS OR CONTACTS. NO MFL OR PFL.	BCFS FAILS TEST 26 PCOF 2A13 FAILS ON R/T NRTS-1

Looking at the related records and in order to capture the Time Between Failure hours, a removal record for MLPRF 11437 is inserted in the data. This is shown in Table 3.

Table 3 Generated Removal Record for MLPRF S/N 11437

Date	Action	Aircraft #	AC Hrs	JCN	Org	Discrepancy	Corrective Action
14-Aug-12	1 Removal	9200003890	4570	122277253	0057 WGH WG	RADAR WOULD NOT DISPLAY ROR CONTACTS. ALL OPS WERE NORM, NO TRACKS OR CONTACTS. NO MFL OR PFL.	** created record **
14-Aug-12	2 Install	9200003890	4570	122277253	0057 WGH WG	RADAR WOULD NOT DISPLAY ROR CONTACTS. ALL OPS WERE NORM, NO TRACKS OR CONTACTS. NO MFL OR PFL.	R2 MLPRF IAW 94-62-04
15-Aug-12	3 Maintenance			122277253	0057 WGH WG	RADAR WOULD NOT DISPLAY ROR CONTACTS. ALL OPS WERE NORM, NO TRACKS OR CONTACTS. NO MFL OR PFL.	BCFS FAILS TEST 26 PCOF 2A13 FAILS ON R/T NRTS-1

Records added for this purpose are noted by the field “Derived” set to true, the statement “Inserted missing mx action record” appended to the field “Derived_Notes”, and the phrase “** created record **” inserted for the “Corrective Action” field. If possible, the Discrepancy field data is copied from the other records.

2.3. Data Analysis Approach

To calculate the Time Between Failure, the maintenance records for removals were reviewed and categorized as removal for maintenance or removal for some other reason based on the discrepancy narrative. If the removal was for a problem specific to the MLPRF, the aircraft hours from when that MLPRF were installed are captured. If MLPRF removal was not due to an MLPRF problem, such as a cannibalization event or removal to facilitate other maintenance, the hours are accumulated.

The data for MLPRF serial number 11347 covers from 04 May 01 to 31 Aug 17. However, to show the method used to calculate Time Between Failure, Table 4 just shows the install and removal events over the dates of 13 Oct 04 to 05 Dec 05. The MLPRF was removed four times; the first for a problem after being flown for 31 hours, the second was a troubleshooting exercise after flying for 188 hours, the third was for a problem after 0 hours and the fourth was for a problem after 34 hours.

Table 4 Generated Removal Record for MLPRF S/N 10752

Date	Action	Aircraft #	AC Hours	Discrepancy	For Mx?	Hours Diff	Time Between Failure Hours
13-Oct-04	2 Install	8500001562	3944	FCF INOP MFL 275			
08-Dec-04	1 Removal	8500001562	3975	HAD TO RECYCLE FCR POWER W/ MFL'S 021, 028, 270	Yes	31	31
10-Mar-05	2 Install	9300000540	2241	338 MFL FOR FCR. MLPRF FAIL			
12-Oct-05	1 Removal	9300000540	2429	REMOVE MLPRF TO TROUBLESHOOT A3542	No	188	
12-Oct-05	2 Install	9300000542	2423	REMOVE MLPRF FOR TROUBLESHOOTING			
13-Oct-05	1 Removal	9300000542	2423	"FCR RECYCLE POWER" IN AIR RECYCLED POWER AND GOT FCR XMTR FAIL. FCR MFL'S 341, 087, 095, 088, 094 WOULD NOT CLEAR.	Yes	0	188

Date	Action	Aircraft #	AC Hours	Discrepancy	For Mx?	Hours Diff	Time Between Failure Hours
20-Oct-05	2 Install	9100000387	3078	FCR DEGR AND FREQ1 DEGR. PFLS W/ 055, 056, 057, 058, 059, 060, 061, 062, 276 MFLS. TRIED RESET INFLIGHT. RADAR UNUSABLE DUE TO NUMEROUS FALSE RETURNS.			
05-Dec-05	1 Removal	9100000387	3112	FCR WOULD SWEEP BUT NOT DETECT ANYTHING REGARDLESS OF MODE. FCR DEGRADE PFL FCR 041,046,053,056,057,059,064,065	Yes	34	34

According to the Universal Synaptics presentation, Figure 8, Page 8, this particular MLPRF went through IFDIS testing on 13 May 08. A plot of the hours flown at removal vs date for this unit is shown in Figure 6. An alternative view of the data is to present the removal for maintenance as an "event" regardless of date. Treating the IFDIS test date as event 0, post IFDIS events count up and pre IFDIS events count down as shown in Figure 7. The data shows that in the six and half years prior to IFDIS testing, MLPRF S/N: 11347 was removed for a maintenance issues seven times with an average flying time of 103 hours. In the nearly eight and half years after IFDIS testing, it has been removed twice with an average of 812 flying hours.

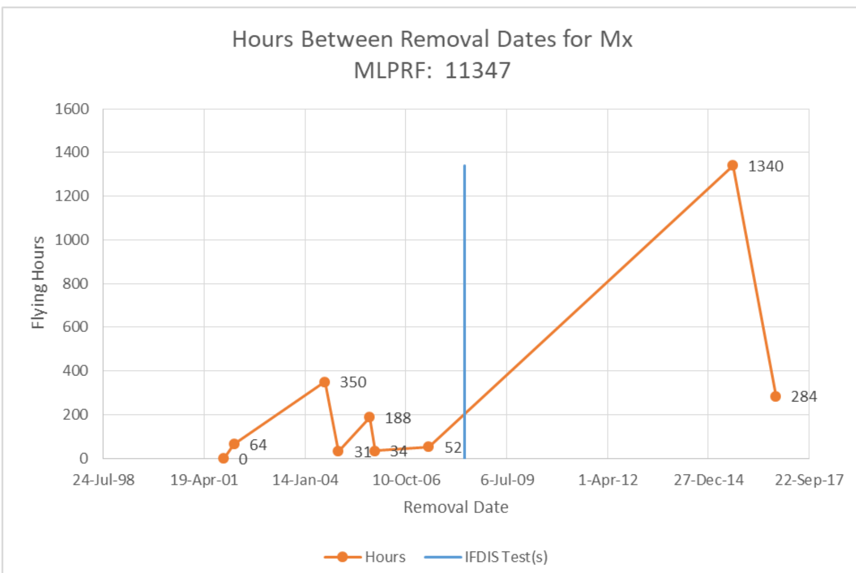

Figure 6 Hours Between Removal Dates for Mx for S/N: 11347

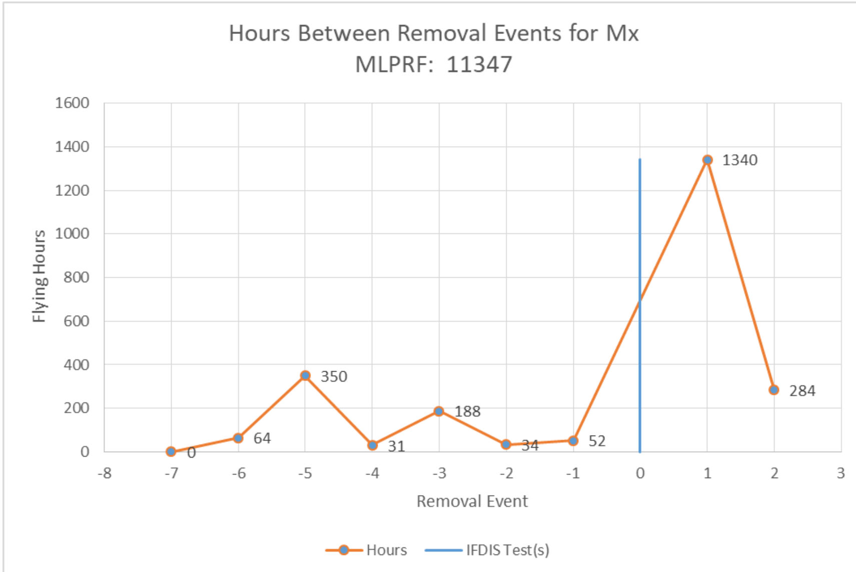

Figure 7 Hours Between Removal Events for Mx for S/N: 11347

2.4. REMIS Data Validation of 13 LRUs from Universal Synaptics Study

There are over 2,500 MLPRF serial numbers in the REMIS data. Rather than examine all 2,500 records, a more rapid approach was to use the REMIS data for the MLPRF units presented in the Universal Synaptics report.

2.4.1. Universal Synaptics Presented IFDIS Performance Results

The Universal Synaptics presentation[3] is shown in Figure 8.

[3] Ken Anderson, *Intermittent Fault Detection & Isolation Reduces No Fault Found (NFF) and Enables Cost Effective Readiness*, Universal Synaptics, 12 October 2016, 22

MLPRF: Results

	Before IFDIS Testing	IFDIS Test Date	After IFDIS Testing	
Serial Number	Average Hours Between Depot Repair		Average Hours Between Depot Repair	Increase in Average Hours Between Depot Repair
10074	182	8-Sep-08	1884	1702
11347	168	13-May-08	1267	1099
10849	59	2-Apr-09	941	882
10888	286	17-Sep-08	1132	846
11877	257	20-Apr-10	1010	753
10725	79	4-Jan-10	697	618
11437	72	4-Nov-09	622	550
11863	463	4-Nov-08	1008	545
11188	567	5-May-09	1102	535
11525	164	14-May-08	646	482
10386	157	23-Feb-09	611	453
11792	127	15-Oct-07	581	453
11732	70	28-Apr-09	477	407
11296	24	20-May-09	430	406
11267	317	28-Jul-08	713	396
11665	183	16-Nov-10	568	385
10752	707	20-Jul-09	1086	379

Figure 8 Universal Synaptics MLPRF Performance Report

The source document for Figure 8 does not contain an explanation on how the hours shown were calculated. Instead of trying to validate those hours, we focused on the Time Between Failure in REMIS. Note that Time Between Failure information is sent to REMIS from IMDS and not DRILS, so the data presented is from the perspective of base maintenance.

2.4.2. Analysis of MLPRFs in Universal Synaptics Presentation

The data contained in Figure 8 is repeated in part in Table 5. Columns 1 through 4 are the same information presented in Figure 8. Columns 5 through 7 are the results of the REMIS data analysis. Column 5 is the MTBF of the MLPRF leading up to IFDIS testing. Column 6 is the MTBF of the MLPRF after IFDIS testing and column 7 is the percent change (calculated as (col6-col5)/col5). The detailed charts for these MLPRFs are in Appendix A. Note that MLPRFs that show an increase in MTBF following IFDIS testing are highlighted in light green.

Table 5 MLPRF Performance Before and After IFDIS (Universal Synaptics Brief)

Serial Number (1)	IFDIS Test Date (2)	Vendor-Reported average Hrs Before IFDIS (3)	Vendor-Reported Average Hrs After IFDIS (4)	REMIS MTBF Before IFDIS (hours) (5)	REMIS MTBF After IFDIS (hours) (6)	% Change (7)
10074	8 Sep 08	182	1,884	194	1,088	461%
10386	23 Feb 09	157	611	66	663	905%
10725	4 Jan 10	79	697	356	410	15%
10752	20 Jul 09	707	1086	699	383	-45%
10849	2 Apr 09	59	941	23	491	2,035%
10888	17 Sep 08	286	1,132	103	812	688%
11188	5 May 09	567	1,102	223	201	-10%
11267	28 Jul 08	317	713	45	132	193%
11296	20 May 09	24	460	329	200	-39%
11347	13 May 08	168	1,267	103	812	688%
11437	4 Nov 09	72	622	200	32	-84%
11525	14 May 08	164	646	190	244	28%
11668	16 Nov 10	183	568	107	1129	955%
11732	28 Apr 09	70	477	43	129	200%
11792	15 Oct 07	127	581	100	570	470%
11863	4 Nov 08	463	1,008	79	791	901%
11877	20 Apr 10	257	1,010	87	522	500%

2.4.3. Interim Conclusion

The resulting analysis shows that based on the time between failures, 13 of the 17 MLPRFS in the listed show an increase in MTBF following IFDIS testing. The average MTBF prior to IFDIS use is 115 hours and after is 600 hours. The average improvement is 618%.

Below is additional information on the four MLPRFs that exhibited a decrease in MTBF:

- S/N 11437: Minimal data - There was only one install/removal event after IFDIS testing and the last entry for this unit was August of 2012.
- S/N 11188: This unit has not returned to the Depot since 2012 and has remained at base level. Last record is an install on 18 January 2018.
- S/N 11296: This unit has returned to the Depot 3 times since IFDIS testing on 20 May 2009. Last record is an install on 22 August 2016
- S/N 10752: This unit has returned to the Depot once since IFDIS testing on 20 July 2009. Last record is an install on 1 November 2017

2.5. REMIS Data Analysis on other IFDIS-tested MLPRFs

To provide a more complete analysis, it is necessary to look at the MTBF of other IFDIS tested MLPRFs. While it is not known how many of the 2,500 MLPRFs in the REMIS data have been IFDIS tested, approximately 425 of them contain the phrase “IFDIS Tested” in the corrective action entry.

2.5.1. Analysis of Random Sample

Using randomly selected records, fifty additional MLPRFs were analyzed and the results are shown in Table 6. Note that MLPRFs that show a positive MTBF change following IFDIS testing are highlighted in light green.

Table 6 MLPRF Performance Before and After IFDIS

Serial Number	IFDIS Test Date	EMIS MTBF Before IFDIS (hours)	REMIS MTBF After IFDIS (hours)	Percent Change
10949	04-Jan-10	193	63	-67%
11592	14-Sep-11	218	65	-70%
10484	18-Nov-10	127	80	-37%
10419	12-Jun-14	188	366	95%
10435	29-Nov-07	55	380	591%
10167	07-Dec-12	162	265	64%
10166	22-Aug-11	73	58	-21%
10922	13-Sep-11	127	48	-62%
11993	04-Oct-11	166	249	50%
10165	25-Oct-11	117	154	32%
11617	04-Oct-11	114	70	-39%
10083	04-Aug-11	275	708	157%
10168	13-Sep-11	67	210	213%
11614	31-Aug-11	136	76	-44%
11316	12-Aug-11	303	223	-26%
11651	08-Jan-08	44	69	57%
10558	05-Nov-09	137	175	28%
11099	05-Aug-11	180	210	17%
11484	09-Dec-10	96	158	65%
11131	30-Apr-16	136	26	-81%
11608	23-Jun-11	110	136	24%
11078	03-Aug-09	461	51	-89%
10163	01-May-12	139	88	-37%
11083	02-Sep-10	84	154	83%
10696	26-Jan-12	90	20	-78%
11234	14-Dec-09	149	68	-54%
10311	01-Oct-08	153	223	46%
11861	27-Jan-12	219	237	8%
10439	05-Dec-11	356	201	-44%
11886	03-Aug-11	661	87	-87%
10759	20-May-14	200	255	28%
11180	07-Dec-06	127	121	-5%
10593	08-May-07	98	143	46%
11692	14-Jan-13	59	29	-51%
12042	06-Sep-11	30	26	-13%
10031	02-Feb-09	167	633	279%
11214	27-Sep-11	121	45	-63%
10216	14-Oct-09	213	404	90%
11535	03-Oct-11	29	30	3%
10553	27-Apr-16	145	14	-90%
10855	09-Apr-08	141	429	204%
10712	15-Mar-11	27	227	741%
10934	12-Apr-11	48	640	1233%
11311	24-Feb-10	41	188	359%
11567	25-Oct-11	589	136	-77%
11413	30-Jan-10	143	358	150%
10851	17-Jun-11	44	69	57%
10521	14-Jun-13	125	84	-33%
10777	13-Sep-11	368	594	61%
10611	02-Sep-10	29	1,171	3938%

2.5.2. Interim Conclusion

The results show that 28 of the 50 (56%) MLPRFs exhibited improved MTBF following IFDIS testing. The MTBF of those 28 MLPRFs increased from 129 hours to 316 hours with an average improvement of 310%.

Similarly, inclusion of all 50 MLPRFs shown in Table 6, (although less dramatic) reveals that after IFDIS testing, the overall MTBF of all fifty of the MLPRFs increased an average of 151% – average MTBF improved from 162 hours to 210 hours, indicating that IFDIS testing has significant merit.

3. Final Conclusion

Analysis of REMIS data from 1999 to 2017 shows that of the 17 specifically selected MLPRFs and the 50 randomly selected MLPRFs that 41 out of 67 (61%) showed improved MTBF. And for those MLPRFs that showed an improvement, the MTBF increased from 124 hours to 406 hours with the average increase of 409%.

It should not be surprising that IFDIS did not work for all MLPRFs. The IFDIS tests for intermittent faults in the LRU enclosure (backplane and connection points) only after the shop replaceable circuit card assemblies have been removed from the LRU. Therefore, faults due to defective circuit card assemblies are not detected by the IFDIS. Because of the likelihood of the presence of intermittent faults, it is also not surprising that the MLPRFs selected for inclusion in the Universal Synaptics show dramatic improvement in performance over the randomly selected 50 additional units. Analysis shows that the use of IFDIS does yield substantial and, likely cost-effective improvement in MTBF of the MLPRF.

Appendix A Detailed MLPRF Charts

A.1 S/N: 10074

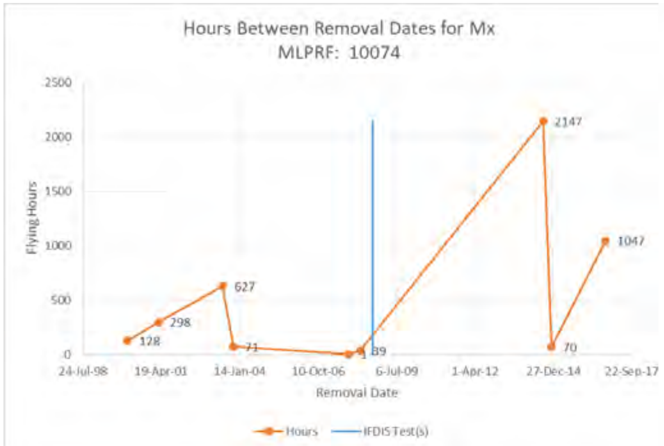

Figure 9 Hours between removal dates for MLPRF 10074

Figure 10 Hours between removal event for MLPRF 10074

Table 7 Hours between failure for MLPRF 10074

Date	Count	Hours	Avg
15-Feb-00	-6	128	
13-Mar-01	-5	298	
10-Jun-03	-4	627	
24-Oct-03	-3	71	
5-Nov-07	-2	1	
5-Apr-08	-1	39	194
8-Sep-08	0		
21-Aug-14	1	2147	
1-Dec-14	2	70	
24-Oct-16	3	1047	1088

A.2 S/N: 11347

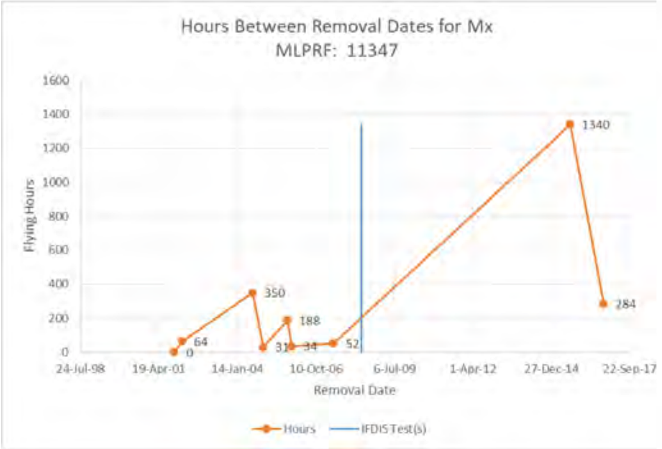

Figure 11 Hours between removal dates for MLPRF 11347

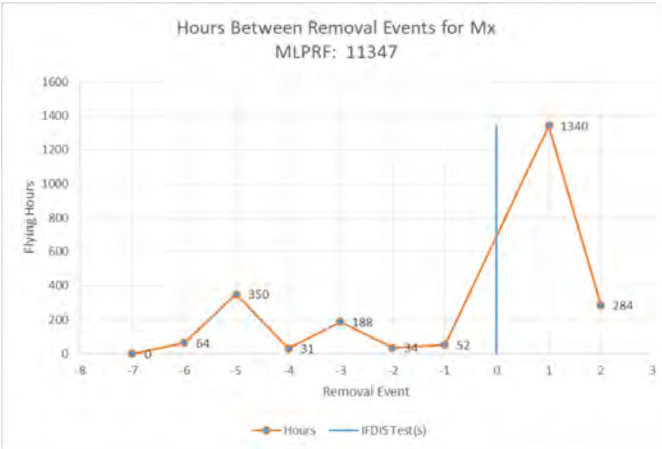

Figure 12 Hours between removal event for MLPRF 11347

Table 8 Hours between failure for MLPRF 11347

Date	Count	Hours	Avg
26-Oct-01	-7	0	
9-Feb-02	-6	64	
28-Jul-04	-5	350	
8-Dec-04	-4	31	
13-Oct-05	-3	188	
5-Dec-05	-2	34	
24-May-07	-1	52	103
13-May-08	0		
27-Aug-15	1	1340	
24-Oct-16	2	284	812

A.3 S/N: 10849

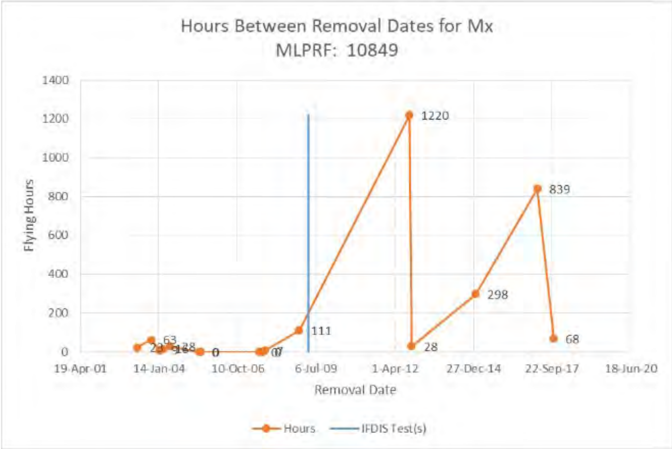

Figure 13 Hours between removal dates for MLPRF 10849

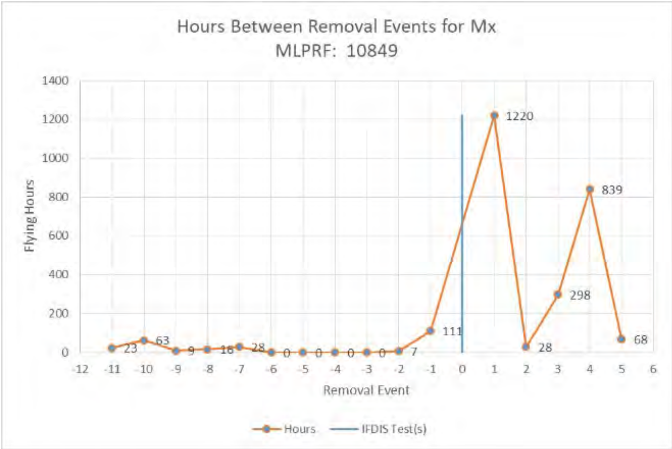

Figure 14 Hours between removal event for MLPRF 10849

Table 9 Hours between failure for MLPRF 10849

Date	Count	Hours	Avg
20-Apr-03	-11	23	
9-Oct-03	-10	63	
25-Jan-04	-9	9	
8-Mar-04	-8	16	
3-Jun-04	-7	28	
15-Jun-05	-6	0	
29-Jun-05	-5	0	
12-Jul-07	-4	0	
24-Aug-07	-3	0	
20-Sep-07	-2	7	
3-Dec-08	-1	111	23
2-Apr-09	0		
5-Oct-12	1	1220	
1-Nov-12	2	28	
25-Jan-15	3	298	
19-Mar-17	4	839	

Date	Count	Hours	Avg
13-Oct-17	5	68	491

A.4 S/N: 10888

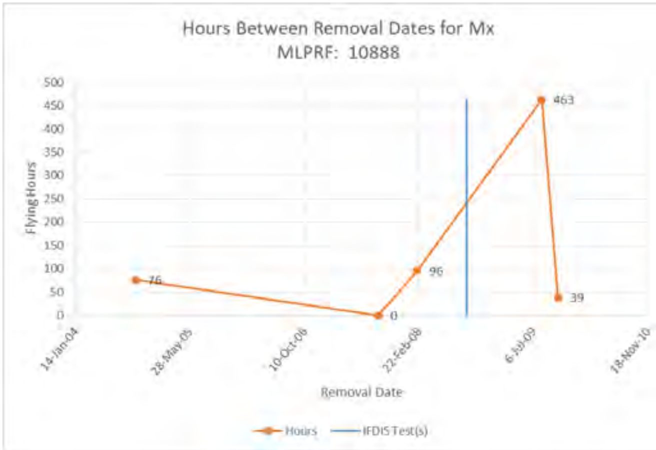

Figure 15 Hours between removal dates for MLPRF 10888

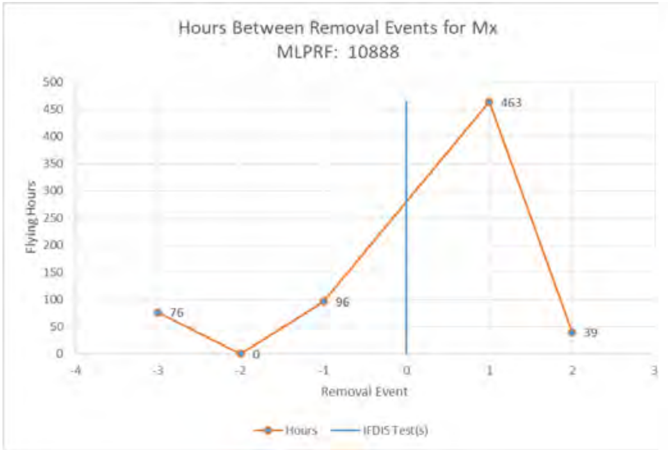

Figure 16 Hours between removal event for MLPRF 10888

Table 10 Hours between failure for MLPRF 10888

Date	Count	Hours	Avg
15-May-04	-6	131	
4-Aug-05	-5	260	
20-Sep-07	-4	11	
5-Mar-08	-3	75	
17-Jul-08	-2	44	
12-Aug-08	-1	0	87
20-Apr-10	0		
1-Dec-11	1	996	
15-Jan-14	2	472	
29-Aug-14	3	99	522

A.5 S/N: 11877

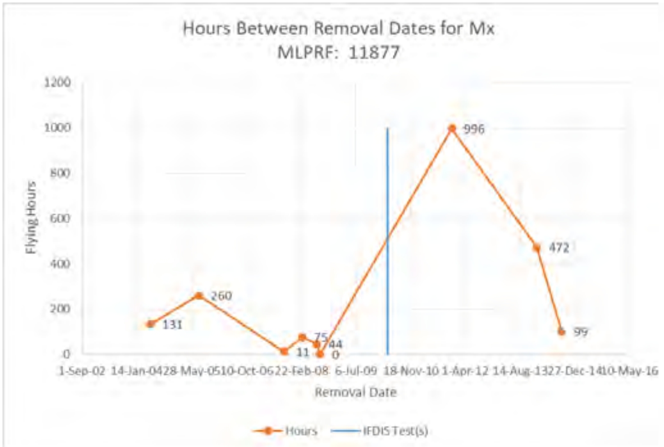

Figure 17 Hours between removal dates for MLPRF 11877

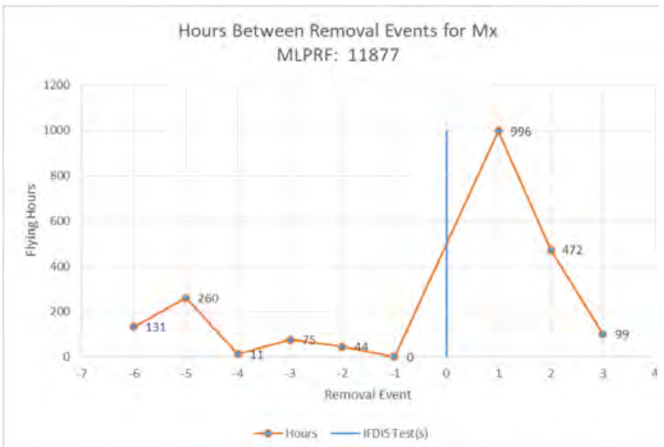

Figure 18 Hours between removal event for MLPRF 11877

Table 11 Hours between failure for MLPRF 11877

Date	Count	Hours	Avg
15-May-04	-6	131	
4-Aug-05	-5	260	
20-Sep-07	-4	11	
5-Mar-08	-3	75	
17-Jul-08	-2	44	
12-Aug-08	-1	0	87
20-Apr-10	0		
1-Dec-11	1	996	
15-Jan-14	2	472	
29-Aug-14	3	99	522

A.6 S/N: 10725

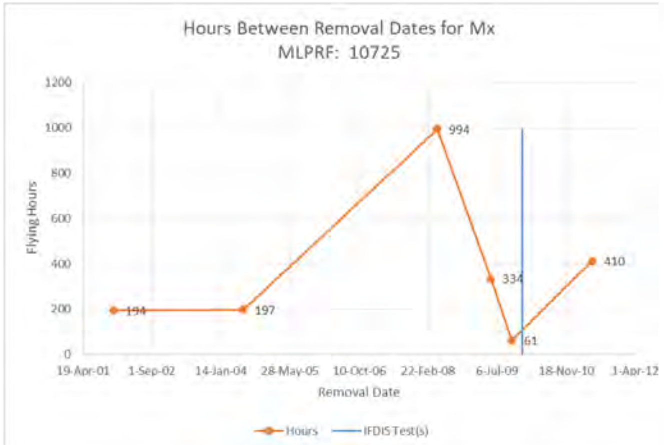

Figure 19 Hours between removal dates for MLPRF 10725

Figure 20 Hours between removal event for MLPRF 10725

Table 12 Hours between failure for MLPRF 10725

Date	Count	Hours	Avg
27-Nov-01	-5	194	
23-Jun-04	-4	197	
29-Apr-08	-3	994	
22-May-09	-2	334	
21-Oct-09	-1	61	356
4-Jan-10	0		
25-May-11	1	410	410

A.7 S/N: 11437

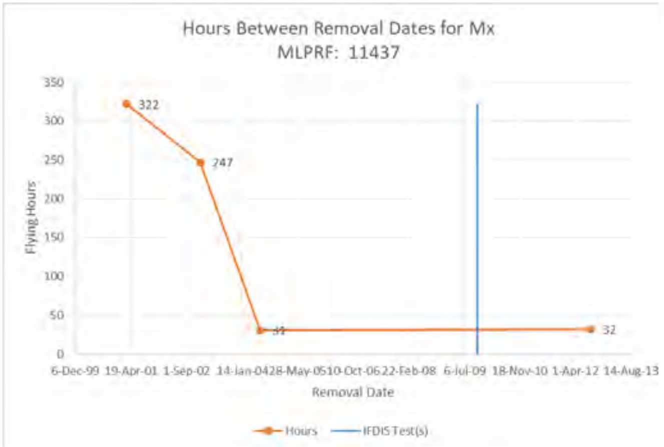

Figure 21 Hours between removal dates for MLPRF 11437

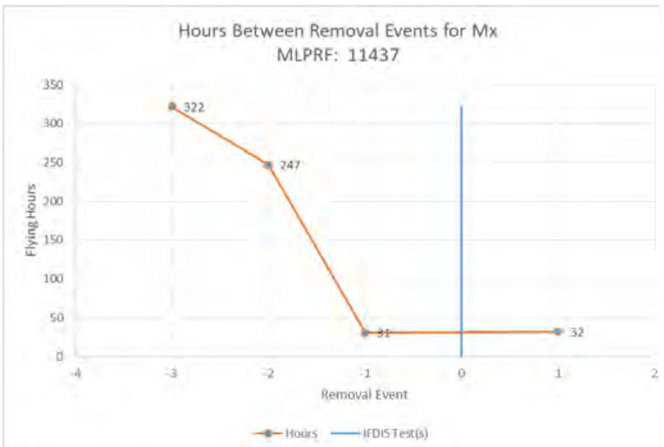

Figure 22 Hours between removal event for MLPRF 11437

Table 13 Hours between failure for MLPRF 11437

Date	Count	Hours	Avg
13-Mar-01	-3	322	
3-Jan-03	-2	247	
25-Jun-04	-1	31	200
4-Nov-09	0		
14-Aug-12	1	32	32

A.8 S/N: 11863

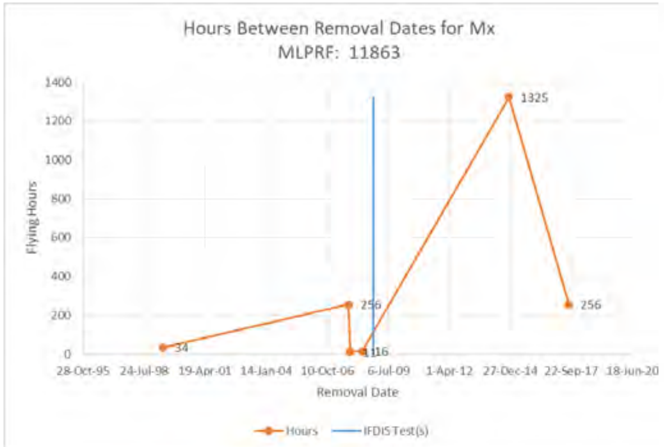

Figure 23 Hours between removal dates for MLPRF 11863

Figure 24 Hours between removal event for MLPRF 11863

Table 14 Hours between failure for MLPRF 11863

Date	Count	Hours	Avg
1-Jun-99	-4	34	
26-Sep-07	-3	256	
26-Oct-07	-2	11	
8-May-08	-1	16	79
4-Nov-08	0		
4-Dec-14	1	1325	
12-Aug-17	2	256	791

A.9 S/N: 11188

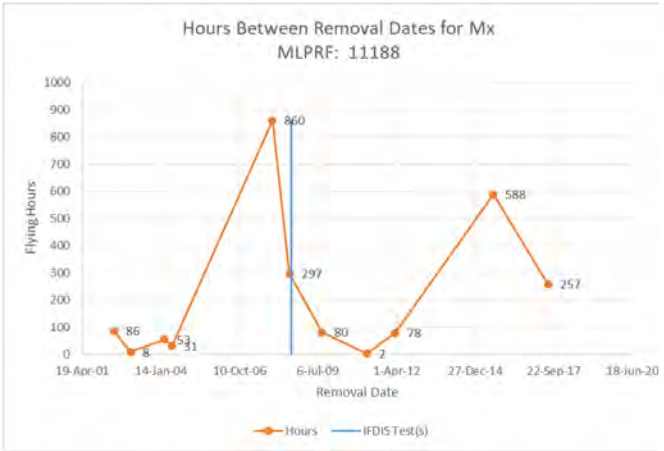

Figure 25 Hours between removal dates for MLPRF 11188

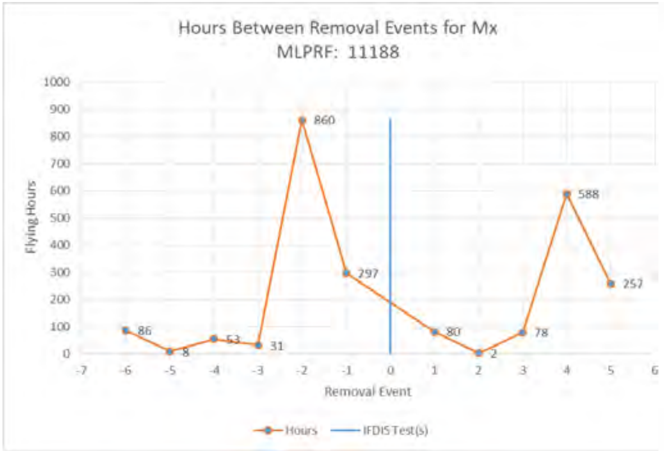

Figure 26 Hours between removal event for MLPRF 11188

Table 15 Hours between failure for MLPRF 11188

Date	Count	Hours	Avg
31-May-02	-6	86	
29-Dec-02	-5	8	
3-Mar-04	-4	53	
8-Jun-04	-3	31	
7-Dec-07	-2	860	
10-Jul-08	-1	297	223
31-Jul-08	0		
28-Aug-09	1	80	
23-Mar-11	2	2	
16-Mar-12	3	78	
18-Aug-15	4	588	
11-Jul-17	5	257	201

A.10 S/N: 11525

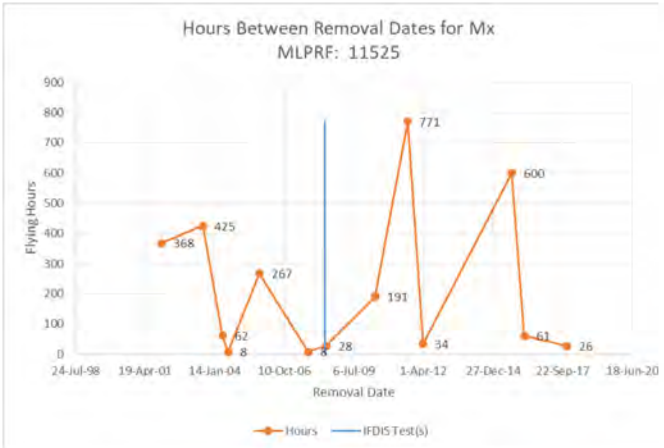

Figure 27 Hours between removal dates for MLPRF 11525

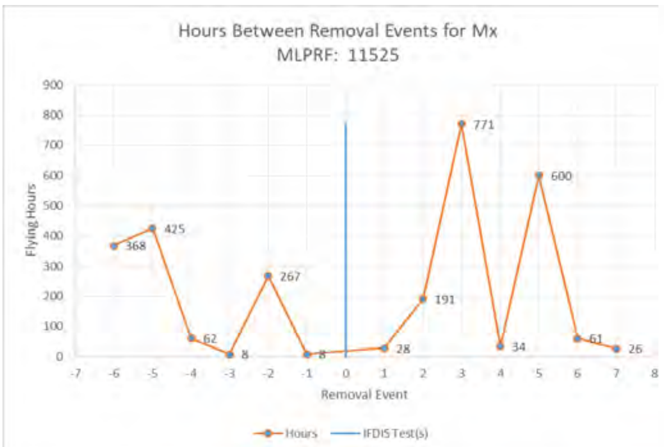

Figure 28 Hours between removal event for MLPRF 11525

Table 16 Hours between failure for MLPRF 11525

Date	Count	Hours	Avg
12-Dec-01	-6	368	
30-Jul-03	-5	425	
5-May-04	-4	62	
28-Jul-04	-3	8	
20-Oct-05	-2	267	
20-Sep-07	-1	8	190
14-May-08	0		
6-Jun-08	1	28	
11-May-10	2	191	
16-Aug-11	3	771	
23-Mar-12	4	34	
24-Sep-15	5	600	
18-Mar-16	6	61	
22-Nov-17	7	26	244

A.11 S/N: 10386

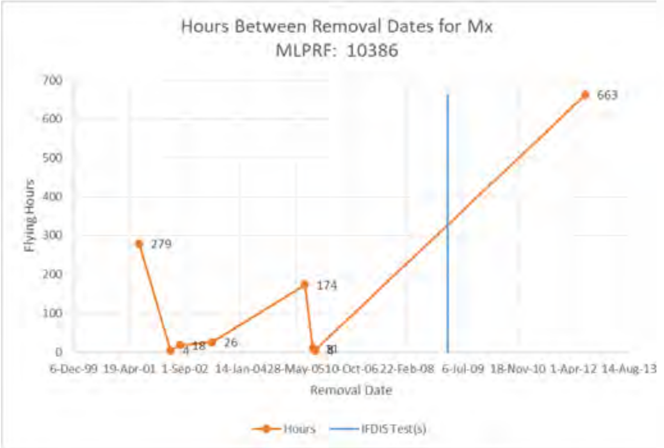

Figure 29 Hours between removal dates for MLPRF 10386

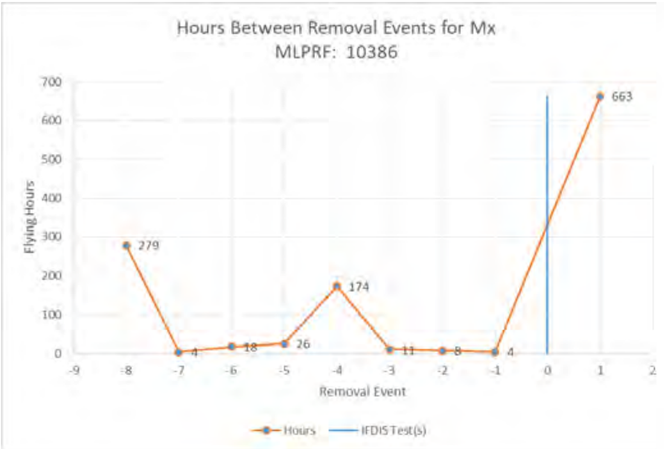

Figure 30 Hours between removal event for MLPRF 10386

Table 17 Hours between failure for MLPRF 10386

Date	Count	Hours	Avg
17-Jul-01	-8	279	
23-Apr-02	-7	4	
17-Jul-02	-6	18	
4-May-03	-5	26	
16-Aug-05	-4	174	
26-Oct-05	-3	11	
15-Nov-05	-2	8	
16-Nov-05	-1	4	66
23-Feb-09	0		
19-Jul-12	1	663	663

A.12 S/N: 11792

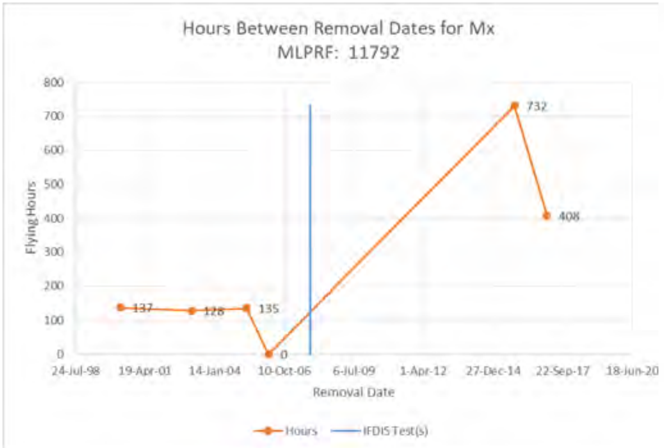

Figure 31 Hours between removal dates for MLPRF 11792

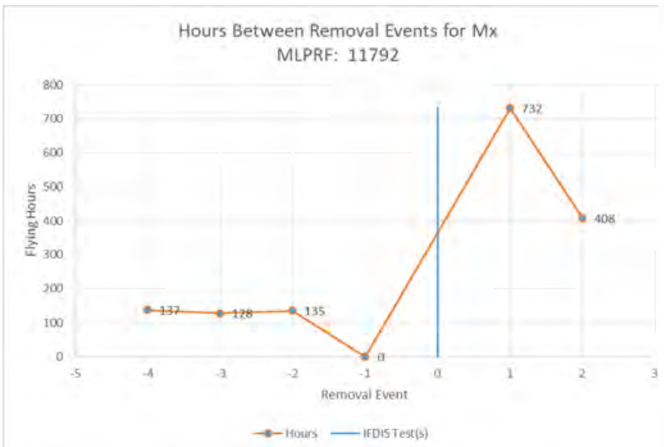

Figure 32 Hours between removal event for MLPRF 11792

Table 18 Hours between failure for MLPRF 11792

Date	Count	Hours	Avg
3-May-00	-4	137	
12-Feb-03	-3	128	
17-Apr-05	-2	135	
28-Feb-06	-1	0	100
15-Oct-07	0		
1-Nov-15	1	732	
10-Feb-17	2	408	570

A.13 S/N: 11732

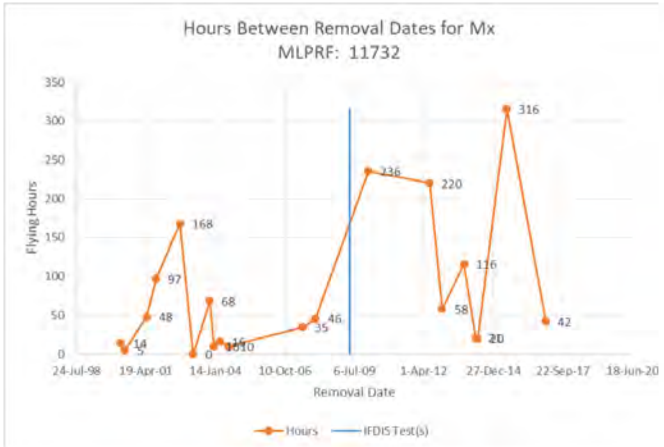

Figure 33 Hours between removal dates for MLPRF 11732

Figure 34 Hours between removal event for MLPRF 11732

Table 19 Hours between failure for MLPRF 11732

Date	Count	Hours	Avg
24-Apr-00	-12	14	
21-Jun-00	-11	5	
30-Apr-01	-10	48	
14-Sep-01	-9	97	
28-Aug-02	-8	168	
28-Feb-03	-7	0	
25-Oct-03	-6	68	
23-Dec-03	-5	10	
19-Mar-04	-4	16	
19-Jul-04	-3	10	
27-Jun-07	-2	35	
26-Dec-07	-1	46	43
28-Apr-09	0		
22-Jan-10	1	236	
22-Jun-12	2	220	
21-Dec-12	3	58	

Date	Count	Hours	Avg
31-Oct-13	4	116	
18-Apr-14	5	21	
16-May-14	6	20	
11-Jul-15	7	316	
18-Jan-17	8	42	129

A.14 S/N: 11296

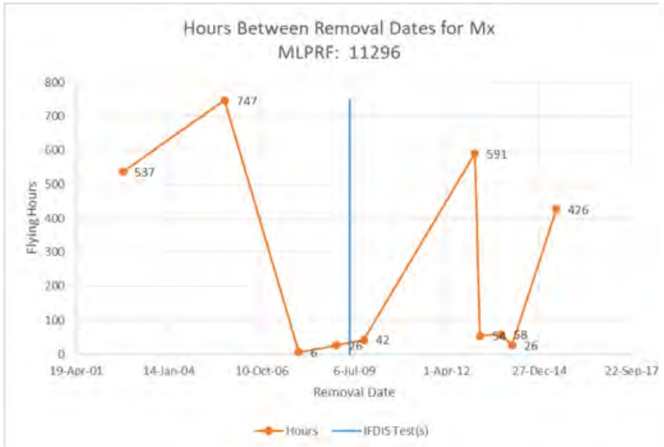

Figure 35 Hours between removal dates for MLPRF 11296

Figure 36 Hours between removal event for MLPRF 11296

Table 20 Hours between failure for MLPRF 11296

Date	Count	Hours	Avg
5-Sep-02	-4	537	
8-Sep-05	-3	747	
16-Nov-07	-2	6	
29-Dec-08	-1	26	329
20-May-09	0		
20-Oct-09	1	42	
30-Jan-13	2	591	
30-Mar-13	3	54	
15-Nov-13	4	58	
9-Mar-14	5	26	
30-Jun-15	6	426	200

A.15 S/N: 11267

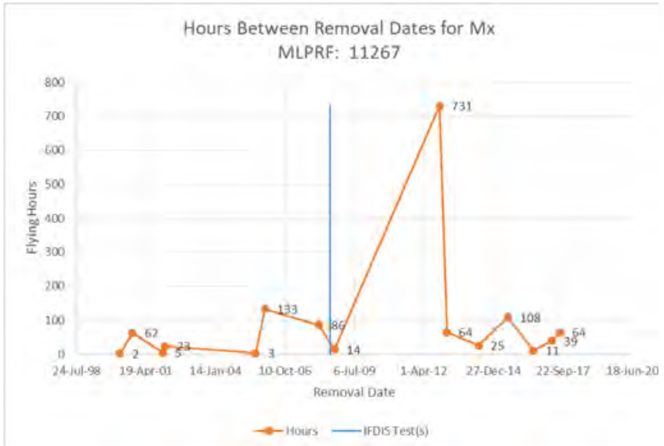

Figure 37 Hours between removal dates for MLPRF 11267

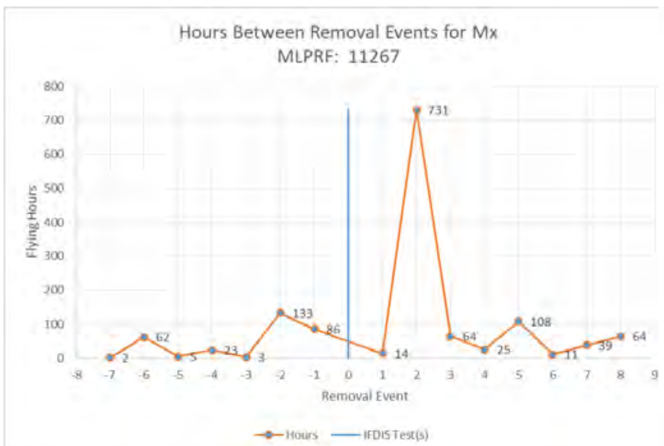

Figure 38 Hours between removal event for MLPRF 11267

Table 21 Hours between failure for MLPRF 11267

Date	Count	Hours	Avg
14-Apr-00	-7	2	
10-Oct-00	-6	62	
19-Dec-01	-5	5	
18-Jan-02	-4	23	
15-Aug-05	-3	3	
29-Dec-05	-2	133	
15-Feb-08	-1	86	45
28-Jul-08	0		
24-Sep-08	1	14	
14-Nov-12	2	731	
26-Feb-13	3	64	
29-May-14	4	25	
22-Jul-15	5	108	
25-Jul-16	6	11	
12-Apr-17	7	39	
16-Aug-17	8	64	132

A.16 S/N: 11665

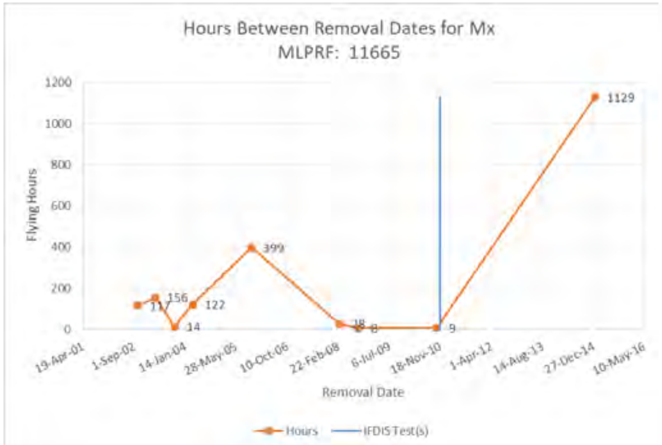

Figure 39 Hours between removal dates for MLPRF 11665

Figure 40 Hours between removal event for MLPRF 11665

Table 22 Hours between failure for MLPRF 11665

Date	Count	Hours	Avg
10-Oct-02	-8	117	
31-Mar-03	-7	156	
5-Oct-03	-6	14	
30-Mar-04	-5	122	
27-Oct-05	-4	399	
6-Mar-08	-3	28	
10-Sep-08	-2	8	
14-Oct-10	-1	9	107
16-Nov-10	0		
12-Jan-15	1	1129	1129

A.17 S/N: 10752

Figure 41 Hours between removal dates for MLPRF 10752

Figure 42 Hours between removal event for MLPRF 10752

Table 23 Hours between failure for MLPRF 10752

Date	Count	Hours	Avg
4-Aug-99	-3	84	
6-Jan-06	-2	1966	
13-Jun-07	-1	46	699
20-Jul-09	0		
18-Jan-12	1	1110	
24-Jan-12	2	7	
17-Apr-12	3	6	
2-Feb-16	4	428	
1-Nov-17	5	366	383

Appendix B Source Documents

Reference	Document
Ken Anderson, *Intermittent Fault Detection & Isolation Reduces No Fault Found (NFF) and Enables Cost Effective Readiness*, Universal Synaptics, 12 October 2016	ifdis-phm2016-1610 12173402.pdf

Solving the Department of Defense (DoD) Intermittence Problem

A Framework for an Intermittent Fault Detection (IFD) Solution

December 2018

Deputy Assistant Secretary of Defense Materiel Readiness

Forward from DASD(MR)

Forward from DASD(MR)

Electronics maintenance is a leading driver of weapon systems non-availability, accounting for over $16B annually in sustainment costs. It is not uncommon for up to 50% of electronic components entering maintenance to be No-Fault-Found (NFF); exacerbating electronics availability issues and resulting in $2B in non-value-added sustainment costs annually.

Intermittent electronics failures are a leading contributor to DoD's NFF problem; challenging us over the years by proving hard to duplicate and elusive to diagnose. With very few exceptions, our electronics test equipment is designed to address steady-state electrical disruptions; obscuring the root cause of intermittent failures.

We now have the capability to detect and isolate extremely short duration intermittent failures in complex electronics equipment. These capabilities are currently being installed or are operational at Hill Air Force Base, Fleet Readiness Center Miramar, Fleet Readiness Center Southwest and Naval Surface Warfare Center Crane. In each instance where we have stood up and used these capabilities, we have experienced a steep decline in NFF events; leading to markedly greater materiel availability, improved reliability, and significant cost reductions.

To address this issue, I am championing a Department-wide initiative to rapidly promulgate intermittence detection and isolation capabilities, as defined by MIL-PRF-32516, across our sustainment enterprise. Outlined in this document is the "Framework for Implementing Intermittent Fault Detection and Isolation Capabilities" across the Military Services. Utilizing this framework to implement this critical capability will result in a significant increase in weapon system availability and a corresponding reduction in sustainment costs.

Kenneth D. Watson
Deputy Assistant Secretary of Defense
For Materiel Readiness

Executive Summary

Intermittent faults are a failure mode that significantly impact weapon system availability and sustainment costs. This document provides the framework for the implementation of an Intermittent Fault Detection (IFD) and isolation capability of Electrical Wiring Interconnect System (EWIS) and Line Replaceable Unit/Weapon Replaceable Assembly (LRU/WRA) within the Department of Defense (DoD). The introduction includes a definition of intermittent faults as defined in MIL-PRF-32516. It discusses the inability to detect and isolate intermittent faults in aircraft wiring bundles and LRUs/WRAs using conventional test equipment. Information is also provided with regards to how you know if aircraft EWIS or LRU/WRAs are experiencing intermittent faults.

The Joint Intermittence Test (JIT) team, consisting of participants from the Air Force, Army, Navy, and other agencies in cooperation with industry was instrumental in identifying diagnostic equipment capable of detecting intermittent faults. One overarching capability that the JIT identified, is that IFD equipment must take readings while the fault is occurring. In order to accomplish this task, diagnostic/test equipment must be capable of monitoring all conductive paths continuously and simultaneously while simulating the specified Type/Model/Series (TMS) aircraft and EWIS or LRU/WRA operating environment.

To aid Military Services in identifying diagnostic equipment capable of detecting and isolating intermittent faults, examples of Air Force and Navy implementation of the Universal Synaptics Intermittent Fault Detection & Isolation System™ (IFDIS™) at Hill Air Force Base and Fleet Readiness Center Southwest (FRC-SW) are discussed. In addition, Appendices are included which describe case studies of the IFDIS and Voyager Intermittent Fault Detector™ (VIFD™). This information is provided so that the reader is able to benefit from the experience of other agencies. The appendices also provide requirement identification, a business case analysis (BCA), a list of resources, and points of contact for Air Force and Navy locations where equipment is operational or in the installation process.

The main emphasis of this document is the "IFD Capability Implementation Framework and Guidance". The intent of this framework is to recommend steps an organization may utilize to successfully implement IFD and isolation of EWIS and LRUs/WRAs across DoD. The framework is divided into four steps:

1. Build awareness and buy-in within the organization that short duration intermittence is a failure mode that is affecting readiness and efficiency.
2. Identify IFD opportunities and introduce the IFD solutions.
3. Acquire and implement the IFD solutions.
4. Validate the results and expand IFD implementation.

The first two steps are actions that the JIT and DASD(MR) can assist to build awareness and support within the DoD organization/agency or platform program office. After the DoD organization/agency or platform program office is engaged, the second step involves identifying the LRUs/WRAs most affected, and the appropriate maintenance level for implementation. The JIT can employ available data tools and previous experience to assist with this analysis. Step three is the DoD organization/agency or platform program office responsibility to acquire and implement the capability. In step four, the organization/agency, with JIT assistance, will validate the results and support the expansion of IFD equipment implementation.

Intermittence faults are significantly affecting DoD readiness and sustainment costs, yet the capability to significantly reduce that impact is available today. This document is intended to assist DoD organizations in gaining awareness of their intermittence problems, describing an available solution, and assisting with the implementation of this capability within their organizations.

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Intermittent Fault Definition (IFD)[1]

Intermittent faults are short duration discontinuities (opens/shorts) that occur in conductive paths in LRUs/WRAs chassis/backplanes. Intermittent faults occur as a result of various operational environmental stimuli, including, but not limited to, thermal stress, vibrational stress, gravitational G-force loading, moisture and/or contaminant exposure, as well as changes in the material due to age and use, such as the growth of tin whiskers, metal migration and delamination of materials. These faults can occur individually and/or in rapid succession on any chassis or backplane circuit. Fault durations range in time from nanoseconds to milliseconds and have variable impedances. These circuit path disruptions are frequently caused by: cracked solder joints; intermittent coax lines (e.g., shield corrosion, damaged center conductor, etc.); broken, cracked or frayed wires; loose clamps; and unsoldered pins. These circuit path disruptions often cause functional failures/faults in LRU/WRA chassis and backplanes whose root cause(s) cannot be detected and isolated using conventional automatic test equipment (ATE) and troubleshooting processes. Lacking the ability to detect and isolate intermittent failures and provide environmental stimuli during test and repair process, such assets are commonly reported as no-fault-found (NFF) or as one of the quasi-NFF repair codes (e.g., cannot duplicate (CND), no trouble found (NTF), retest OK (RETOK), beyond capability of maintenance (BCM), disassemble-clean-reassemble (DCR), etc.). The reader is also referred to MIL-PRF-32516 for short-duration faults, long-duration faults, open and short definitions.

Aircraft electrical wiring interconnect system (EWIS) and LRU/WRA wiring failure modes include: opens, shorts, mis-wiring and intermittent fault. It should also be noted that intermittent faults may be induced as a result of maintenance on the aircraft or LRU/WRA. This document will address the intermittent fault failure mode.

1.2 Background

The Department of Defense (DoD) is challenged by the inability to detect and isolate intermittent faults in aircraft wiring bundles and LRUs/WRAs using conventional test equipment. These faults include short duration opens and shorts, degraded and intermittent signals, and insulation degradation. The magnitude of the challenge is daunting, with the DoD spending approximately $2B annually[2] just removing and replacing LRUs/WRAs that, when tested, are determined to be NFF. Additionally, legacy electronic components are experiencing increasingly reduced reliability because of component age, usage, and in some cases maintenance actions. Intermittent faults are mechanical in nature and can include failures in solder joints, wiring, wire wraps, connectors, etc., which only manifest as operational failures due to temperature, vibration, and other external environmental stimuli. The duration of these intermittent events can range from nanoseconds to seconds, may oscillate repeatedly during an event or may just be a single occurrence during a given testing session. Intermediate and depot maintenance actions, such as the reseating of a degraded connection, solder joint, etc., can temporarily cause the intermittent connection to function properly for days, or even weeks after, and may only manifest as a repeat operational failure after

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1 MIL-PRF-32516

2 Office of the Secretary of Defense (OSD), Weapon System No Fault Found (NFF) Study, 2011

several months. This leads to a constant revolving cycle for EWIS and the LRU/WRA (removal, maintenance testing resulting in NFF, and subsequent reinstall on aircraft).

The intermittent fault failure mode, is unpredictable in nature, and creates an impossible troubleshooting task for the technician or maintainer trying to diagnose a potential electrical intermittency problem in a complex system of continuity paths. The intermittent fault event possibly occurring on one or more of thousands of potential circuits, and occurring by chance in a given timeframe, or possibly not at all while the technician or maintainer is actively looking for issues in the EWIS or within the LRU/WRA. Additionally, conventional test equipment has limited ability to isolate intermittent faults, because this test equipment tests LRUs/WRAs using a point-to-point, single-point in time testing. Another limitation for conventional test equipment is the inability to simulate operational conditions during test, which makes it impossible for the test equipment to induce a repeat of the intermittent event, which may be the catalyst for the operational failure in the first place. In some instances, external technician intervention, (i.e., removing and reseating of subassembly replaceable assemblies (SRAs), which should be considered external stimuli), causes the intermittent failure to become a hard failure, which can then be isolated with the conventional test equipment. Intermittent faults may be found using conventional test equipment to a limited extent, but this is only possible when faults have degraded to the extent that they are closer to becoming long-duration or known faults. Additionally, conventional test equipment tends to find only intermittent faults on system circuits that are well-understood and where faults have previously been found after, a considerable amount of time has been expended.

Visual inspection processes lack effectiveness and can identify only a relatively small portion of total weapon system wiring problems.

1.3 Problem

Intermittent faults are a growing problem and many of the maintenance issues of which repair facilities contend are directly related to interconnectivity problems on the aircraft EWIS or within electronic components or assemblies. Hard failures, where wiring issues are evident, are relatively routine to detect and repair, and not all hard failures involve wiring. However, major electrical issues and even critical down-line failures may occur when an electrical fault appears only intermittently, in short duration, under operational conditions (such as high G-force loading and extremes in temperature or stress, or vibrational states) that are difficult to replicate. These intermittent faults are difficult to identify, isolate, and ultimately repair.

There was no standardized, automated, DoD-approved process to consistently detect these faults. Industry developed IFD and diagnostic equipment to identify these faults. In addition, this industry development included the integration of the diagnostic equipment with environmental test chambers and vibration tables to simulate the LRU/WRA operating environment. There was also no analytical methodology to validate the performance capabilities for the various levels of current in-service diagnostic equipment. The two main challenges in determining the causes of increased aircraft maintenance related to CND/NFF are: (1) the inability to test and drive to the root cause of intermittence issues from either the EWIS or aircraft electronic equipment; and (2) understanding that there are no trending methods that can be applied to intermittency behaviors as every failure instance is unique to the aircraft operational environments and associated maintenance practices. This is further complicated because the failure is often diagnosed as EWIS or electronic equipment failure and not reported as an aircraft wiring failure. When the removal and replacement maintenance concept does not resolve the issue, personnel then typically resort to the use of conventional point-to-point test equipment (e.g., Automatic Wire Test Set (AWTS), DIT-MCO Wiring Analyzers, Flexible Automatic Circuit Tester (FACT), etc.). If the point-to-point test equipment does not find a wiring issue, maintenance personnel may then begin a physical process of inspection that includes the use of human senses, available wiring diagrams and fault isolation procedures (FIPs) when available. Visual inspection is limited to approximately 25% of the total wiring on the aircraft.

Appendix I contains a list of reference material which provides additional information about intermittent faults.

1.3.1 Intermittent Fault Failure

The question is often asked as to how you know if aircraft EWIS or LRU/WRAs are experiencing intermittent faults. LRU/WRAs differ in function and complexity, so failure mechanisms will vary for each LRU/WRA, and as a result how the failure manifests itself will vary. In the event of limited aircraft failure data or new aircraft installation, an investigation may need to be conducted to determine what has changed in the LRU/WRA installation. There are key factors that need to be investigated to determine if failures are intermittent faults. First the aircraft installation will need to be investigated to determine what has changed in the LRU/WRA installation:

- When did the EWIS or LRU/WRA start experiencing failures?
- Has there been a decrease in reliability and time-on-wing (TOW)?
- Under what conditions are the failures occurring i.e., altitude (low temperature), taxi or idle (high temperature), flight operations (vibration), etc.?
- Were there modifications to the aircraft EWIS, LRU/WRA, or other interfacing components such as sensors?

Answering these questions is critical to determine if the failures are operational or system integration, and not intermittent fault issues.

LRU/WRAs that have been operating satisfactorily for longer periods of time and are experiencing a reduction of reliability and TOW are excellent candidates for investigation of intermittent faults. Key symptoms to look for are:

- Declining reliability and TOW.
- High or increasing aircraft removal rate.
- LRU/WRA internal component failures which appear to be random without a common component failure.
- Depot and Intermediate level troubleshooting with conventional diagnostic equipment or original equipment manufacturer (OEM) test equipment resulting in CND, NFF, NTF, RETOK diagnosis.
- Repeat failures on aircraft after return to operation.

A review of the U.S. Air Force (Section 2.2.2) and Navy experiences (Section 2.2.3), and the case studies in Appendices D and E provide the following common themes for an agency to investigate EWIS or LRU/WRA failures for intermittent faults:

- ➢ Decreasing reliability and TOW.
- ➢ Conventional test equipment unable to determine failure cause.
- ➢ High rate of CND, NFF, NTF, and RETOK results during maintenance troubleshooting.
- ➢ Subsequent failure of the LRU/WRA upon return to operation after maintenance.

1.3.2 IFD Equipment

There is a lot of diagnostic equipment in the market place which claim that they can detect and isolate intermittent faults. Since the fault is intermittent, there is one overarching capability that any IFD equipment must have: ***you must take readings while the fault is occurring***. In order to accomplish this task, diagnostic/test equipment must be capable of monitoring all conductive paths continuously and simultaneously while simulating the specified TMS operating environment. This will allow for duplication of the EWIS or LRU/WRA intermittent failures in the repair maintenance facilities that were experienced in flight.

It is extremely important to monitor all LRU/WRA chassis conductive paths continuously and simultaneously to detect the intermittent fault which may occur on any conductive path or multiple conductive paths at the same time. Intermittent faults as defined by MIL-PRF-32516 may occur individually and/or in rapid succession on any chassis or backplane circuit. In addition, the fault durations range in time from nanoseconds to milliseconds. If the diagnostic equipment is not taking readings on all conductive paths at the same time, it may miss an intermittent fault which is occurring on a single or multiple conductive path which are not being read at the time of the fault.

It is also extremely important to simulate the operating conditions under which the intermittent fault occurs. Intermittent faults within EWIS and LRU/WRAs may only occur during certain operating conditions. As previously discussed, CND, NFF, NTF, and RETOK reported maintenance findings are often the result of equipment being tested in a benign environment. It is not until the EWIS or LRU/WRA is stimulated with temperature and/or vibration that the intermittent fault occurs.

1.4 IFD Equipment Standardization

1.4.1 MIL-PRF-32516 Specification

1.4.1.1 Purpose

Prior to March 2015, no specification/standard for IFD equipment existed. MIL-PRF-32516 was developed to define the minimum performance requirements for equipment to detect and isolate nanosecond, microsecond and millisecond conductive paths and intermittent faults which can occur in any and all of the hundreds to thousands of LRU/WRA chassis and backplane circuits and their wire harnesses was needed.

1.4.1.2 Highlights

Classifies intermittent faults into three categories: Category 1 – under 100 nanoseconds; Category 2 – 101 nanoseconds to 500 microseconds; and Category 3 – 501 microseconds to 5 milliseconds.

Defines diagnostic equipment:

- Functions and applications

- User interface
- Expandability
- Performance characteristics

The Specification appendices provide guidance on using vibration, temperature, and vibration/temperature to stimulate intermittent faults for their detection.

1.4.2 Intermittent Fault Emulator (IFE)

1.4.2.1 Purpose

The challenge in developing IFE equipment is validating their capability to locate the intermittent faults. By its very nature intermittent faults appear randomly typically under specific environmental operating conditions. A method was needed to emulate an intermittent fault on a known conductive path with known duration, repetition, amplitude and wave shape.

1.4.2.2 Description

The IFE is test equipment designed to emulate intermittent faults that occur in the LRU/WRA conductive paths and cable harnesses. The emulator has 256 test channels available that can be programmed with variable resistance faults of 100 nanoseconds to 500 milliseconds duration individual faults, which can also be grouped into burst faults as a 5MHz pulse from 3-5 microseconds. The IFE contains software-controlled semiconductor switches, which can simulate combined individual and burst conductive path faults of programmed or pseudorandom duration on programmed or pseudorandom conductive paths. The purpose of the IFE is to emulate an intermittent fault of known duration on a known conductive path to verify the capability of test equipment to detect and isolate this simulated fault. Each IFE channel has four software-controlled semiconductor switches to randomly create four variable fault resistances.

1.4.2.3 MIL-HDBK-527

This handbook was published to provide guidance and lessons learned for acquisition organizations when using the IFE to evaluate IFD and isolation technologies, methods, and/or devices prior to acquisition. The handbook includes information in regard to the IFE User Manual, IFE programming considerations, and IFE pinouts for constructing an Interface Adaptor Harness (IAH). IFD equipment manufacturers and suppliers can demonstrate and verify their test equipment capabilities to detect and isolate intermittent faults by using the IFE. This handbook is for guidance only and cannot be cited as a requirement.

The handbook recommends a two-step procedure as a best practice when using the IFE. The first step is to evaluate the multi-channel capability of the IFD equipment using the IFE. The second step uses a signal generator to determine the equipment's capability to detect events down to 100 nanoseconds. This two-step procedure is particularly important when the IFD equipment stimulus voltages and currents are below 5 volts and 30 milliamps for frequencies from 40KHz to 10MHz.

1.5 Intermittent Fault Impact Summary

As discussed above, intermittent faults result in significant increased cost due to: loss of mission, removal/failure-troubleshooting/NFF/re-install **DO-LOOP**; cannibalization or BCM. Intermittent faults have become a recognized **Failure Mode**, which is characterized by decreasing reliability and TOW. One of the main symptoms of an intermittent fault failure mode problem is a high rate of CND, NFF, NTF, and RETOK failures reported by the maintenance activities.

Intermittent faults have been identified by the Deputy Assistant Secretary of Defense Materiel Readiness (DASD(MR)) and JIT as a problem costing the DoD over $2B annually. In addition, diagnostic equipment having the capability to monitor all conductive paths continuously and simultaneously while simulating the specified TMS operating environment has been identified as the solution.

2. IFD Technologies

2.1 Evaluation of IFD Technologies[3]

A Request for Information (RFI) N68335-15-RFI-0505 was issued on 28 May 2015. Replies were received from six companies: (1) Dragoon ITCN; (2) Trimble Sustainment Engineering, Inc; (3) Eclypse International Corp; (4) Universal Synaptics Corp; (5) Williams RDM; and (6) Solavitek Inc.

Technology evaluations were held the week of 4 January 2016. Of the six responders to the RFI, three companies were extended an invitation to participate in the Industry Week: (1) Eclypse International Corp, (2) Universal Synaptics Corp., and (3) Solavitek, Inc. During the session, government representatives from Naval Air Warfare Center Aircraft Division (NAWCAD) Lakehurst and from Fleet Readiness Center Southwest (FRC-SW) evaluated the IFD capabilities using an IFE. Of the companies evaluated, the Universal Synaptics IFDIS™ and VIFD™ were the only diagnostic equipment that met the MIL-PRF-32516 requirement to simultaneously monitor all EWIS or LRU/WRA conductive paths.

2.2 IFD Technologies and Initial Implementation Approach

2.2.1 IFDIS

Uses IFD circuitry which simultaneously and continuously monitors every electrical path in the LRU/WRA chassis, all at the same time, while exposing the LRU/WRA to the simulated operational environment. The IFD analog hardware neural network circuitry detects and isolates faults events as short as 50 nanoseconds (0.00000005 seconds) occurring on any LRU/WRA circuit during test. Graphical test results show the precise locations of the intermittent fault for quick repairs of the problems. In addition to detecting and isolating intermittent faults, the IFDIS will automatically interrogate and store the as-designed wiring configuration (Automap) for a good unit and then based on that "gold" configuration, will detect any open, short, ohmic, impedance, drift or mis-wiring problem in subsequent LRU/WRAs. Each new unit under test (UUT) part number family will require the development of Interface Test Adapters (ITAs), also referred to as Test Program Sets (TPSs), to interface with LRU/WRAs, which can then be utilized for the entire asset population.

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[3] Joint Intermittence Testing (JIT) Capability, Phase II Final Report (National Center for Manufacturing Sciences, 3025 Boardwalk, Ann Arbor, Michigan 48108-3230) December 2016

- The IFDIS includes custom ITAs, which electrically connect to all the chassis circuitry through both internal and external connections. The ITA includes Form, Fit & Interface replicas of the UUT electronic modules. Tying the environmental system together is a master control computer, color laser printer, uninterruptable power supplies, a shaker expander head, hardware to interface the shaker and chamber, interconnecting wiring, miscellaneous hardware, and master control software, which includes UUT configuration and environmental stress profiles.
- It should be noted that the TPS cables used by AWTS diagnostic equipment have been successfully used with IFDIS. For activities already using AWTS equipment, this is a potential cost savings. In addition, IFDIS may be used to detect and isolate intermittent faults in the AWTS TPS cables.
- Installed in 256 test point modules (1,280 per 7U rack-space), the IFDIS test range expandability is virtually unlimited. Regardless of the number of test lines, the IFDIS does not lose nanoseconds of test coverage.

Tables 1 and 2 provide design and performance requirements for integrated environment test chamber and vibration system. In addition, Figure 1 is an example of an IFDIS installation.

2.2.1.1 IFDIS Features

- Monitors all LRU/WRA circuits simultaneously and continuously for intermittent faults.
- Detects anomalies in current flow that occur for as short as 50 nanoseconds.
- Uses an environmental chamber and shaker table to simulate the LRU/WRA operational environment (temperature and vibration).
- Verifies there are no permanent (as opposed to intermittent) defects in circuit continuity.
- Checks LRU/WRA point-by-point for open circuit paths or circuit paths with abnormal resistance.
- Detects shorted and mis-wired circuits.
- Compares circuit impedance signatures against nominal values.
- Detects problems in filtering circuits, transformers, Linear Variable Differential Transformers (LVDTs), synchro's, etc. that would not be detected using direct current-based ohmic measurements.
- Allows user to see degree of noise or drift on a selected circuit between two test points.
- Graphically displays measurement results using a logarithmic scale that makes small circuit changes readily apparent.
- Test point expandability
- Minimum: 256
- Maximum: 20,480
- Connector Interface to ITA: high capacity – mass-interconnect panel(s) with up to 1,280 contacts per panel.

Table 1. IFDIS Recommended Environment Chamber

Exterior Dimensions (door closed)	62 in. wide x 104 in. deep x 96 in. high
Interior Workspace	40 in. wide x 40 in. deep x 38 in. high
Temperature Range	-68°C to+177°C (most LRU/WRAs do not require testing to full range of chamber temperature capabilities)
Temperature Control Stability	±1°C as measured at the control/measuring sensor after stabilization
Cooling (Pull-Down Rate)	10°C per minute to -40°C
Heating (Heat-Up Rate)	20°C per minute to +70°C
Electrical Requirements	480V, 62A, 60Hz

Table 2. IFDIS Recommended Vibration System

Head Expander Working Surface Dimensions	18 in. wide x 25 in. deep
Shaker Dimensions	40 in. wide x 30 in. deep x 33 in. high Note: Shaker sits beneath environmental chamber and therefore does not affect the overall system footprint
Amplifier Dimensions	21 in. wide x 35 in. deep x 75 in. high
Sine Force, Peak	2,205 pound-force
Random Force, RMS	2,205 pound-force
Frequency Range (With Head Expander)	20 to 2,000 Hertz
Displacement	2 in. peak to peak
Internal Load Support Capability	350 pounds
Electrical Requirements	480V, 40A, 60Hz
Shop Air Requirements	100 psi

Figure 1. IFDIS Example

See Appendix H for IFDIS equipment that has been procured and currently deployed within DoD.

2.2.2 U.S. Air Force IFDIS Experience

The U.S. Air Force was experiencing a high NFF rate with the F-16 aircraft Modular Low Power Radio Frequency (AN/APG 68 Radar System MLPRF) LRU. Using conventional testers, they were unable to detect the problem in the MLPRF LRUs 51% of the time. They originally discovered the chassis intermittent in 1999 using a microscope where they were able to find ribbon cables which had cracked solder joints. The MLPRF SRUs had a 90% NFF rate. As a result, the Air Force initiated a massive ribbon cable re-soldering program. No Depot tester was able to detect the intermittent circuits. The Air Force discovered IFDIS capability in 2006. Two IFDIS systems were stood up in 2009 through a Small Business Innovative Research (SBIR) Phase III. Figures 2, 3 and 4 show a side view of the MLPRF with the cover removed, bottom view showing the MLPRF chassis backplane ribbon cable and MILPRF with ITAs attached and ready for test. One IFDIS was set-up in the F-16 MLPRF repair shop and the other was set-up in a "bad actor" laboratory. As part of this effort over 400 MLPRFs were tested. Testing results included: (1) intermittent faults were detected and isolated in 60% of the units tested; (2) mean operating hours between depot repair increased from 290 to 926 hours; (3) ranking on the mission impaired capability awaiting parts (MICAP) list was lowered (previously near the top of the list for over a decade); and troubleshooting time reduced by over 100%.

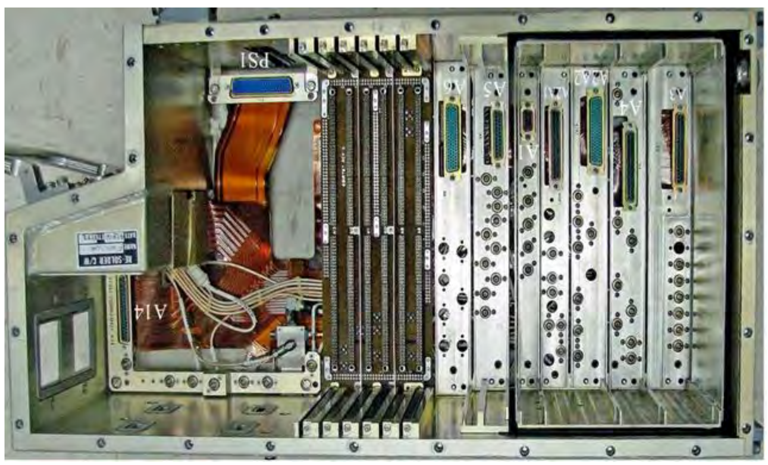


Figure 2. MLPRF Chassis

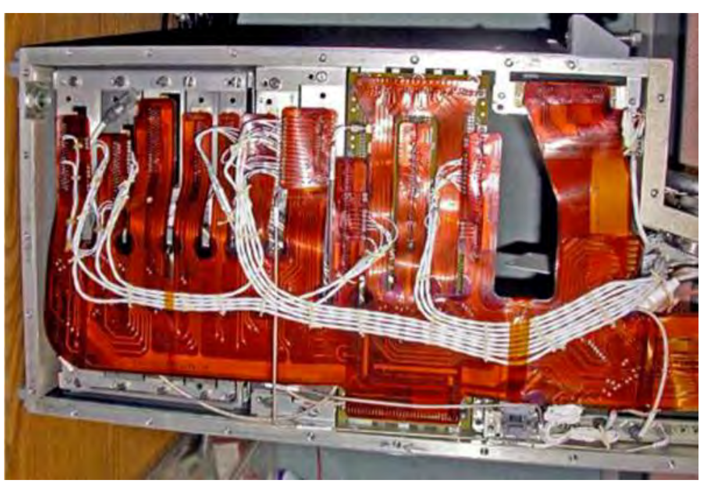


Figure 3. MLPRF Chassis with Ribbon Cable

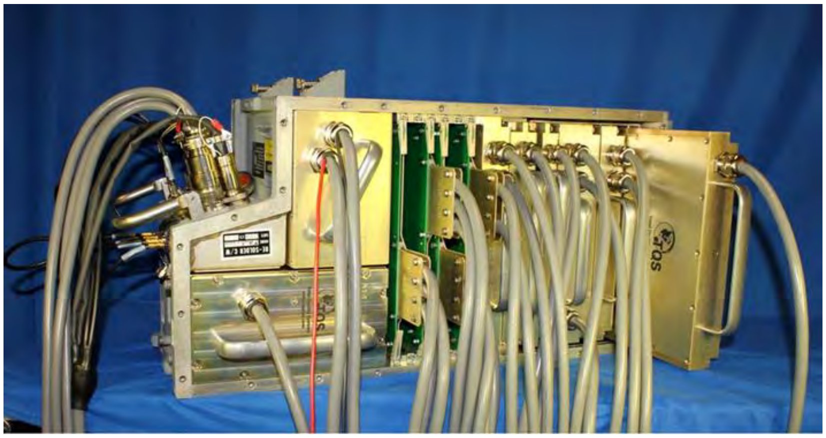


Figure 4. MLPRF with ITA Installed and Ready for Test

2.2.3 U.S. Navy IFDIS Experience

The U.S. Navy F/A-18E/F Generator Converter Unit (GCU), which is the primary aircraft electrical power system, was the second highest WRA degrader in the Navy aircraft inventory. It had high NFF and mission incapable rates. There were no means or equipment to detect intermittence or reduce NFF. The F/A-18 fleet GCU mean time between failure (MTBF) was 140 hours.

In 2011, FRC-SW sent five RFI GCUs to Universal Synaptics for testing, which were ready for aircraft installation. FRC-SW did not share information with regard to the condition of the GCUs prior to testing. Four out of five GCUs failed for intermittent faults. Based on this data, FRC-SW procured an IFDIS to test F/A-18 A-D, E/F GCUs.

In December 2015, Commander Fleet Readiness Centers (COMFRC) briefed the Office of the Secretary of Defense (OSD) on the IFDIS technology and the issues FRC-SW had found with GCU intermittence chassis/backplane/connectors. Based on that meeting, COMFRC made the decision to conduct an IFDIS Technology Demonstration Project:

- Project Intention
  - Gather data to validate that NFF is a significant cause of unidentified and repeated failures in the GCU chassis.
  - Validate IFD technology detects and isolates faults in WRA chassis.
  - Document GCU TOW post-IFDIS test and repair.
  - Simulate IFDIS tested GCU impact on normal fleet operations.
  - Validate the assumption that conventional ATE cannot detect and isolate intermittence.

- Expected Results
  - Detection and isolation of intermittent circuits in GCU chassis; validation of ATE testing GAP for intermittence.
  - Increase the MTBF (TOW increase = Increased Readiness).
  - Decrease in turnaround time (TAT) and man-hours expended at the Intermediate and Depot level by 30%.

- Lessened impact and cost to supply (i.e., erroneous SRA failures due to chassis intermittence).
- Ability to focus on "actual" contributing factors to GCU failure rates outside of chassis intermittence.
- Potential decrease in Intermediate and Depot level inductions (long-term).

➢ Logistics

- Identified 16 randomly selected "M" condition (In-Work – turned over to maintenance for processing) GCUs (GCU upgrade G2/G3 Mix) from Fleet Readiness Center – West (FRC-W), Lemoore for testing and data capture (All of the GCUs had an initial run over the conventional test equipment and were awaiting parts).
- GCUs sent to FRC-SW, San Diego for IFDIS testing/repair/re-test.
- Returned GCUs to FRC-W for the re-build process and gathered data on TAT, man-hours, replaced parts, ATE run time).
- Re-installed original GCU components to simulate Intermediate level repair processes and replaced only those components that failed during final WRA testing to keep pilot costs low.
- Gathered TOW data in a pre-determined Lemoore Super Hornet squadron (Strike Fighter Squadron (VFA-122), GCUs installed as a set, on the aircraft port/starboard sides.
- Supply officer controlled the GCUs for the pilot process.
- Wing updated TOW on a weekly basis.
- Four GCUs were held as spares to keep pilot GCUs in a controlled environment.

➢ Pilot Timeframe

- 6 Months – 1 year (GCU disassembly began 15 December 2015, IFDIS testing began 19 January 2016).
- Upon Reaching 200 hours TOW per GCU.

➢ Results Summary

- Testing validated that the IFD technology accurately detects and isolates faults in WRA chassis.
- Demonstrated there is an intermittence identification and isolation technology GAP resident in the conventional ATE as approximately 69% of GCUs had intermittence issues and in most cases called out an erroneous part that tested good after IFDIS.
- Latest data shows an overall Mean Flight Hours Before Removal (MFHBR) increase of three times.
- Decrease in TAT and man-hours expended at the Intermediate level by approximately 67%. COMFRC realized an unexpected benefit from IFDIS testing. The Aircraft Engines Components Test Set (AECTS) is used to test and troubleshoot GCUs. Lengthy troubleshooting on the test bench has created capacity constraints at both the Intermediate and Depot level repair facilities. Average AECTS test/troubleshooting time without IFDIS testing was 22 hours. After IFDIS testing AECTS test/troubleshooting time was reduced to an average of 7 hours. This was a realized reduction of 15 hours per GCU.

Figures 5 and 6 show the F/A-18E/F GCU with the complete unit with covers on and ATAs installed in test chamber ready for test, respectively.

Figure 5. F/A-18 E/F Generator Converter Unit

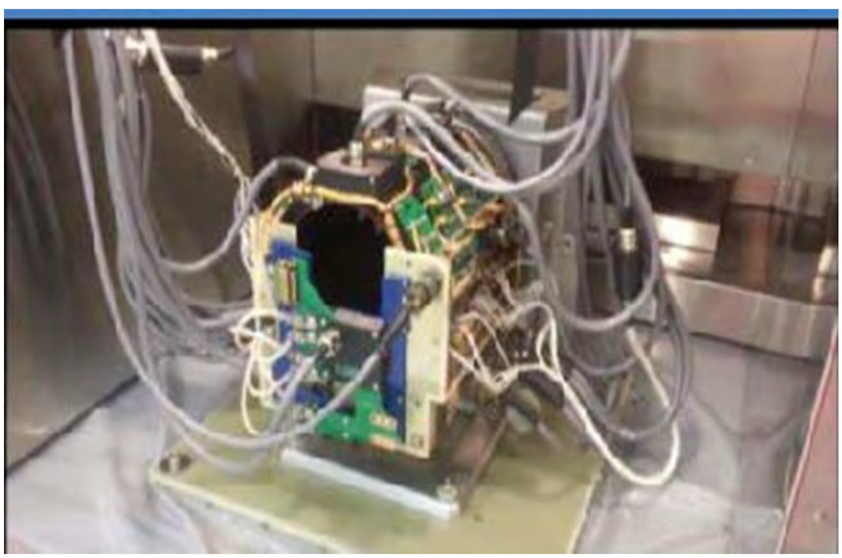


Figure 6. F/A-18 E/F GCU with ITA Installed

2.2.4 VIFD

The VIFD uses the same IFD technology as IFDIS, which tests all LRU/WRA electrical conductive paths simultaneously. VIFD is a portable unit with additional wiring diagnostic capability and without the environmental and vibration test equipment is best suited for the Intermediate or Organizational level maintenance of EWIS and LRU/WRAs. Table 3 shows the features of the VIFD and Figure 7 is a picture of a VIFD with the lid open. See Appendix E for examples of the VIFD demonstrated.

Table 3. VIFD Features

Intermittency	Intermittent faults detected to less than 50 ns on every test point, simultaneously and continuously
Continuity	Programmable continuity checks against referenced values
Log Scope	Instant display of a circuit's or component's stability
Shorts	Two modes providing shorts indication and shorts tracing capability
Analyze	Provides an impedance signature for the LRU/WRA
AutoMap™	Rapid mapping of circuits for complex and/or ad hoc testing
Distance-to-Fault (option)	Integrated Spread-Spectrum TDR locates distance-to-fault to within 1% up to 3650m (approx. 12,000 feet)
Circuit Analyzer (option)	Integrated Huntron 30 technology provides Signature Analysis capabilities

Figure 7. VIFD Example

See Appendix H for VIFD equipment that has been procured and currently deployed within DoD.

3. IFD Capability Implementation Framework and Guidance

This section focuses on a DoD-wide framework to implement the game-changing IFD technologies successfully demonstrated at Navy FRC-SW and Air Force Hill Air Force Base. The framework, developed by a JIT team composed of a variety of stakeholders across the DoD, builds upon previous experiences at both facilities and leverages MIL-PRF-32516 to implement these proven IFD technologies within the military services to perform short duration intermittence testing on aircraft EWIS and LRU/WRA backplanes and chassis across the lifecycle; from initial manufacture to sustainment, across the DoD and at all levels of maintenance (Organizational/Intermediate/Depot). This framework will also leverage the DoD Maintenance Availability Data Warehouse (MADW) to identify target opportunities for IFDIS and VIFD deployment.

3.1 Scope

The purpose of this framework and guidance is to suggest steps that an organization could use to implement IFD and isolation of EWIS and LRUs/WRAs within the DoD. Diagnostic equipment capable of detecting intermittent faults was identified by the JIT team. There has been limited procurement and deployment of IFD equipment. The next step is to educate the DoD agencies in regard to the seriousness of the intermittent fault problem, get their buy-in and procure and deploy IFD equipment across DoD.

3.2 IFD Implementation Framework

The implementation framework is divided into four steps:

- First, build awareness and buy-in within the organization that short duration intermittence is a failure mode that is affecting readiness and efficiency.
- Second, identify IFD opportunities and introduce the IFD solutions.
- Third, acquire and implement the IFD solutions.
- Fourth, validate the results and expand IFD implementation.

3.2.1 Step One: Awareness/Buy-In

Communicate within the organization and build awareness that electronics failures are a leading availability and cost driver. Emphasize that short duration intermittence is a viable failure mode that is DoD recognized. The JIT team, working in support of IFD Technology Center of Excellence and IFD Certification Central Agency, will assist the DoD organization in identifying candidates to be tested by the IFDIS and VIFD technologies and in the development of a communications plan to implement the new technologies.

3.2.1.1 Develop Communication Plan

- Engage OSD and the Military Services senior level leadership to build awareness and gain buy-in.
- Discuss intermittence problem and solution with maintainers, and supply chain personnel in the organizations.
- Discuss problem and solution with engineers in the program management offices.
- Talk to other services/agencies.
- Coordinate with IFD Technology Center of Excellence and IFD Certification Central Agency.

3.2.1.2 Incentivize the Program Management Airs

- Advocate for recognition of short duration intermittence as a viable failure mode.
- Illustrate the magnitude of the problem.
- Educate on available solutions.
- Leverage IFDIS and VIFD.
- Identify training requirements.

3.2.2 Step Two: Identify Opportunities and Introduce IFD Solution

3.2.2.1 Identify Opportunities (Agency and JIT responsibility)

Using available data and tools such as MADW, MICAP, and identification of repeat offenders/bad actors, JIT will support the agency in determining the platforms/EWIS/LRUs/WRAs within the organization where intermittence is creating the greatest impact on equipment availability and costs. Include a top-down approach at the macro level that collectively engages DoD and the owning service to identify the top availability and cost drivers. Leaders should serve as process initiators and assist in providing collaborative resourcing. Additionally, verify the intermittence fault impact with EWIS/LRU/WRA and/or platform manager.

MADW data may be used to identify the EWIS and LRU/WRA candidates by platform. The MADW is a DoD enterprise database system of record that contains maintenance task and materials requisition records across each of the service components (Army, Navy, Air Force, and Marine Corps). The LRU/WRA priority listing will be based on the maintenance cost and LRU/WRA non-availability days (Appendix F).

Guidance is provided in Section 1.3.1 in regard to determining the individual platform intermittent fault problem. It is recognized that each service and platform must assess its individual priorities based on cost, reliability, availability, etc. The above recommendations will be based on the latest MADW data and should be a good starting point for the DoD agencies and platforms program office. DoD agencies and program offices may also decide to use their own maintenance databases and decision-making algorithms to prioritize their maintenance requirements.

The agency should conduct a BCA to determine the potential impact and return-on-investment that could be realized with a capability to determine intermittence faults on the identified components or chassis.

See Appendix F for Intermittent Fault Failure data.

3.2.2.2 Introduce IFD Solution

The JIT team evaluated the continued use of existing fielded conventional test equipment. As discussed in Sections 1.2 and 1.3, this was not considered to be an acceptable option due to the inability of conventional test equipment to detect intermittent faults. The JIT team analyzed the information presented in this document and developed and valuated the below recommended IFD solution implementation process.

3.2.2.3 Recommended IFD Solution Implementation Process

The organization, with JIT assistance, presents and/or demonstrates the potential IFD capability and benefits to the EWIS or LRU/WRA and/or platform manager and gains their support, and to the applicable leadership level to garner support and build advocacy.

Prior to any decision in regard to which technology to apply to resolving aircraft EWIS and LRU/WRA issues, the cognizant engineering authority must do an in-depth analysis of the aircraft failures and their impacts on aircraft readiness. The cognizant engineering authority will need to do a BCA to determine the technological approach and alternative solutions (Appendix B). The analysis should include, but not be limited to:

- Analysis of the nature of EWIS or LRU/WRA failures.
- Quantify the costs: operating and support (O&S) costs; Aviation Depot Level Repairable (AVDLR) costs, maintenance labor, TOW, MTBF, etc.
- Alternatives: status quo, technology approaches, organizational repair level requirements, support equipment requirements, etc.
- Investment costs: non-recurring costs, recurring costs including maintenance of support equipment and obsolescence.
- Analysis of alternatives.

3.2.2.4 IFD Integration by Maintenance Level (Agency responsibility)

Each DoD agency or platform program office must assess the maintenance level of IFD integration. As discussed in Section 1.3.2, IFD equipment is recommended once the service or platform has determined its intermittent fault issues. There are three maintenance levels (Organizational, Intermediate, and Depot) to be considered based on the nature of the intermittent faults, platform and funding availability. Two examples of IFD equipment have been evaluated in numerous case studies (Appendices D and E). In addition, Section 2.1 discusses the capabilities and functions of these two types of IFD equipment. Both versions of the IFD equipment discussed in Section 2.1 use the same IFD technology.

- **Organizational/Intermediate Maintenance Level**
  The VIFD, or equipment with similar capabilities, is recommended. This equipment has the advantage of IFD and portability but is not integrated with environmental and vibration test equipment. As a result, this equipment may be taken to the vehicle platform to diagnose failures but is limited because the operational environmental conditions are not being duplicated to stimulate the intermittent fault. Manual manipulation of EWIS and LRU/WRA connections may be used to stimulate the intermittent fault. Failure to identify the intermittent fault may require EWIS or LRU/WRA removal for further maintenance action. This equipment has the advantage of reduced cost and logistical footprint, but reduced capability of detecting the intermittent fault without environmental/vibration stimulation of the EWIS or LRU/WRA. In addition, this equipment has fewer test points (128, 256, or 512 test points) than the IFDIS recommended for the Depot level maintenance.

- **Depot Maintenance Level**
  The IFDIS, or equivalent IFD equipment, is recommended. This equipment has the advantage of IFD and is integrated with environmental test chamber and vibration test equipment. It is not portable and the EWIS or LRU/WRA must be removed from the platform to diagnose failures. This integrated system has the advantage of being able to simulate the operating environment of the EWIS or LRU/WRA. It has been found as indicated in the case studies included in Appendices D and E that subjecting the EWIS or LRU/WRA to the platform operating environment is a key factor in causing the intermittent failure to re-occur. In addition, this equipment has an increased number of test points (256 to 20,480 test points). This equipment has the disadvantage of increased cost and logistical footprint due to the integration of the combined environmental test chamber (temperature and vibration) equipment but has much increased capability of detecting the intermittent faults.

3.2.3 Step Three: Acquire and Implement the IFD Solutions

3.2.3.1 IFDIS & VIFD Equipment

The organization procures and implements IFDIS and VIFD equipment at Depot and/or Intermediate/Organic maintenance activities where the readiness and return-on-investment impact are the highest. The JIT team will monitor the fleet usage of the IFD technology to determine implementation, training, and installation issues, which may impede the full effectiveness of the technology. The team will report lessons learned to OSD and the Military Services for ways to improve intermittent fault prevention and diagnosis. In addition, the JIT team will recommend test/repair procedures for effectively integrating conventional and IFD equipment. See Appendix H for IFDIS and VIFD equipment that has been procured and currently deployed within the DoD.

3.2.3.2 ITAs

ITAs are used to connect the IFD equipment to the EWIS or LRU/WRA being tested for intermittent faults. New ITAs will be required as new EWIS or LRU/WRA maintenance requirements are identified. The AWTS currently deployed in the DoD services has already developed TPS cables for a variety of EWIS and LRU/WRAs applications. The IFD using an adapter cable is capable of using the AWTS TPS and reducing the requirement for additional ITA development. Using the IFD with the AWTS TPS also has the added benefit of determining any intermittent faults within the AWTS TPS.

3.2.3.3 Resources

Obtain resources needed for appropriate capability demonstrations, and subsequent implementation (if applicable), through the military service(s), agency, or OSD. The following are some of the resources that may be available to assist in the implementation of IFD equipment (see Appendix C for additional information):

- **Capital Investment Program (CIP)**
  CIP is a potential source of funding for acquiring IFD equipment. CIP was established under the DoD Financial Management Regulation for all DoD activities under Defense Business Operations Fund (DBOF).

- **Depot Activation Workload Stand-Up**
  DoD Instruction 5000.02 Operation of the Defense Acquisition System, Para 5.d(14)(b)1. states that "the Program Manager will ensure resources are programmed and necessary IP deliverables and associated license rights, tools, equipment, and facilities are acquired to support each of the levels of maintenance that will provide product support; and will establish necessary organic depot maintenance capability in compliance with statute and the Life Cycle Sustainment Plan (LCSP)".

- **Small Business Technology Transfer (STTR)**
  The Small Business Technology Transfer (STTR) expands funding opportunities in the federal innovation research and development (R&D) arena. Central to the program is expansion of the public/private sector partnership to include the joint venture opportunities for small businesses and nonprofit research institutions. The unique feature of the STTR Program is the requirement for the small business to formally collaborate with a research

institution in Phase I and Phase II. STTR's most important role is to bridge the gap between performance of basic science and commercialization of resulting innovations**.**

Note: The IFDIS procured by both the U.S. Air Force and U.S. Navy were procured under a Phase III SBIR Topic AF01-296. Contact Hill Air Force Base SBIR Office for further information.

- **Commercial Technologies for Maintenance Activities (CTMA) Program**
  Created in 1998, the CTMA Program is a joint effort between the DoD and the National Center for Manufacturing Sciences (NCMS). Its objective is to ensure American troops and their equipment are ready to face any situation, with the most up-to-date and best-maintained platforms and tools available. It provides technology development and insertion in support of reliability and sustainment, and must always benefit the U.S. military, industrial base and the public good.

- **Cooperative Research and Development Agreement (CRADA)**
  A CRADA is an agreement between a federal laboratory and a non-federal party to perform collaborative R&D in any area that is consistent with the federal laboratory's mission. CRADAs are the most frequently used mechanism for formalizing interactions and partnerships between private industry and federal laboratories and the only mechanism for receiving funds from non-federal sources for collaborative work.

3.2.3.4 Train the Workforce

Establish an IFD awareness and training program at the organization and Military Service where the IFD equipment will be utilized.

3.2.3.5 Enterprise Level (OSD and JIT responsibility)

- **JIT Working Integrated Product Team (WIPT)**
  Advise and assist in the implementation of a DoD IFD solution. Actions will include but not be limited to: (1) educate and inform DoD agencies leadership; (2) develop programs to incentivize program managers and maintenance activities; (3) assist DoD agencies and program managers in identifying high cost and readiness drivers; and (4) establish team support within DoD agencies to further the implementation of an intermittent fault technology.

- **Establish the IFD Technology Center of Excellence**
  Work with NSWC Crane (Airborne Electronic Attack Fleet Support Team) to establish a IFG Technology Center of Excellence. The purpose of this Center of Excellence is to review and evaluate new and innovative technologies for detecting and analyzing intermittent faults. This Fleet Support Team (FST) is uniquely suited to becoming the Technology Center of Excellence because of their current responsibilities of supporting airborne electronic attack WRAs installed on EA-6B, EA-18G, and P-8 aircraft. In addition, will evaluate new technologies through participation in recurring Industry Days.

- **Establish the IFD Certification Central Agency**
  Work with NAWCAD Lakehurst to establish an IFD Certification Central Agency. This presents an opportunity for standardization and centralization of DoD IFD policy and practice in a way that would not be feasible for diagnostic systems that detect hard faults. A DoD Joint Intermittent Test Center of Excellence (CoE) will be established. The primary function of the CoE will be to maintain a validated products list of products that have demonstrated the ability to detect Category 1 intermittent faults (see MIL-PRF-32516) in their intended fault environment. The CoE will be capable of testing new technologies to determine if the technologies can, in fact, detect intermittent faults, and how short of a time duration the intermittent fault candidate technology can detect. The CoE director will have decision authority as to which products are added to, or removed from, the Validated Products List. The responsibilities of the IFD Certification Central Agency shall include, but not be limited to: diagnostic equipment validation; participation in Industry Days; updating and developing new test capabilities/procedures; updating test methods as needed; updating the IFE; updating MIL-PRF-32516 and MIL-HDBK-527. In addition, the IFD Certification Central Agency shall ensure compliance to the DoD Automatic Test Systems (ATS) Master Plan including: review of existing ATS and coordination with the ATS Executive Directorate.

3.2.4 Step Four: Validate the Results and Expand IFD Implementation (OSD and JIT responsibility)

Once the IFD solution is implemented, it is important to monitor the results and impact on LRU/WRA availability and costs. These results can be used in efforts to expand IFD implementation across the DoD.

3.2.4.1 Validate the Results

Using MADW, Naval Aviation Active Data Warehouse (DECKPLATE), etc. determine the bad actors, the improvement in reliability and TOW, and ROI (reduced maintenance man-hours and costs) vs. cost investment in IFD (Appendix A). However, validating post testing and repair performance by individual LRU/WRA serial number is a labor-intensive manual process. A statistical method has been developed at Hill Air Force Base to produce an LRU baseline removal rate, and current efforts are underway to analyze 10 years of pre- and post-IFDIS testing and repair data of three F-16 LRUs, the MLPRF, CADC (Central Air Data Computer), and PSP (Programmable Signal Processor). Data from these efforts will be evaluated for their application to validate the results and expand IFD implementation.

3.2.4.2 Expand IFD Implementation and Continue Evaluation of New IFD Technologies

The JIT team, working in support of the IFD Technology Center of Excellence and Certification Central Agency will continue efforts to expand IFD implementation across DoD. Additionally, they will continue to evaluate new IFD technologies. This evaluation will include IFD technologies with the capability to: (1) monitor all EWIS and LRU/WRA chassis conductive paths continuously and simultaneously to detect the intermittent fault which may occur on any conductive path or multiple conductive paths at the same time; and (2) simulate the operating conditions under which the intermittent fault occurs. This review will include industry surveys, Government Industry days such as CTMA, and internet industry research.

4. Conclusion

It is imperative that DoD organizations recognize intermittence faults as a failure mode that is significantly affecting weapon system availability and sustainment costs, and that a capability exists that can be implemented to improve readiness and save billions of dollars each year. However, the implementation of any new capability encounters challenges in the form of resistance to change, requirements determination, procurement costs, and not being aware of the magnitude and impact of the problem. This document is intended to assist DoD organizations in gaining awareness of their intermittence problems, and subsequently implementing this capability to help resolve those problems.

Appendix A – Requirement Identification

A.1 Resources

DoD agencies

A.1.1 NAVAIR DECKPLATE

DECKPLATE is the authoritative Naval Aviation Active Data Warehouse. It is a reporting system, based on the Cognos analysis, query, and reporting tools. It provides report and query capabilities content-equivalent with the current NALDA systems and allows reporting and analysis capability not available with the current systems. The web-based reporting system provides a sound basis for future implementation of emerging Department of the Navy architectural requirements.

It is the next generation data warehouse for aircraft maintenance, flight and usage data. Using Cognos analysis, query and reporting tools the user has the capabilities to effectively obtain readiness data in a near real-time environment, as well as, history data for trend analysis and records reconstruction. It provides on-line management of Technical Directives (TDs) and Kits via the DECKPLATE TD/Kit Management application.

Contact Information:

Commander, Naval Air Systems Command
47123 Buse Road
Building 2272, Suite 540
Patuxent River, MD 20670

A.1.2 Maintenance and Availability Data Warehouse (MADW)

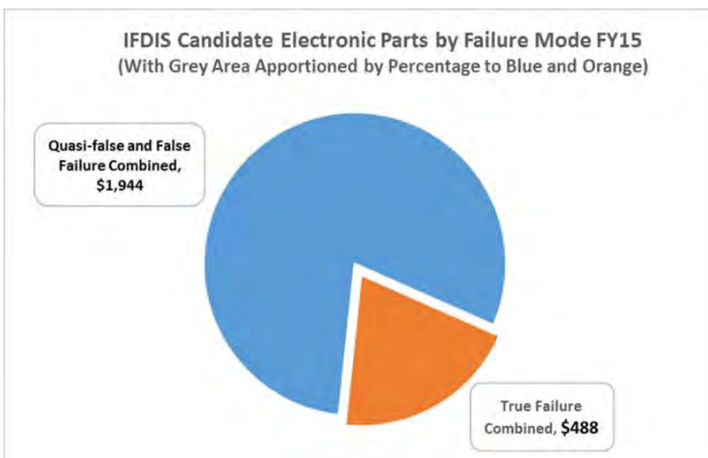
A.1.2.1 MADW Background

- Started in FY2005 as a result of Congressional interest in reducing impact of corrosion on DoD weapons systems, infrastructure and facilities.
- Involves obtaining all maintenance records, costs and non-availability results
- Contains over 1 billion maintenance records – approximately 40 billion data elements. Over 300 million supply and materials purchase records.
- Cost data back to FY04, availability data to FY08.
- Includes value added data elements such as:
    - Object – solved through machine learning.
    - Action – solved through machine learning.
    - Standard work breakdown structure.
    - Reconciled availability and costs in the same record.
    - Preventive/corrective.
    - Parts/structure.
    - Environmental severity.
    - Labor and materials records.

A.1.2.2 MADW Description

The MADW is a DoD enterprise database system of record that contains maintenance task and materials requisition records across each of the service components (Army, Navy, Air Force, Marine Corps). The data warehouse contains all available information on the maintenance cost of repair, equipment availability, and cost per day of availability for DoD equipment. The MADW has a query capability that can be utilized to identify potential target maintenance opportunities where an IFD platform could be implemented to reduce maintenance costs and improve equipment availability significantly.

In the example (Figure A-1), the MADW is used to identify potential IFDIS fault candidates by identifying electronic part failures by their actual failure mode; these faults were broken down into three categories (true failure, false failure, and quasi-false failure). True failures are classified within the MADW as those faults requiring the item be repaired or replaced. False failures describe items that are classified as a failure, but upon further testing, the initial error cannot be duplicated, and the testing determines the item is able to perform as designed. Finally, quasi-false failures denote items that initially tested as failures but when disassembled or cleaned in conjunction with other actions not involving repair or replacement, the item is able to perform as designed. The data was compiled using FY15 as a benchmark and identified over $2.43B of electrical component faults in each of the three categories mentioned above. This analysis attributes $1.9B of the total cost to quasi-false and false-failure items and the remaining $488M as true failure faults.



Failure Mode	Section	Cost (Annual)	Percent
Quasi-false and False Failure	Blue	$1,945	79.9%
True Failure	Orange	$488	20.1%
Total Combined		**$ 2,432 B**	**100%**

Figure A-1. IFD Candidate Electronic Parts by Failure Mode FY15

Utilizing information retrieved from the MADW, "NFF" or "bad actors" represented a significant cost in diagnosis and repair to the aviation community. Figure A-2 represents a data pull from the MADW looking at the cost of those components which were classified as false or quasi-false failures across the Army, Air Force, and Navy for Fiscal Years 2014 through 2016. The "NFF FY14-16" represents the labor and materials costs associated with inspection and replacement of these electrical systems components for aircraft representing a cost over $1.8B.

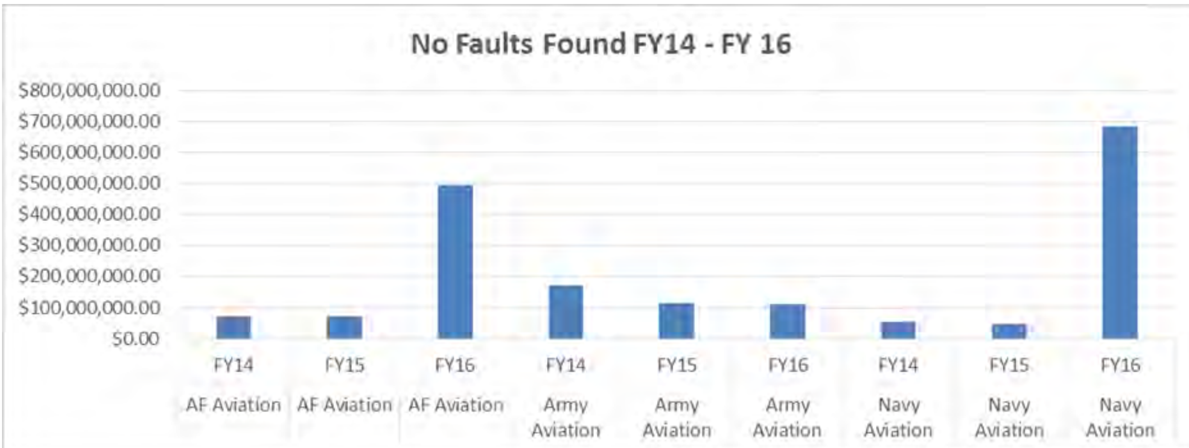


Figure A-2. NFF FY14 – FY16

These figures highlight one area where an IFD could be implemented to pinpoint the exact fault of the equipment. This technology implementation would vastly increase equipment readiness and decrease expenses related to man-hours spent diagnosing problems with antiquated testing equipment that never identifies nor determines the cause of the fault. Putting this technology into practice also presents the opportunity for an enormous costs savings opportunity for the DoD, having the ability to recapture funds that are typically spent year after year replacing parts/systems while never addressing the problem, redistributed and utilized in other crucial maintenance areas is a force multiplier.

Contact Information:

Eric Herzberg, LMI
Eherzberg@lmi.org

Appendix B – Business Case Analysis

B.1 Before any effort to correct a perceived EWIS or LRU/WRA Intermittent Fault NFF problem a BCA will need to be performed to define the following:

- Problem:
  - Analyze failure information and review DoD guidance.
  - Estimate the failure environment and explore trends.
  - Determine warfighting maintenance gaps using input from Fleet advisors.
  - Analyze maintenance data to identify maintenance issues.
  - Perform a technology capability assessment to document the need for a materiel and/or a non-materiel approach, to a specific capability gap. The assessment defines the capability gap in terms of the functional area, the relevant range of military operations, desired effects and time.

Information needed:

- ***How do you get started?***
- ***Formats and examples***
- ***Cost analysis resources within other DoD agencies?***

B.2 Cost Determination

Background information

- Establish baseline tasks for implementing the repair capability.
- Identify cost savings, benefits and AVDLR reductions.
- Identify programmatic impacts on aircraft platforms.
- Identify any repair contracts in-place support.
- Program current costs both in availability and support costs caused by the NFF problem.

B.3 Contact Information

Naval Air Systems Command
AIR-4.2 Cost Group
(732) 323-1049

Appendix C – Resources

C.1 Funding Sources

C.1.1 Capital Investment Program (CIP)

The primary goal of the CIP within the Defense Business Operations Fund (DBOF) is to establish a capability for reinvestment in the infrastructure of business areas to facilitate mid- and long-term cost reductions. The objective is to improve product and service quality and timeliness, reduce costs and foster comparable and competitive business operations. The CIP provides the framework for planning, coordinating, and controlling DBOF resources and expenditures to obtain capital assets.

This policy applies to all activities, or groups of activities, within the Department of the Army, Department of the Navy, Department of the Air Force, or a Defense Agency chartered under the DBOF.

The following requirements must be satisfied to justify CIP funding:

a. Is more economically feasible to purchase than to lease.

b. Meets the Activity's long-range planning and programming objectives as identified in long-range strategic plans.

c. Results in satisfying a documented need that cannot be met as effectively and efficiently by existing equipment and facilities.

d. Complies with DoD Directive 4275.5, "Acquisition and Management of Industrial Resources" and DoD Directive 4270.4, "Unspecified Minor Construction, Emergency Construction, and Restoration of Damaged or Destroyed Facilities, "as well as, other applicable policies and regulations governing the lease and acquisition of equipment and facilities.

e. Includes workload projections that take into account the results of inter-service decisions, workload posture planning decisions, readily available commercial alternatives, and other reasonable options for accomplishing workload.

f. Accomplishes the objective for which the capital asset is justified. The criteria should include, but are not limited to, improved efficiency (savings) or effectiveness; required new capability and capacity that cannot be met with current equipment or facilities; replacement of unsafe, beyond economical repair, or inoperative and unusable capital assets; and mandated environmental, hazard waste reduction, or regulatory agency (state, local or federal) requirements.

g. Meets or exceeds the DoD capitalization criteria.

h. Includes, as appropriate, a pre-investment cost or economic analysis that identifies the reasons and associated expected benefits of the purchase in accordance with the requirements at Paragraph F[4] for an analysis for DBOF capital investments. An economic

[4] DoD Financial Management Regulations, Vol 11B, Chapter 58, December 1994.

analysis must be completed prior to requesting a capital asset be included (1) in the Office of the Secretary of Defense (OSD) budget submission, (2) in the President's Budget submission, or (3) in any request for substitution or reprogramming involving a capital project.

C.1.1.1 Policy

a. Managers at DBOF activities shall identify, prioritize, justify, and budget for capital asset purchases.

b. The capital investment program shall be carried out within the guidelines established by public law, DoD policies, and other regulatory constraints.

c. Only those capital investment projects that have been included in a President's budget for the DoD Component may be financed through the CIP except that, under certain circumstances, as prescribed in Paragraph C.5[5]., during the year of execution, substitutions may be made for projects when operational necessity warrants.

d. The CIP shall not be used to establish an in-house capability for operations that are more economically available through commercial contract except as permitted under OMB Circular A-76, "Performance of Commercial Activities."

e. All capital assets developed, manufactured or otherwise procured by an activity for use of that activity shall be funded through the DBOF capital budget, except those capital assets identified in Paragraph D.5[6].

f. DBOF reimbursement rates shall include an amount estimated, considering the expected workload, to be sufficient to fund the approved CIP.

g. Projects that meet the DoD investment capitalization threshold, both as to cost and useful life, must be:

   (1) Capitalized and depreciated.
   (2) Funded as part of the capital budget.
   (3) Accommodated within approved capital budget authority limits.

h. Projects that meet the DoD investment capitalization threshold also reduce the available capital budget authority.

i. Projects that fail to meet the DoD investment capitalization threshold shall be funded as an operating expense.

j. Each DoD Component will develop procedures to ensure that:

   (1) Capital investment funds are used only for approved projects.
   (2) Every attempt is made to effect timely installation and to realize productivity improvements estimated in budget submissions.

5 Ibid.
6 Ibid.

k. Management improvement initiatives shall be expensed as provided in Chapter 62, Paragraph E.2[7] unless specifically directed otherwise by the Under Secretary of Defense (Comptroller).

C.1.2 Depot Activation Workload Stand-Up

Service-level requirements and guidance on depot activation and/or depot capability establishment are available in some of the following resources:

- Army Regulation 700-127 Integrated Product Support and DA Pam 700-127 Integrated Product Support Procedures discuss the requirement for a Depot Maintenance Support Plan (DMSP), a Depot Source of Repair (DSOR) decision, and a Core Logistics Assessment (CLA). AR 700-127, Para 8-9 specifically tasks Materiel Developers (MATDEVs) will develop a DMSP prior to MS C to ensure core depot capability is properly planned and implemented. DA Pam 700-127 Integrated Product Support Procedures, Para 8-9 provides detailed information about the Army DMSP, as well as how it is developed and what it must contain.
- Air Force Materiel Command (AFMC) Instruction 21-101 Depot Maintenance Activation Planning provides detailed information on depot activation, including the requirement for an Air Force Depot Maintenance Activation Plan (DMAP), and the Program Manager (PM), Product Support Manager (PSM), and Product Support Integrator (PSI) responsibilities. It also provides detailed information about and Air Force requirements for a Depot Maintenance Activation Working Group (DMAWG).
- Naval Air Systems Command (NAVAIR) Standard Work Package (SWP) 6.7.3-103 "Depot Capability Planning" outlines standardized procedures for Depot-level capability planning, which includes both public and private maintenance facilities. NAVAIR SWP 6.7.3-104 "Depot Capability Establishment" also dated 22 May 2014 "provides Maintenance Program Coordinators (MPCs) with standardized procedures for developing and establishing Depot-level capability, which includes both public and private maintenance facilities for Naval Aviation weapons systems. The capability establishment process is a systematic approach for translation of Depot-level maintenance requirements into established capabilities." In addition, SWP 6100-001 "Establishment of Fleet Readiness Center Depot Level Repair Capability" provides standardized processes and procedures for developing and establishing Depot-level repair capability.

C.1.3 Small Business Technology Transfer (STTR) Program

C.1.3.1 STTR Mission and Program Goals

The mission of the STTR Program is to support scientific excellence and technological innovation through the investment of federal research funds in critical American priorities to build a strong national economy.

[7] Ibid, Chapter 62.

The Program's goals are to:

- Stimulate technological innovation.
- Foster technology transfer through cooperative R&D between small businesses and research institutions.
- Increase private sector commercialization of innovations derived from federal R&D.

C.1.3.1.1 STTR Participating Agencies

Each year, federal agencies with extramural R&D budgets that exceed $1B are required to reserve 0.45% of the extramural research budget for STTR awards to small businesses. These agencies designate R&D topics and accept proposals. Currently, five agencies participate in the STTR Program:

- Department of Defense
- Department of Energy
- Department of Health and Human Services
- National Aeronautics and Space Administration
- National Science Foundation

Each agency administers its own individual program within guidelines established by Congress. These agencies designate R&D topics in their solicitations and accept proposals from small businesses. Awards are made on a competitive basis after proposal evaluation.

C.1.3.1.2 Three-Phase Program

The STTR Program is structured in three phases:

- Phase I. The objective of Phase I is to establish the technical merit, feasibility, and commercial potential of the proposed R/R&D efforts and to determine the quality of performance of the small businesses prior to providing further federal support in Phase II. STTR Phase I awards normally do not exceed $150K total costs for 1 year.

- Phase II. The objective of Phase II is to continue the R/R&D efforts initiated in Phase I. Funding is based on the results achieved in Phase I and the scientific and technical merit and commercial potential of the Phase II project proposed. Only Phase I awardees are eligible for a Phase II award. STTR Phase II awards normally do not exceed $1M total costs for 2 years.

- Phase III. The objective of Phase III, where appropriate, is for the small business to pursue commercialization objectives resulting from the Phase I/II R/R&D activities. The STTR Program does not fund Phase III. In some federal agencies, Phase III may involve follow-on non-STTR funded R&D or production contracts for products, processes or services intended for use by the U.S. Government.

C.1.3.1.3 Dollar Amount of Awards Adjusted for Inflation

As stated in the STTR Policy Directive Section 7(j)(2), SBA will adjust the dollar amount of awards for inflation. For FY18, a Phase I award (including modifications) may not exceed $163,952 and a Phase II award (including modifications) may not exceed $1,093,015. Agencies may issue an award exceeding these award guideline amounts by no more than 50%. The adjusted guidelines are effective for all solicitations issued on or after the date of the adjustment and may be used by agencies to amend the solicitation and other program literature. Agencies have the discretion to issue awards for less than the guidelines.

C.1.3.1.4 Competitive Opportunity for Small Business

STTR is a highly competitive program that reserves a percentage of federal R&D funding for awards to small businesses and U.S. nonprofit research institutions. Small business has long been where innovation and innovators thrive. But the risk and expense of conducting R&D can be beyond the means of many small businesses. Conversely, nonprofit research laboratories are instrumental in developing high-tech innovations. But frequently, innovation advances theory, rather than the development of innovative practical applications. STTR combines the strengths of both entities by introducing entrepreneurial skills to high-tech research efforts. The technologies and products are transferred from the laboratory to the marketplace. The small business profits from the commercialization, which, in turn, stimulates the U.S. economy.

C.1.4 CTMA Program

C.1.4.1 Background

The Commercial Technologies for Maintenance Activities (CTMA) Program focuses on defense maintenance, sustainment and logistics. Created in 1998, CTMA is a joint effort between the DoD and the National Center for Manufacturing Sciences (NCMS). Its objective is to ensure American troops and their equipment are ready to face any situation, with the most up-to-date and best-maintained platforms and tools available. It provides technology development and insertion in support of the reliability and sustainment and must always benefit the U.S. military, industrial base and the public good.

CTMA offers a unique contracting vehicle for industry, academia and the DoD sustainment community to work in collaboration to promote technology development, demonstration, and transition new and innovative technologies which enhance warfighter readiness at best cost. It functions through a Cooperative Agreement (CA), which is the legal agreement to conduct R&D that is mutually beneficial for all. The current CTMA Program expires in 2020. The CA offers significant, proven advantages for industry and DoD:

- Enables partners to provide and share personnel, services, facilities, equipment, and other resources in conducting R&D, reducing costs, optimizing resources.
- Improves access to DoD facilities and equipment.
- Streamlines contracting and cost accounting.
- Reduces time between innovation and commercial production.
- Opportunity to enhance DoD readiness while reaching corporate objectives.
- Provides a means of sharing technical expertise, ideas, and information in a protected intellectual property (IP) environment, with non-government partners retaining IP rights.
- DoD maintenance activities have needs and requirements which are potentially solved by innovations created by industry.

C.1.4.2 How it Works?

- NCMS holds an unparalleled contracting vehicle to demonstrate commercial technologies prior to DoD acquisition.

- Companies with innovative solutions join NCMS and leverage CTMA to maximize their investment in technology. The CTMA team learns company goals, strategies, and capabilities. This collaboration guides companies and DoD to secure commercially available technology solutions.
- The CTMA team is experienced, respected, and connected to the DoD maintenance community and industry. This collaboration streamlines the validation and demonstration of requested technologies.
- NCMS quickly develops project teams connecting DoD with industry providers, integrators, and users.

C.1.4.3 Contact Information

Website: www.ncms.org/ctma/

Debra Lilu
Director, CTMA
debral@ncms.org

C.1.5 Cooperative Research and Development Agreement (CRADA)

C.1.5.1 Background

A CRADA is an agreement between a federal laboratory and a non-federal party to perform collaborative R&D in any area that is consistent with the federal laboratory's mission. CRADAs are the most frequently used mechanism for formalizing interactions and partnerships between private industry and the federal laboratory and the only mechanism for receiving funds from non-federal sources for collaborative work.

Under the statute that authorizes CRADAs (15 U.S.C. 3710a), a federal laboratory may provide personnel, services, facilities, and equipment, but no funds, to the joint R&D effort. A non-federal party may provide funds, in addition to personnel, services, facilities, and equipment to the joint R&D effort.

A CRADA defines the tasks to be done within an area of collaboration and grants the government a government-purpose license and the non-federal party a non-exclusive, paid-up, royalty-free license for internal use of any patents that result from the CRADA research. The non-federal party is also granted an option to negotiate either an exclusive or nonexclusive commercial license within a field of use, subject to government-purpose rights. The CRADA also provides protection of proprietary information.

C.1.5.2 How is a CRADA Initiated?

In coordination with the technical representative from agency, contact the Agency Technology Transfer Office to execute a Non-Disclosure Agreement (NDA) to protect any existing IP. Once the NDA is in place, the requesting technical representative from Agency Technology Transfer Office should submit a work statement, highlighting any anticipated collaboration, to Agency's Office of General Counsel. If a CRADA is identified as the appropriate vehicle for the effort and approval to proceed with a CRADA is obtained, the technical representatives from Agency and the non-federal party complete the CRADA Questionnaire.

C.1.5.3 How long does it take to put a CRADA in place?

On average, the CRADA process – from receipt of a completed CRADA Questionnaire to the execution of the CRADA – takes three months but can vary considerably. Additional time may be required for more complex CRADAs, such as those with foreign entities, or with companies using SBIR or STTR funding, both of which require additional approvals.

C.1.5.4 Can an Agency enter into a CRADA with a foreign entity?

Yes. However, proposed CRADAs with foreign entities are subject to review and approval by Director of Research (DOR) prior to CRADA negotiations. An export license may be required depending on the technology. The Principal Investigator (PI) is responsible for determining whether the technology is on the Export Control List and for obtaining approval from the DOR.

C.1.5.5 Can a small business use SBIR or STTR funding to pay for Agency work under a CRADA?

Under the February 2014 SBIR Policy Update, an Agency can use SBIR and STTR funding to pay for its work under a CRADA. However, there are Agency publication and data rights implications for utilizing this type of funding. Please contact the NRL Technology Transfer Office for additional information.

C1.5.6 Other considerations

Preference must be given to business units located, and that agree to manufacture substantially, in the U.S.

C.1.6 Agency/Program Office Funding

If the funding as described in this Appendix is not available, the particular DoD Agency/Program Office should research available funding sources within their activity. Questions to ask in determining a funding source should include:

- **Process for requesting and getting approval?**
- **Purpose of funding?**
- **Time cycle (Request through final approval)?**
- **Restrictions related to use?**

Appendix D – IFDIS™ Case Studies

The following case studies are examples how the IFDIS has been demonstrated on various military and commercial applications:

F-16 Modular Low Power Radio Frequency Unit (MLPRF) (see Section 2.2.2)
F/A-18 Generator Convertor Unit (GCU) (see Section 2.2.3)

EA-6B Audio Intercommunication System (AIC-45)

A Technology Demonstration Project of IFDIS diagnostics capability has taken place with the cooperation and support of the NAVAIR Fleet Readiness Center Southeast (FRC-SE). An EA-6B Audio Intercommunication System (AIC-45) was selected as the test candidate.

Conventional test equipment has been unable to identify intermittent issues or improve AIC-45 availability.

Results: IFDIS testing found intermittent circuits which had previously gone undetected utilizing conventional ATE in 83% of the AIC-45s.

Royal Air Force (RAF) – CH-47 Chinook Helicopter

A Technology Demonstration Project of VIFD diagnostics capability has taken place with the cooperation and support of the United Kingdom, Ministry of Defense and Royal Air Force. CH-47 Chinook high NFF wiring harnesses were selected as the test candidates.

Conventional test equipment has been unable to identify intermittent issues or improve these high NFF wiring harness issues, reduce NFF or improve availability.

Results: VIFD testing is detecting and isolating intermittent wiring issues that cause NFF. These intermittent issues had previously gone undetected utilizing conventional ATE and continuity testers.

Boeing 757 – Auxiliary Power Unit/Engine Controller Unit (APU/ECU)

A Technology Demonstration Project of IFDIS diagnostics capability has taken place with the cooperation and support of one of the world's largest commercial freight and shipping companies. A Boeing 757 Auxiliary Power Unit/Engine Controller Unit (APU/ECU) was selected as the test candidate.

Conventional test equipment has been unable to identify intermittent issues, reduce NFF, reduce Aircraft on Ground (AOG) or improve dispatch reliability and APU/ECU availability.

Results: IFDIS testing detected and isolated nine intermittent circuits in the APU/ECU. The APU/ECU selected for IFDIS testing had been returned "Fully Serviceable" from the OEM prior to IFDIS testing. Since IFDIS testing the APU/ECU has remained on-wing without a single removal and accumulated 10,000 consecutive operational flight hours and growing.

F-16 AN/APG-68 Radar System Antenna Azimuth Elevation (AZ/EL)
Shop Replaceable Unit (SRU)

Background:

- Grounding F-16s
- Current testing methods and equipment unable to identify defects
- Non-reparable item
- Purchase price $1,600.00 each
- IFDIS testing required for GO/NO GO testing

<u>Results</u> from IFDIS testing:

- 95 AZ/EL SRU ribbon cables IFDIS tested:
- 76% tested bad and given a NO/GO for use on F-16 aircraft

Benefits:

- IFDIS is effectively identifying good and bad cables so that good cables are not unnecessarily discarded, and bad cables are not put into F-16 aircraft.
- IFDIS testing of AZ/EL ribbon cables saved the U.S. Air Force over $35,000.00 in just six weeks!

Investment/Cost: $20K

F-16 AN/APG-68 Radar System Antenna

Background:

- High MICAP rates
- Conventional ATE unable to diagnose intermittent/NFF issues, improve reliability or lower MICAP rates

<u>Results</u> from IFDIS testing:

- IFDIS testing quickly identified electronic defects and intermittent faults

NAWCAD Lakehurst Acquisitions

F/A-18 GCU/WRA

- 1 – IFDIS at Naval Air Station Oceana
- 1 – IFDIS at FRC-West Lemoore

ITAs

- APG65
- APG73
- APN194 Altimeter
- APN171 Altimeter

NSWC Crane Division

- 1 – IFDIS and 1 – VIFD
- ITAs: Entire AEA avionics suite (eight WRAs)

Appendix E – VIFD™ Case Studies

The following case studies are examples how the VIFD has been demonstrated on various military and commercial applications:

F-15 Operational Base
Tornado GR4 Fighter Aircraft

The Tornado is the United Kingdom's leading ground attack aircraft. It has been constantly deployed on operations in recent years. The VIFD has been used on two Tornado projects: an industry demonstration project and a fault investigation project.

The nose-wheel steering system is susceptible to intermittent faults that are difficult to diagnose during flight line maintenance, which often leads to speculative replacement of other components. A 2009 pilot project was conducted which successfully demonstrated the ability of the VIFD to detect hard and intermittent faults that conventional equipment was unable to detect. Unserviceable harnesses were confirmed to have intermittency and continuity faults; brand-new harnesses were confirmed as being both intermittency-free and continuity fault-free; and life-expired harnesses were found with intermittent faults even though they passed continuity testing.

In another example, one specific Tornado aircraft had suffered an intermittent fault within the secondary power system since 2006. An analysis of the fault-maintenance history was conducted, along with an IFD of the system. As most of the system LRUs had already been replaced it was agreed that the condition of the wiring should be tested.

Results: The system's wiring integrity was tested with a VIFD and this found that 12% of the cables tested had intermittency/noise/continuity issues.

These cables were repaired by the Royal Air Force (RAF) and then re-tested the system wiring with the VIFD, which confirmed that the system's wiring integrity had been fully restored. Once the aircraft was rebuilt for flight testing it transpired that the intermittent fault's symptoms were unchanged, enabling the RAF to now rule both the LRUs and the wiring out of the diagnosis. An external influence was suspected, and this was traced to a faulty circuit-breaker, which was outside the scope of the wiring tested by the VIFD. Since the circuit breaker was replaced, the fault has not recurred. Overall, the intermittent fault analysis and VIFD testing vastly accelerated the timeframe for isolating the fault, hence a NFF which had persisted for years was ultimately resolved in a matter of weeks.

Helicopter Radio Backplane

A transmitter/receiver LRU from a helicopter radio system, as used in several United Kingdom military helicopter fleets, suffers significant levels of NFF.

Analysis of the design resulted in the decision to focus on testing the ribbon-cable backplane, owing to the fact that this type of component is chronically susceptible to intermittent faults.

Results: The ribbon-cables were tested using the portable VIFD and it was quickly discovered that the vast majority of the ribbon-cables yielded intermittent faults, even though they had been removed from LRUs that were passing in-depth conventional ATE testing.

The faults detected were easily repairable, with further VIFD testing confirming that their full system integrity had been restored.

Sentinel R1 Airborne Stand-Off Radar (ASTOR)

The ASTOR, in the pretext of the Sentinel R1 aircraft, provides long-range, battlefield-intelligence, target-imaging and tracking radar for the RAF and the Army and has surveillance applications in peacetime, wartime and in crisis operations.

The Sentinel fleet has been on active operational service over the last two years and the need to maintain the capability of its mission sensors is paramount.

Results: Using the portable VIFD a technical demonstration project was conducted to test system cable harnesses in order to characterize and trend their integrity and their effect on system availability.

EA-6B AN/*AIC-45*, Intercommunication System
Weapon Replaceable Assembly (WRA)

Background:

- High NFF rate
- High Mission Incapable (MICAP) rate
- No means or equipment capable of detecting intermittent/NFF

Results from VIFD testing:

- 71% of the AIC-45s tested had one or more intermittent circuit that went undetected using conventional ATE

Boeing 757 Auxiliary Power Unit/Engine Controller Unit (APU/ECU)

A Technology Demonstration Project of VIFD capability was conducted with the cooperation and support of one of the world's largest commercial freight and shipping companies. A Boeing 757 APU/ECU was selected as the test candidate. Conventional test equipment has been unable to identify intermittent issues, reduce NFF, reduce AOG or improve dispatch reliability and APU/ECU availability.

Results from VIFD testing: Testing detected and isolated nine intermittent circuits in the APU/ECU. The APU/ECU selected for VIFD testing had been returned "Fully Serviceable" from the OEM prior to VIFD testing. Since VIFD testing the APU/ECU has remained on wing for 255 consecutive days with 2,295 consecutive operational hours and growing.

Sikorsky S-92 Radio Altimeter System – Fault Detection Project

Bristow Helicopters Ltd provide the United Kingdom's Search and Rescue (SAR) helicopter service on behalf of HM Coastguard, using a modern fleet of Sikorsky S-92 and Agusta Westland AW189 helicopters. Following an investigation into a recurring Radio Altimeter fault on one of its S-92s, Bristow decided that – given the vital nature of the SAR role – the standard repair methods being used were not getting to the root cause of the problem quickly enough and that they needed to use a new, innovative approach to achieve a speedy conclusion.

The full Radio Altimeter system's wiring and interconnects was investigated to find out if they contained the cause of the problem.

Results from VIFD testing: The Voyager rapidly detected and located an intermittent fault in part of the system cabling. It had not been possible to detect that fault with the conventional testing and investigation methods used previously.

Spanish Air Force Eurofighter

Indra Systems had been investigating problems with undercarriage wiring on Spanish Air Force Eurofighter. A simple rig on a Mobile Vibration System was used to mount the wiring harnesses in a representative orientation before carrying out IFD testing of the harnesses using a VIFD, while applying vibration stimulus at the same time.

Results: The VIFD testing immediately detected a variety of fault types – including intermittent faults, shorts and high resistances. The wiring faults were found straight away, especially when simulated shocks were applied by the Mobile Vibration System. Note that all of the problems found using the VIFD had previously been undetected by conventional testing means.

Tornado GR4 Aircraft

VIFD testing was applied very successfully on Tornado GR4 aircraft systems in the two projects described below:

Tornado GR4 – Nose Wheel Steering Wiring
The nose-wheel steering system is susceptible to intermittent faults that are difficult to diagnose during flight line maintenance, which often leads to speculative replacement of other components.

Results: A 2009 pilot project was conducted which successfully demonstrated the ability of the VIFD™ to detect hard and intermittent faults that conventional equipment was unable to detect. Unserviceable harnesses were confirmed to have intermittency and continuity faults; brand-new harnesses were confirmed as being both intermittency-free and continuity fault-free; and life-expired harnesses were found with intermittent faults even though they passed continuity testing.

Tornado GR4 – Secondary Power System: the 5-year intermittent fault
In another example, one specific Tornado aircraft had suffered an intermittent fault within the secondary power system since 2006.

An analysis of the fault-maintenance history was conducted, along with an IFD of the system. As most of the system LRUs had already been replaced it was agreed that the condition of the wiring should be tested.

Results: The system's wiring integrity was tested with a VIFD and this found that 12% of the cables tested had intermittency/noise/continuity issues.

These cables were repaired by the RAF and then the system wiring was re-tested, which confirmed that the system's wiring integrity had been fully restored. Once the aircraft was rebuilt for flight testing it transpired that the intermittent fault's symptoms were unchanged, enabling the RAF to now rule both the LRUs and the wiring out of the diagnosis. An external influence was suspected, and this was traced to a faulty circuit-breaker, which was outside the scope of the wiring tested by the VIFD. The circuit breaker was VIFD tested which immediately confirmed that it was highly intermittent – once it had been replaced the fault did not recur.

RAF Sentinel R1 – IFD Testing

The ASTOR system in the guise of the Sentinel R1 aircraft, provides long-range, battlefield-intelligence, target-imaging and tracking radar for the RAF and the Army and has surveillance applications in peacetime, wartime and in crisis operations. The Sentinel fleet has been on active operational service for several years now and the need to maintain the capability of its mission sensors is paramount.

Results from VIFD testing: Using VIFD testers it was successfully tested performance-critical systems EWIS components and wiring. VIFD testing rapidly detected hard and intermittent faults that had not been detected by conventional means, as well as characterizing and trending their integrity and their effect on system availability.

Business Jet Contactor

This contactor was causing problems because they were being rejected for repair but then passed ATE testing, making them NFF items.

VIFD test equipment was able to rapidly set-up to carry out IFD testing. VIFD testing was used for intermittency testing with the contactor in the open and closed configurations, for stability testing with the Log Scope function, and for Continuity to confirm the correct sense of operation.

Results: The testing conclusively detected intermittency and instability on a specific line in the contactor circuit, which the client is now investigating. The test set-up and testing were completed within a day and can now be repeated for rapid and standardized testing of multiple relays.

Helicopter Radio Backplane

A transmitter/receiver LRU from a helicopter radio system, as used in several United Kingdom military helicopter fleets, suffers significant levels of NFF.

Analysis of the design resulted in the decision to focus on testing the ribbon-cable backplane, fitted to the VIFD ITA, owing to the fact that this type of component is chronically susceptible to intermittent faults.

Results: The ribbon-cables were tested using VIFD IFD and integrity testing portable equipment and it was quickly discovered that the vast majority of the ribbon-cables contained intermittent faults and continuity faults, even though they had been removed from LRUs that were passing Depth ATE testing.

Appendix F – Intermittent Fault Failure Data by NIIN and DoD Service

F.1 Background. This appendix details the results of data analysis using MADW. The purpose of the analysis was to identify the top 10 false/quasi-false intermittent LRUs/WRAs for each service that would be candidates for IFD. The analysis excluded any LRU/WRAs which were repaired under a PBL (Performance-Based Logistics) contract. Critical safety items were identified in the list. The discriminators used in the analysis were: cost, availability and cost per day of availability. Used all EI (Engineering Investigation) codes. FY14 and FY15 data was used to conduct the analysis.

F.2 Data by LRU/WRA. The following data is identified by the LRU/WRA, vehicle platform and includes a Table of LRU/WRAs for each DoD service (Tables F-1 – F-3). The intent of the data included in the tables is to identify LRU/WRAs which are potential candidates for IFD because of the LRU/WRA criticality, maintenance cost and non-availability days.

Table F-1. Air Force Aviation LRU/WRAs by Object and Platform

Object	TMS	Maintenance Cost	Non-Available Days
DATA DISPLAY UNIT	F-16C	$48,293,131	51
TARGET ACQUISITION SYSTEM	F-16C	$44,843,636	124
IFF SYSTEM	F-16C	$25,614,521	38
NAVIGATION SYSTEM	F-16C	$14,310,433	42
NAVIGATION SYSTEM	C-130H	$12,402,740	26
INDICATING, ORDER AND METERING	KC-135R	$11,324,172	9
DATA DISPLAY UNIT	MQ-9A	$10,377,094	2
TARGET ACQUISITION SYSTEM	A-10C	$9,299,788	27
WIRING	C-17A	$9,297,600	4
RADAR WARNING SYSTEM	F-15E	$8,548,591	2

Table F-2. Army Aviation LRU/WRAs by Object and Platform

Object	TMS	Maintenance Cost	Non-Available Days
TACTICAL COMPUTER SYSTEM	TACTICAL COMPUTER SYSTEM	$15,944,609	0
NAVIGATION SYSTEM	AN/PSN-13	$6,624,699	0
TERMINAL	AN/TRC-190	$3,514,108	0
WIRING	AH-64D	$3,368,569	10
DIGITAL MESSAGE DEVICE	M1126	$3,360,444	45
INDICATING, ORDER AND METERING	UH-60A	$3,262,683	1
INDICATING, ORDER AND METERING	UH-60L	$3,173,241	2
WIRING	CH-47F	$2,729,370	12
WIRING	UH-60A	$2,687,845	1
WIRING	UH-60L	$2,619,259	3

Table F-3. Navy/Marine Aviation LRU/WRAs by Object and Platform

Object	TMS	Maintenance Cost	Non-Available Days
WIRING	MV-22B	$10,801,664	29
SENSOR	MV-22B	$8,814,719	13
WIRING	CH-53E	$5,406,004	17
TACTICAL COMPUTER SYSTEM	EA-6B	$5,200,996	0.1
WIRING	MH-60S	$4,610,958	15
AUTOMATIC FLIGHT CONTROL	MV-22B	$4,500,882	11
WIRING	MH-53E	$4,318,925	13
SENSOR	T-45C	$3,872,187	18
WIRING	AH-1W	$3,644,375	15
SENSOR	T-45A	$3,153,361	15

Appendix G – Acronyms and Abbreviations

AEA	Airborne Electronic Attack
AECTS	Aircraft Engines Components Test Set
AFLCMC	Air Force Life Cycle Management Center
AFMC	Air Force Materiel Command
AOG	Aircraft on Ground
ASTOR	Airborne Stand-Off Radar
ATE	Automatic Test Equipment
ATS	Automatic Test Systems
AVDLR	Aviation Depot Level Repairable
ATE	Automatic Test Equipment
AWTS	Automatic Wire Test Set
BCA	Business Case Analysis
BCM	Beyond Capability of Maintenance
CA	Cooperative Agreement
CADC	Central Air Data Computer
CBM+	Condition-Based Maintenance Plus
CIP	Capital Improvement Program
CLA	Core Logistics Assessment
CND	Cannot Duplicate
CoE	Center of Excellence
COMFRC	Commander Fleet Readiness Centers
CRADA	Cooperative Research and Development Agreement
CTMA	Commercial Technologies for Maintenance Activities
DASD(MR)	Deputy Assistant Secretary of Defense Materiel Readiness
DBOF	Defense Business Operations Fund
DCR	Disassemble-Clean-Reassemble
DECKPLATE	Decision Knowledge Programming for Logistics Analysis and Technical Evaluation
DMAP	Depot Maintenance Activation Plan
DMAWG	Depot Maintenance Activation Working Group
DMSP	Depot Maintenance Support Plan
DoD	Department of Defense
DoR	Director of Research
DSOR	Depot Source of Repair
EWIS	Electrical Wiring Interconnect System
FACT	Flexible Automatic Circuit Tester
FIPs	Fault Isolation Procedures
FRC-SE	Fleet Readiness Center Southeast
FRC-SW	Fleet Readiness Center Southwest
FRC-W	Fleet Readiness Center West
FST	Fleet Support Team
GAO	Government Accountability Office
GCU	Generator Converter Unit
IAH	Interface Adaptor Harness
IFD	Intermittent Fault Detection
IFDIS™	Intermittent Fault Detection & Isolation System™
IFE	Intermittent Fault Emulator
IP	Intellectual Property

ITA	Interface Test Adapter
JIT	Joint Intermittence Test
LCSP	Life Cycle Sustainment Plan
LRU	Line Replaceable Unit
LVDTs	Linear Variable Differential Transformers
MADW	Maintenance and Availability Data Warehouse
MATDEVs	Material Developers
MFHBR	Mean Flight Hours Before Removal
MICAP	Mission Impaired Capability Awaiting Parts
MTBF	Mean Time Between Failure
MLPRF	Modular Low Power Radio Frequency
MPCs	Maintenance Program Coordinators
NAVAIR	Naval Air Systems Command
NAWCAD	Naval Air Warfare Center Aircraft Division
NCMS	National Center for Manufacturing Sciences
NDA	Non-Disclosure Agreement
NFF	No Fault Found
NIIN	National Item Identification Number
NSWC	Naval Surface Warfare Center
NTF	No Trouble Found
O&S	Operations & Support
OEM	Original Equipment Manufacturer
OSD	Office of the Secretary of Defense
PBL	Performance-Based Logistics
PI	Principal Investigator
PM	Program Manager
PSI	Product Support Integrator
PSM	Product Support Manager
PSP	Programmable Signal Processor
R&D	Research and Development
RAF	Royal Air Force
RETOK	Retest OK
RFI	Request for Information
SAR	Search and Rescue
SBIR	Small Business Innovative Research
SRA	Subassembly Replaceable Assembly
SRU	Shop Replaceable Unit
STTR	Small Business Technology Transfer
SWP	Standard Work Package
TAT	Turnaround Time
TD	Technical Directive
TMS	Type/Model/Series
TOW	Time-on-Wing
TPS	Test Program Set
UDRI	University of Dayton Research Institute
UUT	Unit Under Test
U.S.	United States
VIFD™	Voyager Intermittent Fault Detector™
WIPT	Working Integrated Product Team
WRA	Weapon Replaceable Assembly

Appendix H – IFDS™/VIFD™ Equipment Availability

H.1 Both the Air Force and the Navy have done limited procurements of the Universal Synaptics IFDS and VIFD. This equipment was procured to repair specific LRU/WRA unit failures that were experiencing high rates of NFF codes when being troubleshoot by maintenance personnel. Points of contacts are provided for equipment information and potential maintenance resource capabilities and resources for workload overflow.

H.1.1 Air Force Hill

As discussed in Section 2.2.2, the U.S. Air Force experienced a high NFF rate with the F-16 aircraft Modular Low Power Radio Frequency (AN/APG 68 Radar System MLPRF) LRU. The Air Force procured a total of three IFDIS units located at Hill Air Force Base.

POC: Jeff Cummings
Agency Contact organization: Air Force IFDIS TPOC, 523 EMXS/MXDPA
Email: jeff.cummings@us.af.mil
Phone: (801) 777-1774

H.1.2 NAVAIR

H.1.2.1 FRC-SW (Naval Air Station North Island)

As discussed in Section 2.2.3, The U.S. Navy F/A-18E/F Generator Converter Unit (GCU), which is the primary aircraft electrical power system, was the second highest WRA degrader in the Navy aircraft inventory. It had high NFF and mission incapable rates. FRC-SW procured one IFDIS unit located at Naval Air Station North Island.

POC: Moses Simms
Agency Contact organization: FRC-SW
Email: moses.simms@navy.mil
Phone: (619) 545-0526

H.1.2.2 Naval Air Station Oceana

One IFDIS was procured by NAWCAD Lakehurst and installed at Naval Air Station Oceana. This equipment is in support of the F/A-18E/F GCU.

POC: Michael Williams
Agency Contact organization: FRCMA, Oceana
Email: michael.l.williams5@navy.mil
Phone: (757) 433-5595

H.1.2.3 FRC-W (Naval Air Station Lemoore)

One IFDIS was procured by NAWCAD Lakehurst and installed at FRC-W Lemoore. This equipment is in support of the F/A-18E/F GCU.

POC: Edward Oliviera
Agency Contact organization: FRC West, Lemoore
Email: edward.oliviera@navy.mil
Phone: (559) 998-1260

H.1.2.4 NSWC Crane

One IFDIS unit was procured and installed at NSWC Crane and used to support the EA-6B, EA-18G and P-8A Airborne Electronic Attack (AEA) suite of equipment. In addition, one VIFD unit is installed at NSWC Crane.

POC: Ron Swindle
Email: EA-18_AEA_FST@navy.mil
Phone: (812) 854-8723

Appendix I – Reference Information

[1] OSD/OUSD ATL, Director, Enterprise Maintenance Technology OSD Maintenance Policy and Programs, Commercial Technologies for Maintenance Activities (CTMA) Partners Meeting (2014).

[2] Government Accountability Office (GAO) Report on Military Readiness "DoD Needs to Better Manage Automatic Test Equipment (ATE) Modernization" (2003).

[3] Condition Based Maintenance Plus (CBM+), Joint Intermittence Testing (JIT) Working Integrated Product Team (WIPT) – CBM+ JIT WIPT Charter (2012).

[4] PERFORMANCE SPECIFICATION: MIL-PRF 32516 "*Electronic Test Equipment, Intermittent Fault Detection and Isolation for Chassis and Backplane Conductive Paths"*. Approved for use by all Departments and Agencies of the Department of Defense (2015).

[5] University of Dayton Research Institute (UDRI), Intermittent Fault Detection Project Report, Contract # IDIQ GSA ITSS ID05140071011/Task Order 12 – Prepared for Air Force Life Cycle Management Center (AFLCMC)/Product Support Engineering Division (2018).

[6] Herzberg, Eric, LMI, Briefing to the Joint Intermittence Tester (JIT) Team "Determining the Potential for IFDIS" (2017).

[7] JIT Industry Week Report, prepared by NAVAIR, AIR-1.3.1.8.2, AWSEC Team Lead (2016).

[8] University of Dayton Research Institute (UDRI), Intermittent Fault Detection Project Report, Contract # IDIQ GSA ITSS ID05140071011/Task Order 12 – Prepared for Air Force Life Cycle Management Center (AFLCMC)/Product Support Engineering Division (2018).

[9] Ogden Air Logistics Complex Acquisition Cost Division, G3TL12 F-16 Programmable Signal Processor (PSP) Intermittent Fault Detection & Isolation System CIP Economic Analysis Report (2012).

[10] Cavas, Christopher, Defense News *"Grounded: Nearly two-thirds of U.S. Navy's Strike Fighters Can't Fly"* (2017).

[11] Schogol, Jeff, Marine Times *"More than half of all Marine Aircraft unflyable in December"* (2017).

[12] University of Dayton Research Institute (UDRI), Intermittent Fault Detection Project Report, Contract # IDIQ GSA ITSS ID05140071011/Task Order 12 – Prepared for Air Force Life Cycle Management Center (AFLCMC)/Product Support Engineering Division (2018).

OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE
3500 DEFENSE PENTAGON
WASHINGTON, DC 20301-3500

SUSTAINMENT

APR 11 2019

MEMORANDUM FOR HQDA, G44(M), U.S. ARMY
DEPUTY ASSISTANT SECRETARY OF THE NAVY, EXPEDITIONARY PROGRAMS AND LOGISTICS MANAGEMENT, U.S. NAVY
ASSISTANT SECRETARY OF THE AIR FORCE FOR LOGISTICS AND PRODUCT SUPPORT (ACQ), U.S. AIR FORCE
ASSISTANT DEPUTY COMMANDANT FOR INSTALLATIONS AND LOGISTICS (PLANS), U.S. MARINE CORPS

SUBJECT: Addressing Electronics Intermittence Across DoD's Sustainment Enterprise

Electronics maintenance is a leading driver of weapon systems non-availability, accounting for over $10B in FY18 sustainment costs. It is not uncommon for up to fifty percent of electronic components entering maintenance to be No-Fault-Found (NFF); exacerbating electronics availability issues and resulting in over 278,000 days of end-item system non-availability and approximately $3 billion in non-value added sustainment costs annually.

Intermittent electronics failures are a leading contributor to DoD's NFF problem; challenging us over the years by proving hard to duplicate and elusive to diagnose. With very few exceptions, our electronics test equipment is designed to address steady-state electrical disruptions; obscuring the root cause of intermittent failures.

In accordance with CBM+ policy, capabilities have been developed and fielded that can detect and isolate extremely short duration intermittent failures in complex electronics Line Replaceable Units (LRUs) and wiring. In each instance where we have stood up and used these capabilities, we have experienced a steep decline in NFF events; leading to markedly greater materiel availability, improved reliability, and significant cost reductions.

To address this issue, I am championing a Department-wide initiative to rapidly promulgate intermittence detection and isolation capabilities, as defined by MIL-PRF-32516, across our sustainment enterprise. Accordingly, I ask that each Military Service provide recommendations regarding the best practices used to address intermittence as an electronics failure mode and provide overarching strategic plans to widely and rapidly field intermittent fault detection and isolation capabilities. MIL-PRF-32516 compliant capabilities are currently in operation at Hill AFB, FRC-SW and NSWC Crane. I encourage you to interface with these activities during your efforts.

Please reply to my request within 90 days of the date of this memo. The chair of the DoD Joint Intermittence Team and my point of contact is Mr. Gregory Kilchenstein, (703)614-0862, gregory.j.kilchenstein.civ@mail.mil.

Kenneth D. Watson
Deputy Assistant Secretary of Defense
Materiel Readiness

NOT MEASUREMENT SENSITIVE

MIL-HDBK-525
w/CHANGE 1
24 March 2020

SUPERSEDING
MIL-HDBK-525
25 July 2013

DEPARTMENT OF DEFENSE HANDBOOK

ELECTRICAL WIRING INTERCONNECT SYSTEM (EWIS) INTEGRITY PROGRAM

This handbook is for guidance only.
Do not cite this document as a requirement.

AMSC N/A **AREA SESS**

DISTRIBUTION STATEMENT A. Approved for public release. Distribution is unlimited.

FOREWORD

1. This handbook is approved for use by all Departments and Agencies of the Department of Defense.

2. The purpose of this handbook is to establish Mechanical Equipment and Subsystems Integrity Program (MECSIP) tasks for the development, acquisition, modification, operation, sustainment, and service life extension of an aircraft Electrical Wiring Interconnect System (EWIS). This handbook consists of a series of recommendations which, when applied, will promote the continued operational safety, suitability, and effectiveness (OSS&E) of the EWIS systems throughout all phases of the aircraft's life.

3. Comments, suggestions, or questions on this document should be addressed to AFLCMC/EZSS, 2145 MONAHAN WAY, WRIGHT-PATTERSON AFB OH 45433-7017 or emailed to engineering.standards@us.af.mil. Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online database at https://assist.dla.mil.

SUMMARY OF CHANGE 1 MODIFICATIONS

1. Section 1, paragraph 1.3, has been modified to reflect the current age of FAA EWIS assessment process.

2. In Section 2, MIL-PRF-81309, MIL-HDBK-454, AS58091, and AIR6151 were added as applicable documents.

3. Definitions for circuit breakers and intermittent faults was added to Section 3.

4. In Section 4, paragraphs 4.2.4 and 4.4.4 have been modified to provide additional examples of data mining.

5. In Section 5, paragraph 5.3, additional training resources were added.

6. Section 6, paragraph 6.1, was modified to include fluoropolymer insulations.

7. Section 6, paragraph 6.2, was modified to provide guidance concerning corrosion preventative compounds (CPCs), to clarify TO document numbers, and to include intermittency testing options for connectors to MIL-PRF-32516.

8. Section 6, paragraph 6.5, was amended to provide further guidance on the evaluation, inspection, and cycling of circuit breakers.

9. Appendix A, paragraph A.3 was modified to include applicable Work Packages.

10. Appendix C, paragraph C.2, has been modified to provide further instructions on data mining.

11. Appendix C, paragraph C.4, was modified to include and define the Maintenance and Availability Data Warehouse (MADW).

12. Appendix C, paragraph C.4.4 was amended to provide additional examples of databases.

13. In appendix D, paragraph D.2 was deleted and paragraphs D.4.1 (Design) and D.4.2 (Modification and Upgrade of EWIS) were added.

14. Appendix D, paragraph D.4.5, was modified to provide further guidance on maintenance.

15. Appendix D, paragraph D.4.9, was amended to provide additional guidance concerning fluid contaminants and contaminants requiring special consideration, specifically the use of Corrosion Preventative Compounds (CPCs).

16. Appendix D, paragraph D.5, was modified to include further guidance for cleaning and preserving EWIS.

17. Appendix D, paragraphs D.5.2 and D.5.3, were modified to include further guidance for EWIS inspection.

18. Appendix D, paragraph D.5.5, was amended to clarify references to MIL-HDBK-522 guidelines and to include additional EWIS degradation conditions.

19. Appendix D, paragraph D.6.2, was amended to provide guidance on the use of plastic cable ties and connector failures.

20. Appendix D, paragraph D.6.4, was modified to provide further guidance on terminations.

21. Appendix D, paragraph D.6.7, was modified to include additional guidance on grounding points and to incorporate harness protection guidance.

22. Appendix D, paragraph D.6.9, was modified to provide further guidance on splices.

23. Appendix D, paragraph D.6.11.22, was amended to provide additional guidance on EWIS component identification.

24. Appendix D, paragraph D.9, has been modified to address intermittent fault testing and location.

25. Appendix D, paragraph D.10, was modified to include further guidance on inspection reports.

26. Appendix D, paragraph D.11, was amended to include additional knowledge and skills of personnel who conduct aircraft wiring assessments.

27. In Appendix D, the Aircraft Physical Inspection Log in figure D-2 was modified.

28. Appendix E, paragraph E.3, contains new information for the EWIS component assessment.

29. Appendix E, paragraph E.5.5, was amended to include a note on degradation of materials.

30. Appendix E, paragraph E.5.5.1, contains a new note regarding cautions related to the use of specific wire insulation material and recommendations to remove/replace it.

31. Appendix E, paragraph E.5.5.6 (Seamless composite wire construction) was added.

32. Appendix E, paragraph E.8.1.1, was modified to provide further guidance on the use of retired aircraft for wire sample selection.

33. In Appendix F, table F-III's title was modified to reflect the correct number of example devices.

34. Appendix G, paragraph G.2.2, was amended to provide the objective of segregation materials.

35. Appendix G, paragraph G.3.6, was modified to include AC25-27A as a reference to gain further details in developing an EZAP.

36. Appendix G, paragraph G.3.6.9, was amended to include a note regarding the criticality level of reported discrepancies for prior EWIS components not selected for replacement as part of Task Six.

37. Appendix H, paragraph H.2.1, contains further guidance on EWIS component assessment.

The following modifications to MIL-HDBK-525 have been made:

Paragraph	Modification
1.3	Changed
2.2.1	Changed
2.3	Changed
3.6	Added
3.22	Added
4.2.4	Changed
4.4.4	Changed
5.3	Changed
6.1	Changed
6.2	Changed
6.5	Changed
A.3	Changed
C.2	Changed
C.4	Changed
C.4.4	Changed
D.2	Deleted
D.4.1	Added
D.4.2	Added
D.4.5	Changed
D.4.9	Changed
D.5	Changed
D.5.2	Changed
D.5.3	Changed
D.5.5	Changed
D.6.2	Changed
D.6.4	Changed
D.6.7	Changed
D.6.9	Changed
D.6.11.22	Changed
D.10	Changed
D.9	Changed
D.11	Changed
Figure D-2	Changed
E.3	Changed
E.5.5	Changed
E.5.5.1	Changed
E.5.5.6	Added
E.8.1.1	Changed
Table F-III	Changed
G.2.2	Changed
G.3.6	Changed
G.3.6.9	Changed
H.2.1	Changed

CONTENTS

TABLES

FIGURES

1. SCOPE

1.1 Scope.

This handbook provides weapons systems program offices a systematic process that includes a series of core tasks used to assess an aircraft Electrical Wiring Interconnect System (EWIS) for overall condition, service life extension, and continued airworthiness. It aligns with the Mechanical Equipment and Subsystems Integrity Program (MECSIP) (see MIL-STD-1798) and makes extensive use of lessons learned from EWIS-related military, industry, and Federal Aviation Administration (FAA) Advisory Circulars (ACs) concerned with maintaining aircraft airworthiness. It contains a framework to achieve and maintain the physical and functional integrity of the EWIS. This process should be tailored to meet specific platform, program office, system and/or subsystem requirements or constraints.

The process and core tasks identified should also be tailored relative to platform status: whether in design, newly fielded, or based on years in sustainment. A program's use of this process should provide the information necessary to initiate the appropriate trades relative to the cost of modification or integrity initiatives versus required performance, maintenance and mission impact, total operating cost, and aircraft availability. This handbook is for guidance only and cannot be cited as a requirement.

1.2 Background.

The capability of any military force depends on the mission effectiveness and operational readiness of its weapon systems. A major factor that affects readiness and mission reliability is the integrity (including durability, safety, reliability, and supportability) of the individual systems and equipment that comprise the total weapon system. The EWIS powers and interconnects aircraft subsystems and enables the aircraft to complete missions safely and reliably. This handbook provides a process to assess and maintain the airworthiness of the EWIS as defined in MIL-STD-1798 and MIL-HDBK-516, Airworthiness Certification Criteria. An examination of United States Air Force (USAF) mishaps over a ten-year period shows 53 percent of electrically-related mishaps are associated with wire conductors, connectors, distribution panels, or circuit breakers,[1] which are major components in the EWIS. There were electrical fires or loss of critical circuits in many cases. These can lead to loss of crew or aircraft, crew injuries, aircraft damage, emergency action by the crew, and the loss of mission.

In 1999, the FAA initiated programs to address commercial aircraft EWIS integrity concerns after electrical systems were implicated in several high-profile aircraft accidents. The FAA outlined a program to address the service life of aircraft wiring in transport aircraft, establish the condition of aging wiring system components, and validate the adequacy of visual inspections.

The FAA's Aging Transport Systems Rulemaking Advisory Committee (ATSRAC) was tasked to characterize commercial EWIS integrity and recommend actions to assess EWIS airworthiness. The ATSRAC found evidence of aging wiring, materials degradation, and inadequate installation and maintenance practices. Implementation of the ATSRAC recommendations is a major part of the FAA's Enhanced Airworthiness Program for Airplane Systems (EAPAS) (FAA Aging Nonstructural Systems Research, Christopher D. Smith, Manager, Aging Nonstructural Systems Research FAA, and William J. Hughes Technical Center). This handbook leverages FAA EWIS ACs and applies them in a tailored form to military aircraft electrical systems.

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[1] (A. Cooley, "Survey of Electrical Failures in Aircraft Mishaps," Paper at Third Joint FAA/DoD/FAA Conference on Aging Aircraft, September 1999, Albuquerque NM)

Maintenance and engineering communities will be able to use this handbook to facilitate fact-based decisions regarding the condition of EWIS components, remaining EWIS life, and its continued airworthiness.

1.3 Approach.

The FAA has developed and implemented a process over the last fifteen years to conduct EWIS assessments on commercial transport aircraft. This process uses many of the principles and processes outlined in the FAA EWIS guidance documents and tailors them for a military system. The approach is to promote the integrity of the EWIS system with focus on the following:

a. Emphasis on realistic integrity requirements that will reduce EWIS system failures, such as occur during operational service life, maintenance, and environmental exposure.

b. Development of sustainment requirements (including maintenance and inspection) based on the results of analytical processes.

c. Implementation of force management policies and procedures to ensure training and technical data continuity.

The overall process for the EWIS risk assessment is shown on figure 1.

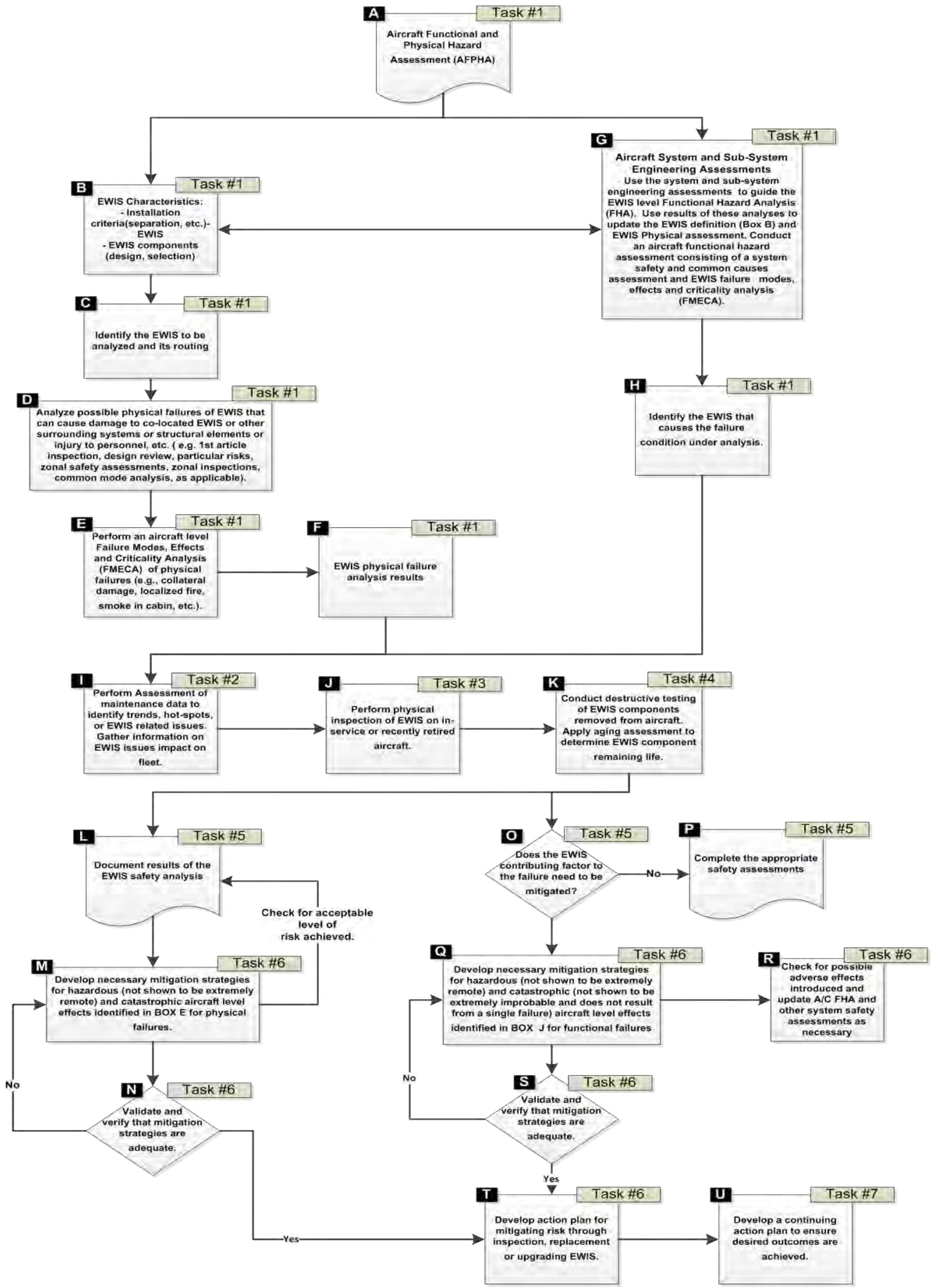


FIGURE 1. Process flow for risk assessment.

1.4 Program overview.

This program is based on the highly successful Aircraft Structural Integrity Program (ASIP) (see MIL-STD-1530) first employed in the late 1950's. This handbook captures the generic features of ASIP and builds upon the evolution and experiences gained over the last five decades. The EWIS program evolved from the FAAs "Aging Aircraft Plan." In 1998, a series of studies examined in-service and retired commercial airliners in the first systematic effort to look at the state of aircraft wiring. The findings showed that wire degradation and failure had multiple causes and were not related solely to age.

The Enhanced Airworthiness Program for Airplane Systems (EAPAS), FAA AC 25-27A, was developed to communicate the Agency's own strategies for improved aircraft safety by emphasizing the integrity of the EWIS.

Application of the principals of this handbook will identify critical EWIS paths and degradation or damage that can then be scheduled for inspection, repair, or replacement. Implementation of the identified maintenance actions—such as inspection, repair, overhaul, replacement of parts, and preservation—will reduce EWIS functional failures and EWIS electrical fires, increase safe operation of the aircraft, increase aircraft availability, and reduce overall system life cycle costs.

This handbook is divided into seven core tasks that follow the processes outlined in military wiring-related documents and the FAA EWIS-related ACs.

1.5 Applicability.

This handbook applies to all systems and components that comprise an aircraft EWIS.

For the purposes of this handbook, "EWIS" denotes any wire, fiber optic link, wiring or fiber device, or a combination of these items (including terminations) installed in any area of the aircraft for the purpose of transmitting electrical energy, signals, or data between two or more electrical end points. The term "wire" denotes bare or insulated wire used for the purpose of electrical energy transmission, grounding, or bonding. This includes electrical cables, coaxial cables, ribbon cables, power feeders, and data buses. Fiber optic wires and associated components are also included in the assessment. Line Replaceable Units (LRUs)/Weapons Replaceable Assemblies (WRAs) are included in the assessment process only to determine the impact of an EWIS fault and the potential impact on system reliability. The EWIS components inside LRUs/WRAs are not considered part of this assessment. This assessment includes but is not limited to the following:

1. Wires, harnesses, and cables
2. The termination point on electrical wires, including bus bars, external relays, switches and passive external components (resistors, diodes, capacitors), junction boxes, contactors, terminal blocks, and terminal boards
3. Circuit protection devices such as circuit breakers, fuses, and other current limiting devices
4. Connectors and connector accessories
5. Shield termination devices
6. Electrical grounding and bonding devices and their associated connections
7. Electrical splices and termination devices such as terminal lugs
8. Materials used to provide additional protection for wires, including wire insulation, wire sleeving, and conduits
9. Shields or braids

10. Clamps and other devices used to route and support the wire bundle (primary support restraint devices)
11. Secondary wiring restraint devices (cable ties, tying tape, etc.)
12. Labels or other means of identification
13. Pressure seals maintaining environmental separation between zones
14. EWIS components inside shelves, panels, racks, junction boxes, distribution panels, and back-planes of equipment racks including, but not limited to, circuit board back-planes, wire integration units, and external wiring of equipment
15. Exclusions are wiring and components inside and external components directly attached to avionic boxes and not serving as an electrical interface to the aircraft (see MIL-HDBK-454).

2. APPLICABLE DOCUMENTS

2.1 General.

The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

2.2 Government documents.

2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein.

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-DTL-38999	-	Connectors, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, or Breech Coupling), Environment Resistant with Crimp Removable Contacts or Hermetically Sealed with Fixed, Solderable Contacts
MIL-DTL-81381	-	Wire, Electric, Polyimide-Insulated, Copper or Copper Alloy
MIL-DTL-87177	-	Lubricants, Corrosion Preventive Compound, Water Displacing, Synthetic
MIL-PRF-81309	-	Corrosion Preventative Compounds, Water Displacing, Ultra-Thin Film

DEPARTMENT OF DEFENSE STANDARDS

MIL-STD-882	-	System Safety
MIL-STD-1530	-	Aircraft Structural Integrity Program (ASIP)
MIL-STD-1678-1	-	Fiber Optic Cabling Systems Requirements and ` Measurements
MIL-STD-1798	-	Mechanical Equipment and Subsystems Integrity Program

DEPARTMENT OF DEFENSE HANDBOOKS

MIL-HDBK-516	-	Airworthiness Certification Criteria
MIL-HDBK-522	-	Guidelines for Inspection of Aircraft Electrical Wiring Interconnect Systems

MIL-HDBK-683	-	Statistical Process Control (SPC) Implementation and Evaluation Aid
MIL-HDBK-454	-	General Guidelines for Electronic Equipment

(Copies of these documents are available online at https://quicksearch.dla.mil/.)

2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein.

TECHNICAL MANUALS AND ORDERS

NAVAIR 01-1A-505-1/ USAF TO 1-1A-14/ USA TM 1-1500-323-24-1	-	Installation and Repair Practices, Volume 1 Aircraft Electric and Electronic Wiring

Each Service issues a dash 2, dash 3, and dash 4 version of this Joint Technical Manual:

NAVAIR 01-1A-505-2	-	Circular Connectors
NAVAIR 01-1A-505-3	-	Rectangular Connectors
NAVAIR 01-1A-505-4	-	Fiber Optic Cabling
USAF TO 1−1A−14-2	-	Circular Connectors
USAF TO 1−1A−14-3	-	Rectangular Connectors
USAF TO 1−1A−14-4	-	Fiber Optic Cabling
USA TM 1−1500−323−24−2	-	Circular Connectors
USA TM 1−1500−323−24−3	-	Rectangular Connectors
USA TM 1−1500−323−24−4	-	Fiber Optic Connectors

(Prospective users of these documents may contact their organizational Tech Manuals Distribution Offices. Contractors can obtain Tech Manuals through their Government Contract Monitor.)

FEDERAL AVIATION ADMINISTRATION (FAA)

Federal Aviation Regulation

FAR Part 25, Subpart H	-	Electrical Wiring Interconnect System

(EWIS) Advisory Circulars

AC 25-16	-	Electrical Fault and Fire Prevention and Protection
AC 25-26	-	Development of Standard Wiring Practices Documentation
AC 25-27	-	Development of Transport Category Airplane EWIS ICA Using an Enhanced Zonal Analysis Procedure
AC 25.1701-1	-	Certification of Electrical Wiring Interconnection Systems on Transport Category Airplanes

AC 43.13-1	-	Aircraft Inspection and Repair
AC 120-94	-	Aircraft Electrical Wiring Interconnection Systems Training Program
AC 120-97	-	Incorporation of Fuel Tank System Instructions for Continued Airworthiness into Operator Maintenance or Inspection Programs
AC 120-102	-	Incorporation of Electrical Wiring Interconnection Systems Instructions for Continued Airworthiness into an Operator's Maintenance Program
AC 25.1309-1A	-	System Design and Analysis

(Copies of these documents are available online at http://www.faa.gov.)

2.3 Non-Government publications.

The following documents form a part of this document to the extent specified herein.

SAE INTERNATIONAL

AIR 6151	-	Torque, Threaded, Application, Electrical Connector, Accessory and Terminal Board Installation
ARP4404	-	Aircraft Electrical Installations
ARP6216	-	EWIS Insulation Breakdown Testing
AS4372	-	Performance Requirements for Wire, Electric, Insulated Copper or Copper Alloy
AS4373	-	Test Methods for Insulated Electric Wire
AS5692/2	-	Circuit Breaker, ARC Fault - Aircraft, Trip Free, 1-20 Amp, Type I
AS50881	-	Wiring, Aerospace Vehicle
AS58091	-	Circuit Breakers, Trip-Free, Aircraft General Specification For
AS81824	-	Splices, Electric, Permanent, Crimp Style, Copper, Insulated, Environment Resistant
JA1011	-	Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes
JA1012	-	A Guide to the Reliability-Centered Maintenance (RCM) Standard

(Copies of these documents are available from https://www.sae.org.

3. DEFINITIONS

3.1 Analysis.

Analysis is the diagnostic effort that illustrates contractual requirements have been achieved. This effort may include solution of equations, performance of simulations, evaluation and interpretation of charts and reduced data, and comparisons of analytical predictions versus test data. The normal reduction of data generated during ground and flight tests is not included. This effort is usually performed by the contractor.

3.2 Branch.

A section of harness that divides off and extends to a point of termination.

3.3 Bundle.

Any number of harnesses or branches routed and supported together along some distance within the aircraft.

3.4 Cable.

Two or more insulated conductors, solid or stranded, contained in a common covering or two or more insulated conductors twisted or molded together without common covering or one insulated conductor with a metallic covering shield or outer conductor.

3.5 Chafing.

The deterioration of a material through repeated relative motion between two or more components. This repeated relative motion can be between wiring system components or a wiring system component and structures or equipment that will likely result in mechanical or electrical failure during the vehicle's specified service life.

3.6 Circuit Breaker. (Added paragraph)

A circuit protection device used to help provide automatic protection that will limit an electrical fault to a single circuit. Its primary function, however, is to minimize the danger of smoke and fire to the conductors (or cables) leading to and from components. It isolates the fault from the power source so that the non-faulted circuits can function in a normal manner.

3.7 Connector plug.

The connector containing the coupling ring or active retention device of the mating pair.

3.8 Connector receptacle.

The connector containing the static retention device of the mating pair.

3.9 EWIS.

Any wire, fiber optic link, wiring or fiber device, or a combination of these items (including terminations) installed in any area of the aircraft for the purpose of transmitting electrical energy, signals, or data between two or more electrical end points.

3.10 Fiber optics.

A general term that describes a light wave or optical communications system. In such a system, electrical information is converted to light energy, transmitted to another location through optical fibers, and is then converted back into electrical information.

3.11 Fireproof.

The capability of a material or component to withstand a 2000 ºF flame (±150 ºF) for 15 minutes minimum, while still fulfilling its designed purpose.

3.12 Fire resistant.

The capability of an item (as defined in “fireproof”) to perform its intended function in designated fire zone areas under heat and other abnormal conditions, as encountered in power plants and auxiliary power unit (APU) installations, that are likely to occur at the particular location or area and withstand a 2000 ºF flame (±150 ºF) for 5 minutes minimum.

3.13 Firewall.
A structural panel designed to prevent a hazardous quantity of air, fluid, or flame from exiting a designated fire zone and cause additional hazard to the aircraft. This structural panel permits penetration of fluid-carrying lines (fuel and hydraulics), ducts, electrical power, and control cables and/or rods through suitable fireproof components or fittings. The firewall and the attached components or fittings must withstand flame penetration and must not exhibit backside ignition for the required test time (15 minutes). The backside temperature should not exceed 450 ºF maximum and the structural panel should have fireproof insulating material installed to limit the backside temperature.

3.14 Fire zone.
A designated area or enclosure generally considered to be within certain selected areas within engine nacelles and APU installations that can, under abnormal operating conditions, experience temperatures approaching 2000 ºF. These conditions are generally the result of fuel or hydraulic line failures, heat duct failures or engine case burn through that allows high-pressure and high-temperature gas to escape from the engine, and similar types of failures. The engine nacelles, APU compartment, fuel-burning heaters, weapon exhaust areas, and other combustion equipment installations are some typical fire zones. Other areas may also be considered fire zone areas; e.g., wheel wells, due to heat generated from the brakes.

3.15 Flammable.
Something (solid, liquid, or gas) with the capacity of being easily ignited and burning quickly.

3.16 Flammable fluid leakage zone.
A fire protection zone on the aircraft where a single failure (such as a fuel leak) will introduce the presence of flammable fluid/vapor.

3.17 Flammable vapor zone.
A fire protection zone on the aircraft where flammable fluid/vapor is routinely present (e.g., inside fuel tanks).

3.18 Group.

A number of wires and/or electrical/optical cables and their terminations secured together within the structure of a bundle or harness. Groups normally contain wire and/or electrical/optical cables pertaining to a single circuit or routed to a single item of equipment.

3.19 Harness.
An assembly of any number of wires, electrical/optical cables, and/or groups and their terminations designed and fabricated to allow for installation and removal as a unit. A harness may be an open harness or a protected harness.

3.20 Improbable occurrence.
An occurrence with the risk of failure shown to be less than 1×10^{-7} events per flying hour (FH).

3.21 Integrity.
Integrity is comprised of the essential characteristics of systems and equipment that allows for specified performance, safety, durability, reliability, and supportability to be achieved under specified operational conditions over a defined service lifetime.

3.22 Intermittent Faults.
Intermittent faults are short duration discontinuities (opens/shorts) that occur at intervals, usually irregular, in conductive electrical paths. These faults typically evolve from exposure to various operational environmental stimuli, including, but not limited to, thermal and/or vibrational stress, gravitational force loading, moisture and/or contaminant exposure, improper manufacturing practices and aging. Cracked solder joints, the presence of conductive contaminants such as flux residues from manufacturing or earlier repairs, improper crimp joints, corrosion products, whiskers, dendrites, electromigration and foreign object damage (FOD) are typical causes of intermittency.

3.23 Maintenance Steering Group – 3 (MSG-3) analysis.
This is a structured analysis, based on Reliability Centered Maintenance principles, that identifies appropriate preventative maintenance tasks to optimize aircraft availability versus maintenance cost. MSG-3 analysis is widely used in the commercial aviation industry.

3.24 Mean Time Between Failures (MTBF).
MTBF is a parameter that historically has been used to define the reliability of components.

3.25 Open harness.
An assembly of wires and/or electrical/optical cables that does not include an outer protective covering.

3.26 Primary support.
Support provided for wiring that carries the weight of the wiring and secures it in the intended position (Also see SAE AS50881, 3.11.1.).

3.27 Protected harness.
A harness that employs some overall outer covering to provide additional mechanical protection for the wires and/or electrical/optical cables contained therein. The added protection may consist of an over-braid, tape wrap, conduit or some other form of protection.

3.28 Redundancy.
Redundancy in design incorporates dual/multiple components or duplicates function to provide operational capability (without degradation) upon failure of a single component or function. Failure of a single component or function must be detectable (i.e., system is both fail operational and fail evident).

3.29 Secondary supports.
Supports used to secure the cabling between primary supports.

3.30 Severe Wind and Moisture Prone (SWAMP) Areas.
Areas such as wheel wells, wing folds and areas near wing flaps, and areas directly exposed to prolonged weather conditions are considered SWAMP areas on aerospace vehicles.

3.31 Spot ties.
Ties other than secondary support ties used to separate a number of wires, electrical/optical cables, groups, or harnesses within a bundle.

3.32 Test.
Empirical efforts performed to prove that contractual requirements have been met. Documented procedures, instrumentation, and known environmental conditions are normally applicable. Compliance or noncompliance is determined by observation, where practical, and evaluation of collected data. Most ground and flight empirical efforts associated with this procurement and acquisition qualify as tests. This effort is usually performed by the contractor.

3.33 Wire.
A single metallic conductor of solid, stranded, or tinsel construction designed to carry current in an electrical circuit but without a metallic covering, sheath, or shield. "Wire" refers to "insulated electrical wire" for the purpose of this specification.

3.34 Wiring.
Wires, electrical/optical cables, groups, harnesses and bundles, and their terminations, associated hardware, and support installed in the vehicle. When used as a verb, it is the act of fabricating and installing these items in the vehicle.

3.35 Wiring components and devices.
The accessory parts and materials used in the installation of electrical and optical wiring, such as terminals, connectors, junction boxes, conduits, clamps, insulation, and supports.

3.36 Wire segment.
A length of wire that is continuous and unbroken between its two intended points of termination. A wire segment that has been broken and then repaired is still considered to be one wire segment.

3.37 Work Unit Code (WUC) Manual.
A manual that assigns a code to each commonly performed maintenance task, thus allowing for tracking of maintenance on specific components and the recording of causes for non-mission capable time, maintenance man-hours, etc.

3.38 Acronyms.

AC	Advisory Circular
A/C	Aircraft
AFB	Airframes Bulletin
AFHA	Aircraft Level Functional Hazard Assessment
APU	Auxiliary Power Unit
ASA/SSA	Aircraft Safety Assessment/System Safety Assessment
ATSRAC	Aging Transport Systems Rulemaking Advisory Committee
BIT	Built-in-Test
CAMP	Continuous Airworthiness Maintenance Program
CCA	Common Cause Analysis
CDCCL	Critical Design Configuration Control Limitation
CPC	Corrosion Prevention Compounds
DAH	Design Approval Holder
DET	Detailed Inspection
EAPAS	Enhanced Airworthiness Program for Airplane System
ECO	Engineering Change Order
ECP	Engineering Change Proposal
EFHA	EWIS Level Functional Hazard Assessment
EWIS	Electrical Wiring Interconnect System
EZAP	Enhanced Zonal Analysis Program
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FH	Flying Hour
FHA	Functional Hazard Assessment
FM	Failure Mode

FMECA	Failure Modes Effects and Criticality Analysis
FQIS	Fuel Quantity Indicator System
GVI	General Visual Inspection
IMDS	Integrated Maintenance Data System
ICA	Instructions for Continued Airworthiness
IPB	Illustrated Parts Breakdown
JDRS	Joint Deficiency Reporting System
JEDMICS	Joint Engineering Data Management Information and Control System
JFOWG	Joint Fiber Optic Working Group
JSWAG	Joint Services Wiring Action Group
KPI	Key Performance Issue
L/HIRF	Lightning and High Intensity Radiated Field
LRU/WRA	Line Replaceable Unit/Weapons Replaceable Assembly
MRBR	Maintenance Review Board Reports
MTBF	Mean Time Between Failures
MSG	Maintenance Steering Group
NALDA	Naval Aviation Logistics Data Analysis
NAVAIR	Naval Air Systems Command
OEM	Original Equipment Manufacturer
PA	Public Address
PASA/PSSA	Preliminary Aircraft Safety Assessment/ Preliminary System Safety Assessment
PDM	Program Depot Maintenance
PHA	Preliminary Hazard Analysis
PHL	Preliminary Hazard List
PM	Program Manager
PVC	Polyvinyl Chloride
RCMA	Reliability-Centered Maintenance Analysis
REMIS	Reliability and Maintainability Information System
RF	Radio Frequency
SAE	SAE International
SHA	System Hazard Analysis
SoS	System-of-Systems
SRHA	System Requirements Hazard Analysis
SSA	System Safety Assessment
SSHA	Subsystem Hazard Analysis
STC	Supplemental Type Certificate
SWAMP	Severe Wind And Moisture Prone
TAA	Technical Airworthiness Authority
TC	Type Certificate
TCTO	Time Compliance Technical Order
TM	Technical Manual
TO	Technical Order
TR	Thrust Reverser

USAF	United States Air Force
WUC	Work Unit Code
XL-ETFE	Cross-linked Ethylene-Tetrafluoroethylene
ZIP	Zonal Inspection Program

4. CORE PROCESS TASKS

The core process tasks in this section should be tailored to specific program office needs and may include all or a combination of these tasks as necessary to assess EWIS condition, support an approach to service life extension, and establish and sustain continued airworthiness. A large portion of the information in appendices A through H was derived from FAA ACs. These documents reference approval authorities as a Design Approval Holder (DAH) or as Type Certificate (TC) or Supplemental Type Certificate (STC) holders. The military airworthiness authority is typically identified as the System Program Manager or Technical Airworthiness Authority (TAA). For this document, the designation will be the TAA when the DAH, TC, or STC holder is called out in a FAA AC.

4.1 Core Process Task One.

Document overall EWIS and identify critical circuit paths and functions (AS50881, AC 25.1701-1, AC 25-27A, and AC 25.1309-1A). (See appendix B for additional guidance.)

4.1.1 Identify EWIS components and materials and all power and signal paths.

4.1.2 Document wiring configuration and circuit schematics and functions.

4.1.3 Document physical wire routing throughout the aircraft.

4.1.4 Conduct an aircraft functional hazard assessment consisting of a system safety and common causes assessment and EWIS failure modes, effects, and criticality analysis (FMECA) (AC 25.1701-1).

4.1.5 Document EWIS components and characteristics such as installation and separation.

4.1.6 Identify catastrophic failure modes and mechanisms in critical EWIS components.

4.1.7 Identify physical failures of the EWIS that can cause damage to co-located EWIS or surrounding systems, structural elements, or injury to personnel.

4.1.8 Develop a Critical Design Configuration Control Limitation (CDCCL) for fuel system EWIS components.

4.1.9 Examine physical separation of Fuel Quantity Indicator System (FQIS) circuits from high-power electrical circuits. This would be based on drawings.

4.2 Core Process Task Two.
Collect and analyze EWIS failure and maintenance data (See appendix C for guidance when utilizing a process to conduct a detailed analysis.)

4.2.1 Document how the aircraft EWIS failure and maintenance data is collected and analyzed.

4.2.2 Review and assess mishap and maintenance databases and applicable Airworthiness Directives.

4.2.3 Interview maintenance and engineering support staff.

4.2.4 Use data mining approaches to examine maintenance and failure data for failure types that include wiring chafing, broken wires, arcing, burned wiring, electrical fires, electrical insulation dielectric failure, and corrosion. Problems related to electrical bonding, fiber optics, connectors, relays, switches, circuit breakers, distribution panels, and other EWIS components that may be included in the data system should also be reviewed. Data mining should also include review of repeated removals of electronic parts and systems (i.e. LRUs and WRAs) that can result in reported no-fault-found (NFF), cannot duplicate (CND), retest OK (RETOK), beyond capability of maintenance (BCM), or disassemble-clean-reassemble (DCR) maintenance actions. Trends in use of these codes can be indicative of intermittent faults within the wiring system.

4.2.5 Review findings, maintenance actions, discrepancies, and repairs accomplished as part of mandatory or voluntary inspections.

4.2.6 Organize data by zone/station, probability, and criticality of failure.

4.3 Core Process Task Three.
Conduct an on aircraft physical and electrical inspection and document overall condition of the aircraft EWIS. Results of this task may be used to identify and target critical problem areas for EWIS initiatives or further evaluation. (See appendix D for guidance.)

4.3.1 Use findings from Tasks One and Two based on the failure criticality to select zones for inspection. Use available wiring design and installation documents SAE AS50881 or applicable platform-specific contractual design/installation documents for additional guidance.

4.3.2 Develop inspection checklist for the selected zones.

4.3.3 Conduct a physical inspection and document overall condition of aircraft electrical system using guidelines established in MIL-HDBK-522.

4.3.4 Specifically examine wiring for exposed conductors, cracked or deteriorated insulation, loss of insulation mechanical properties, excessive splices, presence of contamination/corrosion, or insulation discoloration due to overheating conditions.

4.3.5 Examine circuit breakers, distribution panels, and other conductive path components for corrosion, thermal damage, and electrical degradation.

4.3.6 Large or complex areas should be divided into manageable size. Emphasize Severe Wind and Moisture Prone (SWAMP) and high-maintenance areas.

4.3.7 Prepare and document with photos findings from the physical inspection. Discrepancies that may affect aircraft safety should be identified for immediate action.

4.4 Core Process Task Four.

Conduct a comprehensive materials/aging analysis of wiring and electrical components removed from the aircraft based on information gathered in earlier tasks. (See appendix E for additional guidance.)

4.4.1 Use findings from Tasks One, Two, and Three for selection of EWIS components for removal.

4.4.2 Conduct a lab or visual inspection to document condition of components and follow with a detailed materials examination which may include electrical, mechanical, chemical, and/or destructive aging analysis of selected EWIS components.

4.4.2.1 Wiring insulation and conductor integrity

4.4.2.2 Protective harness materials

4.4.2.3 Shield and ground terminations

4.4.2.4 Connector contact integrity and shield effectiveness

4.4.2.5 Circuit breaker contact integrity and the trip curve

4.4.2.6 Relay contact integrity and actuation performance

4.4.2.7 Switch contact integrity and actuation performance

4.4.2.8 Electrical distribution panel components

4.4.2.9 Terminal boards, ground studs, and connector back shells

4.4.2.10 Compare condition of components with new (unused) components

4.4.3 Apply aging assessment techniques and aging/degradation models to determine remaining life of EWIS components, if available or established.

4.4.4 Review the results of the comprehensive analysis performed on the electrical components removed from the aircraft. Reviews should also include assessment of trends or increases in the number of NFF, CNF, RETOK, BCM, and DCR maintenance codes, which may indicate wiring system intermittency problems.

4.5 Core Process Task Five.

Analyze and provide an overall risk and life assessment of the aircraft electrical system using the findings from the first four tasks. (See appendix F for additional guidance.)

4.5.1 Apply algorithms or models that provide an EWIS risk assessment based on failure histories, failure modes and mechanisms, materials properties, and environmental and maintenance conditions.

4.5.2 Address criticality of the wiring system and its impact on aircraft safety, reliability, and availability.

4.5.3 Review safety assessment process in MIL-STD-882 and AC 25.1701-1.

4.5.4 Consider electrical fires, reported hazards, system reliability, and availability.

4.5.5 Analyze and provide an overall EWIS risk and life assessment using collected data (Tasks One through Four).

4.5.6 Prepare a report on the aircraft EWIS risk and life assessment. Where possible, the report should identify the risk at the device, system, and aircraft level.

4.6 Core Process Task Six.
Apply Overall Analysis toward an action plan (i.e., no changes, implement continuous inspections, partial or total replacement, implement new technologies). (See appendix G for additional guidance.)

4.6.1 Use the collected data from Tasks One through Five to provide recommendations to mitigate risk through inspection, replacement, or upgrade of wiring system components, etc.

4.6.2 Recommend scheduled inspections over system life.

4.6.3 Recommend installation of new technology to improve long-term performance and reduced cost.

4.6.4 Update maintenance manuals to include the following for EWIS fuel tank system components: mandatory replacement times, inspection intervals, related inspection instruction/procedures, and Critical Design Configuration Control limitation for fuel system components.

4.6.5 Prepare a report that details the recommendations on how to mitigate identified risks. The report should include recommended updates/changes to maintenance and inspection processes.

4.7 Core Process Task Seven.
Tailor and apply Core Tasks One through Six iteratively as required to reassess EWIS and to ensure desired outcomes have been achieved and maintained. The tailoring and iterative application should also consider changes in platform-specific program direction and changes to operational requirements such as service life, mission, etc. (See appendix H for additional guidance.)

5. MANAGEMENT METHODS

5.1 General.
The EWIS and ultimately the aircraft safety, reliability, and availability can be improved significantly through performance of the seven Core Process Tasks outlined in this handbook and implementation of an action plan developed from the EWIS assessment; use of timely, effective application of training; accurate attention to detail in the upkeep of technical data; and periodic review and adjustment of the EWIS assessment.

5.2 Policies and guidance.
EWIS policies and guidance must be aligned with the goals of the organizational mission, the primary purpose being maintaining aircraft airworthiness and meeting required performance, availability, and cost.

5.2.1 Quality.
When a culture of excellence is established, quality becomes part of the way business is conducted rather than merely an organizational department. The Quality Control (or uniformed service-specific equivalent) unit must have an overarching goal of the never-ending improvement of the maintenance output. Where there are quality shortfalls, a mechanism must exist to ensure training needs are recognized and action taken to bridge the quality gap.

5.3 Training.

Training courses for electronics/electrical/avionics technicians can be found in the Advanced Wire Maintenance course (J4AMP30000 A48A) created by the Air Force Technical Training Center. Additional EWIS training and courses are available by service and specific platform/weapon system (e.g. Advanced connector and wire repair courses). Training resources for primary EWIS technicians as well as the secondary users can also be found in the FAA training program outlined in AC 120-94. Technicians for military aircraft based on a commercial aircraft (commonly referred to as a commercial derivative aircraft) should review the FAA training program outlined in AC 120-94. See appendix A for a more detailed discussion on training.

5.4 Technical data.

All technical data, whether Illustrated Parts Breakdowns (IPB), Wiring Diagrams, or Fault Isolation Manuals, must be technically accurate. The safety notations and warnings/cautions, along with the technical content, must be continuously upgraded as the information changes. Inaccurate Wiring Diagrams or Fault Isolation Manuals often lead to misdiagnoses of the causes of system failure and waste resources on parts unnecessarily removed and sent to repair facilities.

A frequent cause of faulty technical data occurs when technical manuals (especially wiring diagrams) are not corrected when the system is modified or upgraded. Every weapon system modification or upgrade must receive a corresponding technical data change based on the Engineering Change Order / Proposal (ECO / ECP) when the Time Compliance Technical Order (TCTO) or Airframes Bulletin (AFB) is issued.

Another technical data issue involves the current maintenance data collection processes and systems. Inadequate EWIS Work Unit Codes (WUCs) often lead to misattribution of EWIS failures to aircraft components where failures are first exhibited, such as avionics systems (e.g., display indications). EWIS maintenance WUCs are limited and difficult to define effectively. Current systems and processes fail to capture fully and attribute failures to the EWIS. This results in an underestimation of the extent and impact of EWIS problems. As such, when developing the inspection process and reviewing any maintenance data analysis results, it is imperative that close collaboration is maintained between end users (operators/maintainers), engineering, logistics, and aircraft original equipment manufacturers (OEMs).

6. FAILURE MODES AND LESSONS LEARNED

The failure modes of EWIS components and subsystems follow certain patterns during the failure process as discovered through past EWIS analysis. When EWIS components or subsystems' life exceeds the designed lifespan, they must be replaced to mitigate the risk of loss. Precise analysis is necessary to discover exactly where the "hotspots" of failure clusters are so they can be "selectively replaced." Many of these failure modes (FMs) can be found in MIL-HDBK-522. EWIS components are considered electromechanical devices, which make them susceptible to moving surfaces, wear out, and general wear and tear during maintenance actions.

6.1 Wires.

Wiring is the **most** critical of all EWIS components and most susceptible to damage by various forms of mechanical, electrical, and chemical stresses. The majority of aircraft wiring insulation in military service is of a thin-walled construction and is thus susceptible to various forms of damage such as the following:

1. Primary insulation:
   a. Chafing, fraying, peeling, cuts, cracking, thermal damage, crazing, embrittlement, softening, cold flow, unraveling/layer separation, recession, thinning, and other forms of insulation layer deformation/separation/breaches
   b. Discoloration/charring from stress exposure or aging
   c. Loss of dielectric or insulation resistance
2. Primary conductor and shield braid:
   a. Broken or damaged strands
   b. Corrosion
   c. Red plague type corrosion typically associated with silver-plated copper conductors and fluoropolymer insulations
   d. Diameter reduction
   e. Discoloration from internal or external stress exposure
   f. Short between primary conductor and the shield
3. Cable jacket:

   Chafing fraying, cuts, cracking, thermal damage, crazing, softening, cold flow, unraveling/layer separation, recession, thinning, and other forms of insulation layer deformation/separation/breaches.

The probability of failure and deterioration increases in SWAMP areas or areas in high vibration, high temperature, or severe temperature fluctuations, high moisture, fluid contamination or areas with fluid leaks, or a high-maintenance area. Further guidance on the evaluation and inspection of wiring can be found in MIL-HDBK-522. Degraded or failed wiring should be removed and analyzed to determine the cause of failure so the proper corrective action can be taken.

6.1.1 Splices.

The Joint Services Manual TO 1-1A-14 (see table I) defines a "splice" as the "connection of two or more conductors or cables to provide good mechanical strength as well as good connectivity." The primary failure mode of a splice is high resistance due to failure of the interconnection between the splice barrel and wire. This may be a result of overheating due to improper crimping, corrosion, or aging. Only environmentally sealed, mechanically crimped splices may be used in accordance with the requirements of the airframe manufacturer's standard wiring practices, or SAE AS81824 or equivalent specification, particularly in un-pressurized and SWAMP areas. The possibility of fluid contamination in any installation should always be considered. Use of splices should follow SAE AS50881 guidelines. Further guidance on the evaluation and inspection of splices can be found in MIL-HDBK-522.

6.1.2 Cables.
SAE AS50881 defines “electrical cable” as “two or more insulated conductors, solid or stranded, contained in a common covering or two or more insulated conductors twisted or molded together without common covering or one insulated conductor with a metallic covering shield or outer conductor.” The primary failure modes of a cable are the same as for wires. A common failure mode is a short between shield and primary conductor. Controlled impedance cable (e.g., twisted pair, coaxial cable, etc.) should be accessed for impedance characteristics such as impedance, velocity of propagation, and Voltage Standing Wave Ratio.

6.1.3 Fiber optics.
The Joint Services Manual TO 1-1A-14 defines “fiber optics” as a “general term describing a light wave or optical communications system. In such a system, electrical information is converted to light energy, transmitted to another location through optical fibers, and is then converted back into electrical information.” Failure modes are similar as those for wires but also include degradation of the internal reflective surface. Fiber optic systems are also susceptible to damage and/or contamination at mating surfaces. The Joint Aviation Fiber Optic Working Group (JAvFOWG) is the group of technical experts that provides subject matter expertise in this focus area.

6.2 Connectors.
Many connector configurations exist and most aircraft use the circular MIL-DTL-38999 connector type. Like wire, connectors are also susceptible to damage caused by various forms of exposure. The connector is susceptible to the following:

1. External damage caused by corrosion and mechanical stresses.
2. Internal damage caused in part by excessive handling in areas of frequent maintenance activity.
3. Microscopic (“fretting”) corrosion, worn pins and sockets.
4. Degradation caused by exposure to petroleum-based fluids, moisture, salt water and high humidity, corrosion preventative compounds (CPCs), and cleaning and deicing solutions.
5. Excessive heat in high temperature zones such as engine and auxiliary power unit (APU) bays. The probability of failure and deterioration increases in SWAMP areas.

Connector failures are typically associated with intermittent or “Cannot Duplicate” type issues. Further guidance on the evaluation and inspection of connectors can be found in MIL-HDBK-522. Some intermittent faults associated with connectors may be detected through the use of specialized equipment qualified to MIL-PRF-32516. Duplication of the actual use environment as closely as possible is vitally important when conducting intermittency testing of connectors. Degraded or failed connectors should be removed and analyzed to determine the cause of failure so the proper corrective action can be taken.

When connector damage is discovered, the connectors and/or pins and sockets may need to be replaced to restore the system to its original state. Attempt to use environmentally sealed connectors that meet MIL-DTL-38999 or another defense specification for connectors if connector replacement is required due to damage or system upgrades. Connection-related failures can sometimes be discovered prior to complete system functional failure through reliability analysis on intermittent issues or high “Cannot Duplicate” rates and through aircraft preventative maintenance.

For corrosion prevention compounds (CPCs) such as MIL-DTL-87177 and MIL-PRF-81309 type III used for electronic and electrical applications on external connector surfaces in high vibration areas and SWAMP areas, follow application guidelines in TO 1-1A-14 and in accordance with

General Series Wiring Manuals and weapon system-specific technical manuals. Minimize CPC overspray (especially structural CPCs) and keep material from contacting wire insulation and other insulation products using applicable guidelines and T.O.s for properly masking off sensitive areas since some CPCs can degrade insulation properties or alter flammability. Also, be aware that CPCs can collect dust, sand, and other debris and may not be suitable for certain environments. CPCs should not be applied to any composite/non-metallic connectors or any connectors containing fiber optics.

6.3 Relays.

Like connectors, relays are also susceptible to damage caused by various forms of exposure, as well as “cycle wear.” The relay is susceptible to arcing damage, wear-out of the switching mechanism, or degradation and corrosion from various fluids and heat exposure. Relays typically have a limited service life, which can be shortened significantly if the relay contacts are underrated or near or at their design rating for the intended application. Periodically stuck or jammed contacts or switching mechanisms are evidence of wear-out or premature failure. Discrepant parts should be removed and analyzed to determine the failure cause so the proper corrective or design action can be taken. In some cases, the wiring entering the relay can be the source of a failure. General degradation caused by exposure, resulting in an increased probability of failure caused by corrosion and deterioration, increases in SWAMP areas.

6.4 Switches.

Like relays, switches are also susceptible to damage caused by various forms of exposure; as well as “cycle wear.” The switch is susceptible to arcing damage, wear-out of the switching mechanism, or degradation and corrosion from various fluids and heat exposure. Switches typically have a limited service life which can be shortened significantly if the contacts are underrated or near or at their design rating for the intended application.

Switches that fail to actuate or complete electrical connection should be removed and analyzed to determine the failure cause so the proper corrective action can be taken. In some cases, wire entering the switch can be the source of a failure. General degradation caused by exposure, resulting in an increased probability of failure caused by corrosion and deterioration, increases in environmental exposure in SWAMP areas.

6.5 Circuit breakers.

Circuit breakers are critical devices since they protect the EWIS from over-current conditions and can disable critical circuits if they trip prematurely. Most circuit breakers used on legacy aircraft are thermal mechanical devices that use a calibrated bimetallic element to trip the device when current exceeds the trip curve characteristic. Like switches, circuit breakers are susceptible to damage caused by various forms of exposure, as well as “cycle wear.” The breaker is susceptible to arcing damage, wear-out of the trip mechanism, or degradation and corrosion from various fluids and heat exposure.

Breakers typically have a limited life that can be shortened significantly if the electrical contacts are underrated or marginal for the intended application or if the device is used as a switch. Some common failure modes are the inability to actuate the device or breakers, which require a high reset force (typically from corrosion), premature tripping, overheating due to high contact resistance, and the worst-case failure mode—failure to trip when there is an over-current event. Breakers should be analyzed and replaced to determine the cause of the failure whenever any of these conditions exist. It is possible to measure contact resistance and use the value to assess the overall condition of the breaker. Probability of failure increases in SWAMP areas.

Further guidance on the evaluation, inspection, and cycling of circuit breakers can be found in MIL-HDBK-522, NAVAIR 01-1A-505-1, USAF TO 1-1A-14, and TM 1-1500-323-24-1. Damaged or degraded circuit breakers will need to be replaced to restore system reliability. Upgrading the system with SAE AS5692/2 Arc Fault Circuit Breakers is another method to reduce the risk of arc track wire damage (common occurrence for, but not limited to, polyimide tape wrapped wire construction, MIL-DTL-81381).

6.6 Pressure seals.

A pressure seal is an area where a wire bundle passes through a pressure bulkhead using a bulkhead connector or potted seal fitting. Examples would be between a pressurized and unpressurized bay or where one side of a connector is in a fuel compartment and the other side is in a dry bay area. Pressure seals may also be used when a wire bundle passes through a firewall and other openings in the structure. This is typically a hermetic connector with glass-to-metal seal in the connector pin feed-through; the feed through may also use an elastomeric grommet cork and bottle-type seal.

6.7 Design and installation.

The primary military aircraft EWIS design and installation document is SAE AS50881. This document has current best practices as recommended by military and industry EWIS subject matter experts. It is contractually enforced on some systems while on other systems it is used as a guidance standard by both military program offices and OEMs. Deviation from this document should require extensive engineering analysis. Programs are encouraged to apply the latest version of SAE AS50881 to their EWIS design and installation since it will include the latest safety and design practice improvements as determined by the military and aerospace industry. Programs do need to review changes for cost impact. Programs should also use SAE ARP4404 for additional detailed guidance on the installation and maintenance of EWIS components. This handbook has valuable lessons learned on all types of EWIS components.

6.8 Maintenance.

Wiring maintenance is typically based on aircraft-specific Technical Manuals prepared by the platform OEM or the Joint Service General Wiring, Connector, and Fiber Optic Cabling Technical Manuals that appear in table I. Table I also shows the Technical Manual designations for the U.S. Navy, U.S. Air Force, and U.S. Army, which are now harmonized documents. These manuals are DoD Service-coordinated documents and are regularly updated with the latest wiring practices and repair technologies. These manuals should be used only when they do not conflict with OEM-prepared Technical Manuals, higher-order documents, or contractual requirements. Note that Service-specific requirements are occasionally discussed in these documents. The System Program Manager should regularly review the latest versions of these Technical Manuals. The System Program Manager should encourage his/her maintenance organizations to use the most current versions of these documents and participate in the Joint Services Wiring Action Group (JSWAG), which coordinates changes and updates these Technical Manuals (e-mail: jswag@navy.mil, Website: http://www.navair.navy.mil/jswag).

TABLE I. Joint Services Manual cross-reference.

MANUAL TOPIC	NAVY	AIR FORCE	ARMY
General Wiring	01-1A-505-1	1-1A-14	1-1500-323-24-1
Circular Connectors	01-1A-505-2	1-1A-14-2	1-1500-323-24-2
Rectangular Connectors	01-1A-505-3	1-1A-14-3	1-1500-323-24-3
Fiber Optic Cabling	01-1A-505-4	1-1A-14-4	1-1500-323-24-4

6.9 Other electrical and mechanical systems and interfaces that can impact the EWIS.

The following systems and interfaces can affect the operational safety, suitability, and effectiveness of the EWIS and should be identified, checked, and monitored throughout the life cycle of the aircraft.

6.9.1 Electrical interfaces.

Electrical interfaces are often critical to emergencies. Examples of critical interfaces include, but are not limited to, communications channels between computers, between sensors and computers, and between computers and actuators. Special attention should also be paid to circuits that engage flight modes. Landing rollout mode interfaces, such as anti-skid braking control, should also be taken into consideration.

6.9.2 Flight and throttle controls.

While obvious problems with flight controls are routinely reported by aircrews, many systems degrade slowly. Bearings slowly develop friction, and pawls slowly wear down. What a pilot of an aging aircraft considers normal may in fact be a sign of impending failure. Control sticks and yokes or throttle quadrants are used hundreds of times every flight and need to be carefully examined. Mechanical drive components often operate with an on-condition maintenance philosophy but exist outside normal maintenance procedures and are not checked by Built-in-Test (BIT) functions. Throttle control systems must be reviewed, even on multi-engine aircraft. Engine out scenarios that result in loss of redundant electrical and hydraulic systems can be more critical in aging aircraft than they are in a new air vehicle. As components age, wear or deterioration in one system component is often masked by a secondary system that is taking the extra load. For example, a transmission with dual input stages may be badly worn on one end but still functioning because the other end is carrying the entire load.

6.9.3 Interfacing systems, hardware, and software disciplines subsystems. These systems and subsystems often operate in an integrated fashion with many aircraft configuration items that are outside the engineering responsibilities and boundaries of subsystems engineering. These areas will require special consideration on how to manage the overall life cycle safety of the complete system as many subsystems interface with and rely on electrical systems, egress systems, power systems, structural elements, materials engineering, and avionics.

6.9.4 Systems without BIT tests (partially tested devices).

Many actuators cannot be fully tested on the aircraft. Built-in-Test can test only those parts of a system that are “electrically” monitored and active on the ground. Many other parts of the system may go untested. An example would be an asymmetry control brake that works in both an electrically activated and over speed mode. A BIT test could check the “electrical” activation circuit, but it cannot tell if the brake actually set. An on-aircraft test could verify the brake set in electrical mode, but it may not test the over speed braking mode. Untested modes need to be evaluated for deterioration, and tested modes must be relevant to the particular failure mode being investigated.

7. DETAILED REQUIREMENTS DEVELOPMENT

7.1 Appendix A.

Appendix A describes elements for development of an enhanced EWIS training program.

7.2 Appendix B.

Appendix B describes the data necessary to document the overall EWIS and identify critical circuit paths and functions.

7.3 Appendix C.

Appendix C describes the analysis of existing maintenance data and data mining to disclose EWIS impacts.

7.4 Appendix D.

Appendix D describes elements of physical inspection programs of all EWIS installed on aircraft.

7.5 Appendix E.

Appendix E describes the processes and sampling techniques associated with EWIS component assessment.

7.6 Appendix F.

Appendix F describes tasks for the development of an EWIS risk assessment.

7.7 Appendix G.

Appendix G describes tasks for the development of a risk mitigation action plan.

7.8 Appendix H.

Appendix H describes the application and tailoring of the risk assessment action plan and lessons learned through the aircraft active duty life cycle.

8. NOTES

8.1 Intended use.

The intent of EWIS design is to build a system with the same longevity as the airframe structure per FAA AC 25.1701 (d) (8) (a). However, the current age of some legacy weapon systems significantly exceed the original service life requirements. Moreover, the calculated longevity of these legacy EWIS systems are not uniform throughout the aircraft but are averaged. Some EWIS system components have a much shorter lifespan than the average, and some components' lifespan are much longer than average. EWIS exposure to environmental stresses or personnel performing maintenance will limit EWIS life. Alternately, EWIS in areas infrequently accessed by maintenance personnel or in pressurized or protected environments may increase EWIS life. This handbook outlines a process to capture the available data required to establish and execute an effective EWIS Integrity Program and for service life extension. It should be tailored based upon aircraft specific circumstances (such as maintenance data availability, financial constraints, new platform versus legacy, planned service life, current aircraft age, current or expected mission requirements, etc.)

Execution of the EWIS program as outlined in this handbook will assist in identification and justification of resources required to maintain EWIS integrity and ultimately aircraft airworthiness. Strategies to develop an EWIS integrity action plan will vary from platform to platform, considering aircraft specific circumstances, and may include full aircraft rewiring, targeted rewiring, training initiatives, automated wiring test, scheduled inspections, periodic data monitoring, improved chafe protection, and more. These processes may also be modified as required to provide metrics on the effectiveness of the implemented EWIS integrity strategy (e.g., maintenance data trending/analysis, follow-on hazard assessment, etc.). A properly-applied EWIS Integrity Program will ensure a reliable and airworthy EWIS, which will translate into lower aircraft life cycle costs and improved mission availability.

8.2 Subject term (key word) listing.

Airworthiness
Bundle
Cable
Chafing
Circuit breaker
Clamp
Connector
Failure
Fiber optics
Firewall
Harness
Hazard, fault
Maintainability
Maintenance
Mean Time Between Failure
Receptacle
Redundancy
Reliability
Socket
Splice
Switch
System Safety
Tie
Wire
Work Unit Code

8.3 Change notations.

The margins of this handbook are marked with vertical lines to indicate modifications generated by this change. This was done as a convenience only and the Government assumes no liability whatsoever for any inaccuracies in these notations.

APPENDIX A

ELECTRICAL WIRING INTERCONNECTION SYSTEMS (EWIS) MINIMAL INITIAL TRAINING PROGRAM CONTENT

A.1 SCOPE.

This appendix provides guidance for developing an enhanced EWIS training program. The training is divided into 1) Operators, 2) Maintainers, and 3) Support personnel. Additional training information can be found in AC 120-94.

A.2 AC 120-94, APPENDICES A, B, AND C (REMOTE LOCATION).

J4AMP30000 A48A - Advanced Wire Maintenance Course

Description:

Provides advanced training on wire maintenance procedures as they apply to any aircraft platform utilizing TO 1-1A-14.

Training includes: identification of wire maintenance practices, principles, procedures, inspection, wire repair and build-up for various wire types and cabling to include associated connectors, and basic soldering practices.

Course is 80 hrs. / 10 academic days.

Entry Prerequisites: Completion of Basic Soldering Course or soldering certification/ sign-off through work-center training documents.

Maximum class size is six.

A.3 COURSE OBJECTIVES.

General Procedures

a. Use TO 1-1A-14 and Work Packages 002 00, 003 00, and 026 00 to identify wire maintenance procedures and concepts, with a minimum accuracy of 80 percent.
b. Use TO 1-1A-14 and Work Package 004 00 to identify wire characteristics and techniques, with a minimum accuracy of 80 percent.
c. Use TO 1-1A-14 and Work Package 006 00 to identify Radio Frequency (RF) characteristics, with a minimum accuracy of 80 percent.
d. Use TO 1-1A-14 and Work Package 009 00 to identify wire and cable stripping procedures, with a minimum accuracy of 80 percent.
e. Use TO 1-1A-14 and Work Package 010 00 to identify wire harness installation characteristics, with a minimum accuracy of 80 percent.
f. Use TO 1-1A-14 and Work Packages 011 00, 011 01, and 011 02 to identify wire harness repair procedures, with a minimum accuracy of 80 percent.
g. Use TO 1-1A-14 and Work Package 013 00 to identify contacts and terminal characteristics with a minimum accuracy of 80 percent.
h. Use TO 1-1A-14 and Work Packages 014 00, 014 01, and 014 02 to identify wire and cable splicing and repair characteristics, with a minimum accuracy of 80 percent.

i. Use TO 1-1A-14 and Work Package 021 00 to identify RF connector characteristics, with a minimum accuracy of 80 percent.
j. Use TO 1-1A-14 and Work Package 024 00 to identify connector accessories, with a minimum accuracy of 80 percent.
k. Use TO 1-1A-14 and Work Package 025 00 to identify characteristics of Potting and Sealing Connectors and Electrical Cable Assemblies and Electrical components, with a minimum accuracy of 80 percent.
l. Use TO 1-1A-14 and Work Package 027 00 to identify Terminal Junction System characteristics, with a minimum accuracy of 80 percent.

A.4 INSPECTION ANALYSIS.
Use TO 1-1A-14 and Work Package 004 01 to identify wiring deficiencies, with a minimum accuracy of 80 percent.

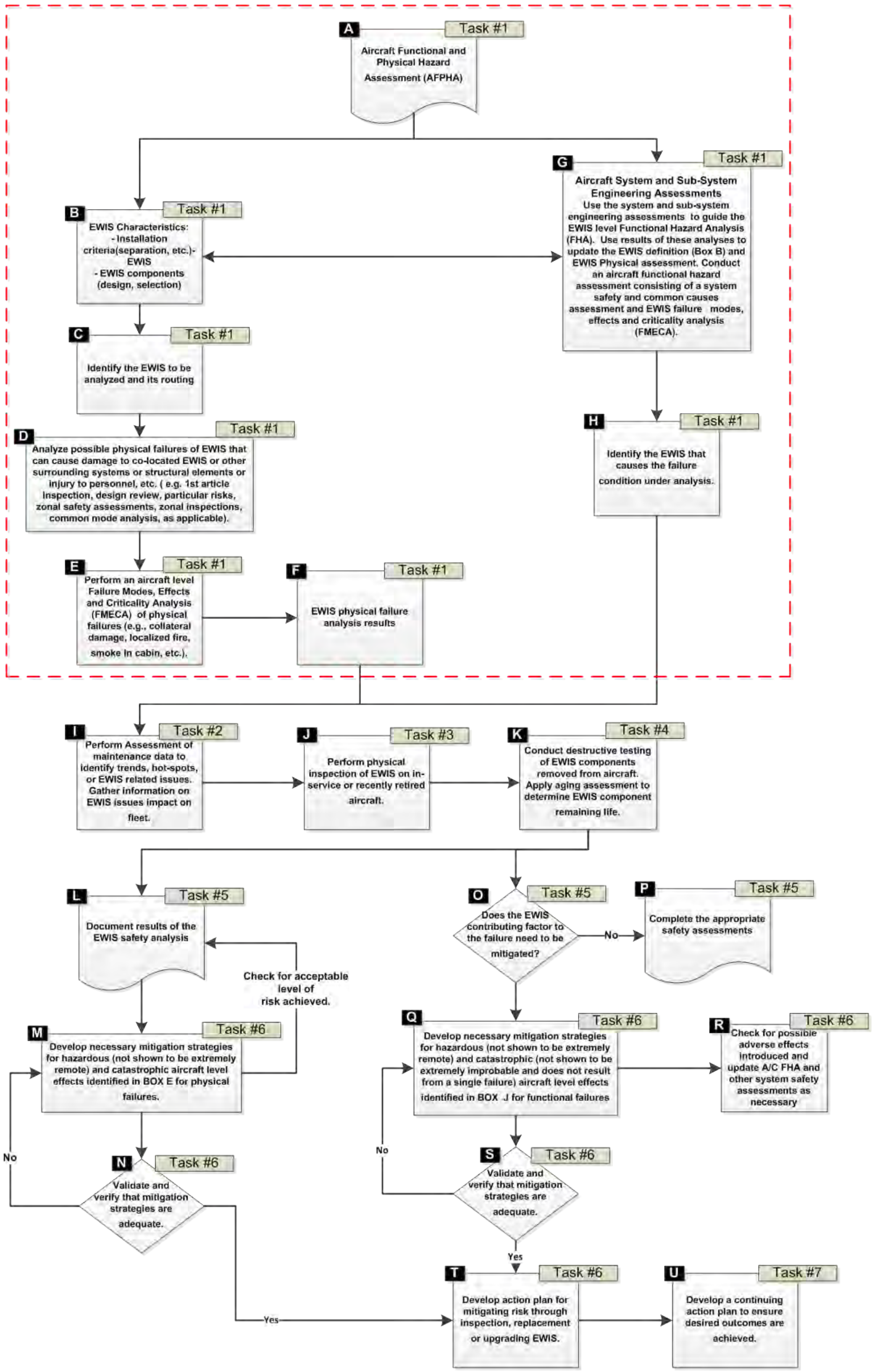
APPENDIX B

EWIS TASK ONE – EWIS DOCUMENTATION

B.1 SCOPE.

The task objective is to generate the data necessary to document overall EWIS and identify critical circuit paths and functions. The task analyses focus on gathering data combined with a preliminary aircraft impact assessment of EWIS device failures.

A simplified process flow for the EWIS risk assessment is shown on figure B-1. This flow chart shows how the data gathered during this phase is combined and utilized through the other tasks performed in the EWIS risk assessment. The tasks performed in Task One are those within the highlighted region.



NOTE: The red-dashed boxed area covers hazard assessment performed in Task #1.

FIGURE B-1. Process flow for risk assessment.

B.2 APPLICABLE DOCUMENTS

B.2.1 General

The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

B.2.2 Government documents

B.2.3 Non-Government publications.

The following document forms a part of this document to the extent specified herein.

SAE INTERNATIONAL

ARP4754 Guidelines for Development of Civil Aircraft and Systems

(Copies of this document are available from www.sae.org.)

B.3 AIRCRAFT FUNCTIONAL AND PHYSICAL HAZARD ASSESSMENT (AFPHA)

Box A: Aircraft Functional and Physical Hazard Assessment (figure B-1). The AFPHA includes both an aircraft functional aircraft hazard assessment and a physical analysis on actual on-aircraft EWIS systems. It assumes that electrical wires are carrying power, signal, or information data. Failure of EWIS under these circumstances may lead to aircraft system degradation effects. The functional hazard assessment consists of the system safety assessments that apply scientific and engineering principles, criteria, and techniques to identify and document hazards at the aircraft and EWIS levels. These analyses are described in more detail in MIL-STD-882 and AC 25.1309-1A. The physical hazard analysis identifies physical failures of the EWIS that can cause damage to co-located EWIS or surrounding systems, structural elements, or injury to personnel. The two assessments combine to comprise the AFPHA.

B.3.1 Aircraft zone breakdown.

If the aircraft does not already have established aircraft zones, these must be identified first. Wherever possible, the definition of zones should follow a consistent method varied only to accommodate particular design and constructional differences. For the purposes of this assessment, the aircraft should be divided into environmental zones. Define the zones, wherever possible, by actual physical boundaries such as wing spars, major bulkheads, cabin floor, control surface boundaries, skin, etc., and include access provisions for each zone.

B.3.2 Zone definition.

The environmental consideration for each zone should include the following:

a. temperature,
b. vibration,
c. chemicals,
d. humidity, and
e. contamination.

Zones should have a consistent environmental condition profile. A zone should be subdivided if major variations in environmental conditions occur within the zone. An example of this is inside the pressure vessel cabin of a transport aircraft. The wiring below the floorboards is likely exposed to contamination from spilled fluids whereas the wiring along the walls to ceiling is unlikely exposed to the same.

Table B-I provides an example set of breakpoints to be used to partition the aircraft into environmental zones. Additions to this breakdown can be made as necessary to best describe the platform under analysis.

TABLE B-I. Example breakpoints for zone environmental conditions.[1]

DATA FIELD	LEVEL 1	LEVEL 2	LEVEL 3
Temperature	Pressure and temperature controlled area	Operation temperature less than 100 ˚C; pressure may be either controlled or uncontrolled.	Operation temperature over 100 ˚C
Vibration	Low vibration (e.g., main fuselage)	Moderate vibration	High vibration (e.g., engines)
Chemicals (toilet fluids, de-icing fluid, etc.)	Isolated area with rare exposure to chemicals	Exposure to chemical may occur but is uncommon.	Regular exposure to chemicals
Humidity	Isolated area with rare exposure to humidity	Exposure to humidity may occur but is limited or uncommon.	Direct exposure to atmosphere (e.g., wheel wells)
Contamination	No contamination likely in these areas	Exposure to contamination may occur but is uncommon.	Highly likely to be exposed to contamination during the course of operations
Other	Any other factor that may impact the longevity of the wiring		

[1] Subsequent EWIS maintenance procedures, developed from this evaluation (Task #6), are designed based on a maintenance zone size. Zone size will be roughly limited to a 6-foot cube.

B.4 EWIS IDENTIFICATION

Box B: EWIS characteristics (figure B-1). Use the aircraft-level FHA results (Box A) to identify EWIS installation criteria and definitions of component characteristics. Results of Box B are fed into the PSSA and SSA of Box G.

The wiring information should be gathered from a “representative aircraft.” The representative aircraft is the configuration of each model series aircraft that incorporates all variations of EWIS used in production on that series aircraft. For example, a particular aircraft model may have both a cargo and transport variation. Dependent on the variation, the resultant EWIS failure hazard assessment must account for any differences between the two versions. The placement of galleys, lavatories, and equipment may affect the routing and furthermore the functional hazard assessment. The resultant EWIS assessment must reflect any such differences.

Sufficient data on the electrical systems is necessary for the failure hazard assessment process. This includes wires (power, signal, and fiber optic), connectors, splices, relays, circuit breakers, power buses, connectors, grounding points, and equipment that is associated with the delivery of electrical power or signal.

B.4.1 Wire information.
The information for wiring may come from wiring lists, wiring diagrams, or a parts list. This information should (at a minimum) include the following:

a. wire ID,
b. pin to pin (from-to data),
c. gauge,
d. system,
e. specification, and
f. length.

An example of the wire data can be seen in table B-II.

TABLE B-II. Example of gathered wire data.

Wire ID	System	From	Pin	To	Pin	Wire Spec	Gauge	Length (in)	DRW #
1JC110 - \1JC110	Environmental controls	JC110	1	\1JC110	1	22759/34	22	60	8721001
*BPZ004 - *BPZ004	Environmental controls	PZ004	*B	*BPZ004	*B	22759/34	22	48	8721001
20JA505 - \20JA505	Environmental controls	JA505	20	\20JA505	20	22759/34	22	155	8721001
2JC110 - *HJA001	Environmental controls	JC110	2	JA001	*H	22759/34	22	120	8721001

B.4.2 Circuit protection device information.
This includes any sort of device that is used for circuit protection such as thermal circuit breakers, arc fault interrupters, fuses, or solid-state protection devices. For these devices, the collected information should include the following:

a. circuit protection device type,
b. reference designator (ref des),
c. current rating,
d. specification,
e. power supply (e.g., 115V or 28VDC), and
f. location (zone).

An example of the circuit protection data is shown in table B-III.

TABLE B-III. Example of gathered circuit protection data.

Ref Des	Type	Rating (A)	Power Supply	Spec	Location	System
P13	Circuit Breaker	5	28VDC	Generic Thermal CB	Flight Deck	Hydraulic Low Pressure Warning
P8	Circuit Breaker	5	28VDC	Generic Thermal CB	Flight Deck	Hydraulic Oil Quantity Indicator
P11-2	Circuit Breaker	5	28VDC	Generic Thermal CB	Flight Deck	Boom Position Indicator
P14	Circuit Breaker	5	28VDC	Generic Thermal CB	Flight Deck	Battery Circuit Breaker Panel

B.4.3 Relays or switching device information.
Switching devices that change the power on a given circuit are included in the EWIS data gathering. For the switching devices, the information gathered should include the following:

a. switching device type,
b. reference designator,
c. specification,
d. configuration (SPDT, DPDT, etc.),
e. location (zone), and
f. system.

An example of the switching data is shown in table B-IV.

TABLE B-IV. Example of gathered switching data.

Ref Des	Type	Config	Location	System
S197	Switch	DPDT	Flight Deck	Engine
S198	Switch	DPDT	Flight Deck	Flight Control
S3-1	Switch	SPDT	Flight Deck	Engine
M288	Relay	SPDT	Flight Deck	Engine

B.4.4 Connectors.
Connectors are used to attach wiring harnesses to LRUs/WRAs or connect through zones. The information gathered on connectors should include the following:

a. reference designator,
b. specification,
c. zone, and
d. systems routed in connector.

An example of the connector data is shown in table B-V.

TABLE B-V. Example of gathered connector data.

Ref Des	Spec	Location	Systems
D51-80	M13.5	Flight Deck	Hydraulic Low Pressure Warning, Hydraulic Oil Quantity Indicator
D51-81	M13.5	Flight Deck	Engine Oil, Bleed Air
D51-82	M13.5	Flight Deck	Fire Protection, Landing Gear

B.4.5 LRUs/WRAs and connected devices.
While the examination of wiring stops at the connection for LRUs/WRAs, function and performance of electrical devices are also included in the EWIS failure hazard assessment. All electrical devices must be catalogued and failure consequence assessed (section B.3). The information gathered should include the following:

a. reference designator,
b. attached connectors,
c. system,
d. function, and
e. location (zone).

B.4.6 Wire harness information.
Box C: EWIS Routing (figure B-1). Identify the EWIS that is to be analyzed and its routing. Ensure the EWIS component qualification satisfies the design requirements; components are selected, installed, and used according to their qualification characteristics; and the aircraft constraints linked to their location.

Use available information (digital mockup, physical mockup, aircraft data, and historical data) to perform inspections and analyses to validate that design and installation criteria are adequate to the zone/function, including considerations of multi-systems impact. Such inspections and analyses may include a first article inspection, design review, particular risk assessment, zonal safety assessment, zonal inspection, and common mode analysis, as applicable. Use such assessments and inspections to ascertain whether design and installation criteria were correctly applied. Special consideration should be given to known problem areas identified by service history and historical data (areas of arcing, smoke, loose clamps, chafing, arc tracking, interference with other systems, wires and cables that are required to regularly flex, such as those in doors and hatches, etc.). An in-depth historical data evaluation is performed in Task Two.

Among the more difficult information to gather for the wire assessment is the wiring harness information. Basic wire harness routing information, such as zone, can be gathered from installation drawings. Additional information, such as proximity to equipment and hydraulic/fuel lines, may require examination of a representative aircraft. If multiple models are considered in the assessment, the routing on each of these aircraft should be identified.

The harness routing information should include the following:

a. termination points,
b. harness protection (if any),
c. nearby harnesses and separation distances,
d. nearby hydraulic/fuel lines and separation distances, and
e. zone(s) in which the harness is routed.

An example of this information is shown in table B-VI.

TABLE B-VI. Example of gathered harness data.

Harness Ref Des	Harness Protection	Nearby Harnesses	Nearby lines	Zone
74A753209-9CAB	Open Harness	74A753210-9CAC	Hydraulic Return Line	Flight Deck
74A753210-9CAC	Open Harness	74A753209-9CAB	Hydraulic Return Line	Flight Deck
74A753227-9CGA	Nomex	74A753209-9CAB	Fuel line	RH trailing wing
74A753228-9CGA	Open Harness	None	None	Under Floor, Cabin
74A753237-9BVA	Open Harness	None	None	Under Floor, Cabin

The routing within each of these harnesses should also be gathered. This includes the wire routing through each harness and requires the division of harnesses into logical sections where no branching occurs, called bundle sections.

The information associated with the bundle sections should include the following:

a. harness identifier or ref des,
b. section identifier,
c. length,
d. protection, and
e. termination points.

The wire routing can be identified when the harnesses are divided into bundle sections. The information for the wire sections should include the wire ref des and the bundle section identifier.

B.5 EWIS SEPARATION IDENTIFICATION

The EWIS routing information through the aircraft must be gathered to provide data on systems co-located within harnesses, harnesses in close proximity, and nearby hydraulic/fuel system equipment. Often this information cannot be gathered from wiring diagrams alone. Wiring harnesses may have many branches, and the physical/functional composition can change for each branch. The routing of the wires within the harnesses is critical to electrical arc damage analysis.

Examination of the installation diagrams requires identification of both the wiring harness routing and the termination points (connectors, devices, terminal blocks, etc.). Once the routing and termination points are identified, the harnesses can then be manually examined and their locations will be described (e.g., harness W334, zone, door 9). Note the following benefits of identification:

1. Provides location information to easily correlate harnesses with hot spot environments in the aircraft (see section C.6.2).
2. Significantly increases the accuracy of severity of wire failure analyses. This improved accuracy is due to additional information on collocated systems (not to be conducted in Task One).
3. Improves the electrical arc damage potential projection as the constituent wires can be identified, and the available power can be better determined. This also increases the validity of arc damage projections to nearby objects (not to be conducted in Task One).

As each aircraft model has different components and different systems routed in different locations, this assessment will need to be done for at least each aircraft model and may be necessary for each aircraft depending on build standard.

B.6 EWIS PHYSICAL FAILURE IMPACT

Box D: EWIS Physical Failure Impact (figure B-1). Regardless of probability, a single arcing failure should be assumed for any power-carrying wire. The intensity and consequence of the arc and its mitigation should be substantiated. Special considerations should be given to cases where new (previously unused) material or technologies are used. This requires that the selection of wires must consider known characteristics in relation to each installation and application to minimize the risk of wire damage, including any arc tracking phenomena.

The potential arc damage at any location in a wire bundle is dependent on a number of factors, which include (but are not limited to) the following: distance from the generator, number of power wires in the harness, and wire insulation type. Additional information can be gathered from the harness examination, as it provides the ability to perform collocation analyses effectively.

An example of the physical damage assessment is shown in table B-VII. In this example, the safe physical separation from each harness bundle section is assessed as the branching within the harness can affect the safe physical damage distance. In this particular application, three separation distances were identified: hydraulic lines, open harnesses, and protected harnesses.

TABLE B-VII. Example physical failure analysis on selected bundle sections.

Harness Ref Des	Harness Protection	Bundle Section	Power Classification	Safe Separation from Hydraulic Line (inch)	Safe Separation from Open Harness (inch)	Safe Separation from Nomex Protected Harness (inch)
74A753209-9CAB	Open Harness	A	High	2	3	2.5
74A753209-9CAB	Open Harness	B	High	2	3	2.5
74A753209-9CAB	Open Harness	C	Medium	1	1.5	1
74A753227-9CGA	Nomex	A	Low (signal)	N/A	N/A	N/A
74A753227-9CGA	Nomex	B	Low (signal)	N/A	N/A	N/A

B.6.1 Aircraft-Level Physical Failure.

Box E: EWIS Physical Failure Aircraft-Level Impact (figure B-1). The impact analysis performed in Box D should be examined at the aircraft level. The impacts of these failures and their criticality should be assessed as they correspond to the FMECA and the failure severity table.

B.6.1.1 Common Cause Assessment.

Only single common cause events or failures need to be addressed during the physical failure analysis as described in this handbook. Multiple common cause events or failures need not be addressed.

In relation to physical effects, it should be assumed that wires are carrying electrical energy and that, in the case of an EWIS failure, this energy may result in hazardous or catastrophic effects directly or when combined with other factors (e.g., fuel, oxygen, hydraulic fluid, or damage by passenger/crew). These failures may result in fire, smoke, emission of toxic gases, damage to co-located systems and structural elements, and/or injury to personnel. This analysis considers all EWIS from all systems (autopilot, auto throttle, Public Address (PA) system, etc.) regardless of the system criticality.

The physical damage evaluations completed in section B.6 should be used to determine the impact on nearby systems and components. An example of this assessment is shown in table B-VIII.

TABLE B-VIII. Example assessment of arc damage on nearby system components.

Harness Ref Des	Bundle Section	Impacted Target	Safe Separation to Target (in)	Current Separation Distance (in)	Potential Impact
74A753209-9CAB	A	74A753209-9CAB	2.5	3	N/A
74A753209-9CAB	B	Hydraulic Return Line	2	1	Physical standoffs separate the harness from the hydraulic return line. Arc damage modeling suggests potential for hydraulic line breach in case of arc failure.
74A753209-9CAB	C	Hydraulic Return Line	2	1.5	Physical standoffs separate the harness from the hydraulic return line. Arc damage modeling suggests potential for hydraulic line breach in case of arc failure.
74A753227-9CGA	A	N/A	N/A	N/A	Contains only signal wires. No arc possible.

B.6.1.2 Catastrophic physical failure assessment.

No ignition source may be present at each point in the fuel tank or fuel tank system where catastrophic failure could occur due to ignition of fuel or vapors. This must be verified via the following:

1. Determination of the locations subject to highest temperatures and allowing a safe margin below the lowest expected autoignition temperature of the fuel in the fuel tanks.
2. Demonstration that no temperature at each place inside each fuel tank, where fuel ignition is possible, will exceed a safe operating temperature. This must be verified under all probable operating, failure, and malfunction conditions of each component whose operation, failure, or malfunction could increase the temperature inside the tank.
3. Demonstration that an ignition source could not result from each single failure, from each single failure in combination with each latent failure condition not shown to be extremely remote, and from all combinations of failures not shown to be extremely improbable. The effects of manufacturing variability, aging, wear, corrosion, and likely damage must be considered.

B.6.1.3 EWIS physical failure analysis results.

Box F: Physical failure analysis documentation (figure B-1). From the EWIS physical failure analysis, document the following:

a. physical failures addressed,
b. effects of those physical failures, and
c. viable mitigation strategies developed (the validity of the mitigation strategies evaluated in Task Six).

The physical failures, both direct and common causes, should be documented and, if necessary, possible mitigation strategies for unsatisfactory results should be developed. The selection of the mitigation technique used is determined in Task Six.

B.7 AIRCRAFT SYSTEM AND SUBSYSTEM ENGINEERING ASSESSMENTS

Box G: Use the aircraft system and sub-system engineering assessments to guide the EWIS-Level Functional Hazard Assessment (EFHA). These analyses are performed to satisfy requirements such that the occurrence of any failure condition that would prevent the continued safe flight and landing of the aircraft is extremely improbable. Conduct an aircraft-level functional hazard assessment (AFHA) that consists of a system safety and common cause assessment and EWIS FMECA. Use the results of these analyses to update the EWIS definition (Box B) and EWIS physical assessment. Once the EFHA is completed, feedback these results into higher-level subsystem and aircraft engineering assessments.

The system safety engineering assessments are defined in MIL-STD-882 and SAE ARP4754.

A summary of the analyses provided in MIL-STD-882 are listed below:

a. Preliminary Hazard List (PHL), Task 201
b. Preliminary Hazard Analysis (PHA), Task 202
c. System Requirements Hazard Analysis (SRHA), Task 203
d. Subsystem Hazard Analysis (SSHA), Task 204
e. System Hazard Analysis (SHA), Task 205
f. Functional Hazard Analysis (FHA) of an individual system or subsystem, Task 208
g. System-of-Systems (SoS) to identify unique SoS hazards, Task 209.

A summary of the engineering assessments provided in SAE ARP4754 used to develop the risk assessment and identify hazards per FAA guidelines for EWIS are below:

a. Functional Hazard Assessment (FHA) (also referred to as the AFHA in this document), examines aircraft and system functions to identify potential functional failures and classifies the hazards associated with specific failure conditions.
b. Preliminary Aircraft Safety Assessment/Preliminary System Safety Assessment (PASA/PSSA) establishes the aircraft or specific system or item safety requirements and provide a preliminary indication that the anticipated aircraft or system architectures can meet safety requirements.
c. Aircraft Safety Assessment/System Safety Assessment (ASA/SSA) collects, analyzes, and documents verification that the aircraft and systems, as implemented, meet the safety requirements established by the PASA and the PSSA.
d. Common Cause Analysis (CCA) establishes and verifies physical and functional separation, isolation, and independence requirements between systems and items and verifies that these requirements have been met.

Use the severity categories taken from the MIL-STD-882 (table B-IX) to examine the EWIS devices identified in the previous sections. These devices must be associated with a failure consequence.

TABLE B-IX. Severity Categories.[1]

DESCRIPTION	SEVERITY CATEGORY (CAT)	MISHAP RESULT CRITERIA
Catastrophic	1	Could result in one or more of the following: death, permanent total disability, irreversible significant environmental impact, or monetary loss equal to or exceeding $10M
Critical	2	Could result in one or more of the following: permanent partial disability, injuries or occupational illness that may result in hospitalization of at least three personnel, reversible significant environmental impact, or monetary loss equal to or exceeding $1M but less than $10M
Marginal	3	Could result in one or more of the following: injury or occupational illness resulting in one or more lost work day(s), reversible moderate environmental impact, or monetary loss equal to or exceeding $100K but less than $1M
Negligible	4	Could result in one or more of the following: injury or occupational illness not resulting in a lost work day, minimal environmental impact, or monetary loss less than $100K

[1](Source: MIL-STD-882E, Table I)

At this stage in the assessment, the failure consequence should focus on direct EWIS component loss. Examples of failures to consider include the following:

a. Loss of connector.
b. Loss of relay or switch.
c. Loss of a wire harness or individual section of a wire harness.

An example of a system device evaluation can be seen on figure B-2. A CAT 1 component has been identified (red-outlined box) and four devices feed information or power into the component (devices 1, 2, 3 and 6). Each device connected to the CAT 1 component are examined to determine if any other devices are necessary to ensure the reliable operation of the CAT 1 component (e.g., identify if the source data for Device 6 comes from Device 4 and 5).

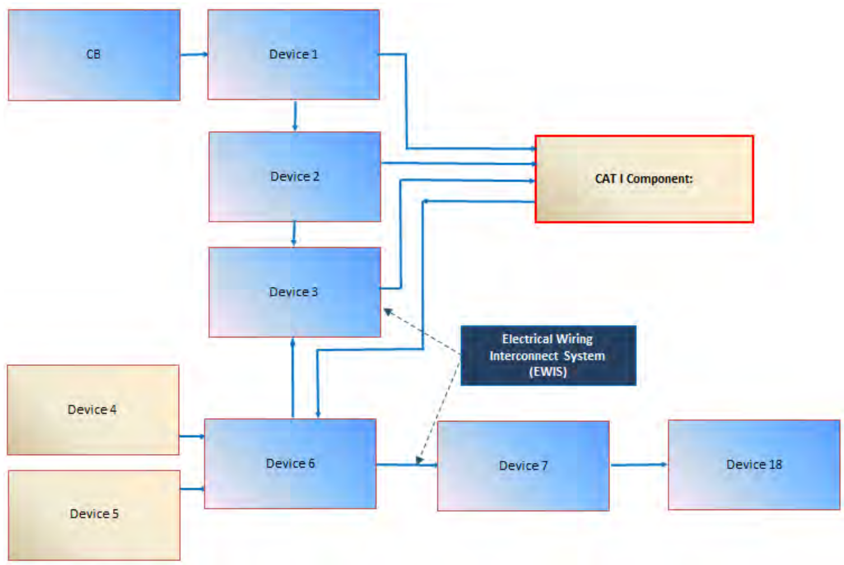


FIGURE B-2. Example system diagram for CAT 1 component.

B.7.1 Identify catastrophic failure modes for critical EWIS components.

Box H: Hazardous and catastrophic failure conditions (figure B-1). Use the analyses in Box G to determine if the EWIS associated with the system under analysis can contribute (in whole or in part) to the failure condition under study. The assessment should examine common cause failure for redundant systems routed in the same harness or in close proximity to one another.

Determine whether the EWIS failure requires mitigation. Any EWIS failures that requires mitigation should be identified and included in the Task One report. Strategies for mitigation will be developed and verified in Task Six. If no mitigation is necessary, complete the appropriate safety assessment.

Document the results of the functional failure assessment. The results of the assessment will be used to direct the inspections performed (Task Three), component selection for degradation assessment (Task Four), EWIS risk assessment (Task Five), and mitigation strategies (Task Six).

APPENDIX C

EWIS TASK TWO – DATA ANALYSIS

C.1 SCOPE

This appendix describes the analysis of existing maintenance data and data mining to disclose EWIS impacts and is based upon information provided in MIL-HDBK-683, Statistical Process Control (SPC) Implementation and Evaluation Aid.

C.2 OVERVIEW

The overall risk assessment can benefit from the analysis of existing maintenance data. Use data mining approaches to examine maintenance and failure data for failure types that include wiring chafing, broken wires, arcing, burned wiring, electrical fires, electrical insulation dielectric failure, and corrosion. Also search for problems related to electrical bonding, fiber optics, connectors, relays, switches, circuit breakers, distribution panels, and other EWIS components that may be included in the data system under review.

Data mining should also include review of repeated removals of electronic parts and systems (i.e. LRUs and WRAs) that can result in reported no-fault-found (NFF), cannot duplicate (CND), retest OK (RETOK), beyond capability of maintenance (BCM), or disassemble-clean-reassemble (DCR) maintenance actions. Trends in use of these codes can be indicative of intermittent faults within the wiring system.

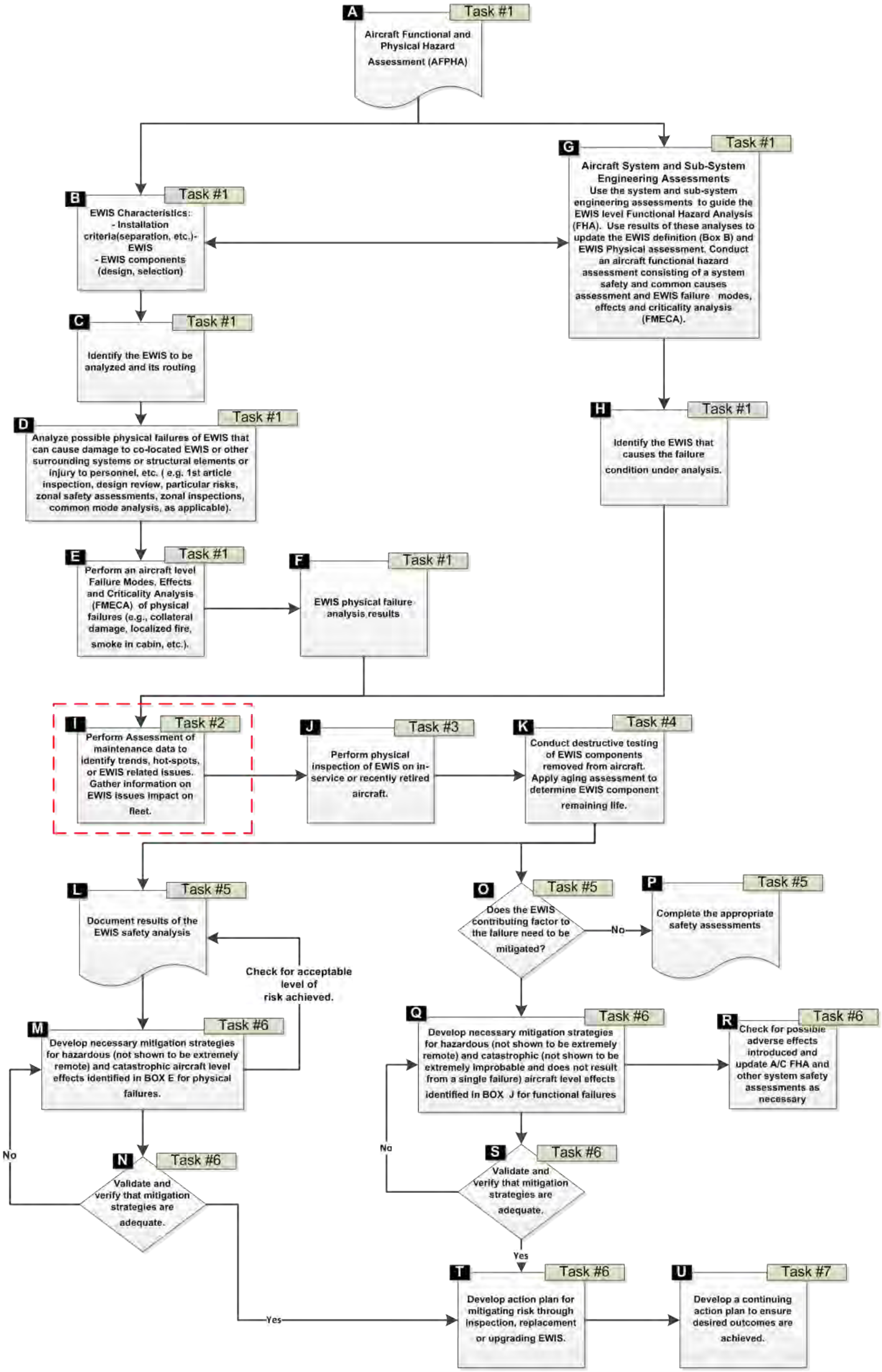
Data mining ultimately provides insights into the aircraft condition and how the aircraft is maintained. By conducting this analysis, the data retrieved can be used to identify:

a. hot spots (systems that are main drivers of maintenance actions),
b. the scale of EWIS repairs,
c. areas for focus during the inspection process (Task Three), and
d. the overall risk assessment process.

There are multiple ways to review and analyze the data; thus, it is possible to misinterpret the data and arrive at incorrect conclusions. Techniques and analyses described here are generalized and are independent of the maintenance data source.

The reliability of EWIS component historical data is uncertain. While important information and previously unidentified issues may be identified through the data assessment process, the historical data analysis conclusions should be reported with caution and not overstate the aircraft condition. This information is one part of an overall EWIS risk assessment process and must be combined with more information to determine the overall impact on the aircraft.

The dependencies of Task Two efforts are shown on figure C-1.



NOTE: The red-dashed boxed area includes the data analysis performed in Task Two.

FIGURE C-1. Process flow for risk assessment.

C.3 GENERAL

The first step is to determine EWIS condition and extent of problems (or Root Cause). Solution formulation is normally a more straightforward process if all problems are identified. The following analytical methodologies have been used to identify conditions and/or performance gaps.

Different analytical methods are available for use; each one is valid for a given situation or environment. A thorough understanding of the methods listed below is essential for the analyst to use statistical and cost analyses accurately to diagnose EWIS-related issues.

C.3.1 Visual observation.

Visual observation is valid under certain conditions; however, it depends largely on the observer's experience, knowledge, and degree of access. This type of observation provides limited information and may not be useful or meaningful for complex situations. This method is limited as a stand-alone analysis and should be considered useful when combined with the other methods.

C.3.2 Comparative analysis.

Comparative analysis may be performed statistically or visually and involves comparing two or more like processes or items to identify variations or differences. Though a viable stand-alone method, it is normally used in conjunction with other methods.

C.3.3 Statistical analysis.

Statistical analysis is the methodical study of data used to reveal facts, correlations, and trends about data. It is useful in conjunction with comparative and visual analysis.

C.3.4 Analysis process.

The analysis process is the methodical conversion of data into information for managerial decision-making and control. It amalgamates the three previous methods into a single, coherent analytical process. This combination makes it the most robust of these problem-solving processes.

C.4 DATA MINING PROCESS

Though there is no single best way to mine data, there are some "best practices" available. However, a standard, basic process is recommended for congruence between projects. The data mining process will vary based on the way the project is conducted.

Data is usually downloaded from the Reliability and Maintainability Information System (REMIS), G081 (Maintenance Data collection system for U.S. Air Force Mobility Aircraft), Integrated Maintenance Data System (IMDS), DECKPLATE, Joint Deficiency Reporting System (JDRS), and/or the Air Force or Naval Safety Center data into a program that allows data analysis and filtering.

Maintenance and Availability Data Warehouse (MADW) is a DoD enterprise database system of record that contains maintenance task and materials requisition records across each of the service components (Army, Navy, Air Force, Marine Corps). The MADW can be mined to find maintenance records, costs and non-availability results, and has a query capability that can be used to identify potential target maintenance opportunities to reduce maintenance costs and improve equipment availability significantly.

Use of particular measures are encouraged to maintain an accurate and reliable product, such as system data being prepared (or "scrubbed") then separated into units based on WUC.

C.4.1 Field, Depot, and Engineering Surveys.

These surveys address issues concerning EWIS components (e.g., connectors); subsystems (e.g., WUC 23000-engines); and related issues such as management, Technical Manuals, and training. The questionnaires are directed at all personnel involved with the EWIS sustainment process and should be completed at all levels of the logistics organization. For example, questions concerning power plant maintenance (WUC 23000) would be directed to everyone involved in flight line maintenance. All Bases with the related airframes and EWIS systems would be selected to participate in the survey.

Different questions would be sent to the depot facilities as they have a different type of maintenance environment geared primarily toward preventative and heavy maintenance.

System program engineers, logistics personnel, and systems safety personnel would receive questions concerning requests for assistance and various issues that require their resolution.

C.4.2 Goals for filtering of data.

The following are the goals of the data analysis:

a. Identify where EWIS issues exist in the fleet.
b. Determine the size of EWIS-related issues.
c. Provide insight into how EWIS failures affect aircraft systems electrically and physically and how they relate to the risk assessment process.

C.4.3 Maintenance databases.

Maintenance and service databases are filled with entries from maintenance personnel. Historically, in the USAF, these databases were primarily designed to track part usage and manage inventory. As a side benefit, the databases can provide useful engineering data. While there is guidance provided to fleet maintainers to use common terminology in these databases, there are often misspellings, incorrect term usage, improper system identification, and multiple entries for the same issue.

Data entry errors can cause a simple keyword search to produce incomplete and/or invalid results and lead to the incorrect conclusions. A brief list of keyword terms is included in C.4.5.

C.4.4 Identify available data.

Maintenance actions are recorded in fleet-specific databases. Database systems are continually updated and enhanced since they are integral to managing aircraft operationally. The USAF and United States Navy (USN) have developed new data management systems that allow organizations to query aircraft platform maintenance data. The USAF uses the IMDS, and the USN uses DECKPLATE, which accesses the Naval Aviation Logistics Data Analysis (NALDA) system. Examples of specific databases include REMIS, G081, JDRS, Naval Safety Center HAZREP, and the Air Force Safety Automated System (AFSAS). These databases store information on aircraft maintenance actions using categories such as the WUC, a narrative with a brief problem description, or a corrective action description.

Unfortunately, many records have the wrong WUC assigned and the problem and correction action descriptions are poorly written due to misspellings, generalizations, and shorthand notation. Information mining of these databases often requires an exhaustive combination of keyword searches and ultimately a subject matter expert to read and interpret each maintenance record manually. This last action introduces subjectivity and can lead to more conclusions that are erroneous.

C.4.5 Keyword search.
The maintenance data can be acquired manually or automatically. If performed manually, all components of the maintenance entry or SIB entry should be reviewed for wire-related data. If performed automatically, a search algorithm will need to be developed. The algorithm will need to be verified manually for 95 percent accuracy as a minimum.

The algorithm will not disseminate the difference between what is intended and what is meant. For example, for a search of corrosion issues, the words "rot" and "rust" would be included in the search word bank as both are corrosion related. However, the search algorithm will also pull out any maintenance actions with the word "rotary" or "thrust" if the search is not generated properly. Thus, the results will be skewed.

Looking through "wire glasses" and using words with double meanings (e.g., the word "wire") will also yield inaccurate results. While wire is related to wiring issues, “safety wire” on a fastener (bolt or screw) also results from that search. Safety wire maintenance actions are common for a variety of components and may have no relation to the EWIS.

An effective search algorithm would be to use “wir” or “cabl” and not “safety wir” to capture EWIS wiring records. This would locate records with “wire,” “wiring,” “wired,” “cable,” and “cables” and eliminate safety wire (wiring) records.

Simple human narratives input errors are another issue that directly affects the results, such as misspelled words and trade names. For example, a search was done for maintenance-related activities related to polyimide wire. The search returned zero results. Thirty results were returned when the search was repeated with the trade name “Kapton®.” Over 150 results were returned when the search was repeated with “Capton” (improper spelling).

Given the data condition within these databases, it is unlikely that all EWIS data can be identified unless an extensive manual effort is performed. Thus, the goal should be to achieve greater than 95 percent. This will not identify all of the actions performed on the EWIS but will give enough insight for risk assessment purposes and support recommendations made in Task Six.

The list provided in table C-I is not all-inclusive and should be supplemented by interviews with fleet maintainers. Fleet-specific terminology should be added to the keyword search.

TABLE C-I. Sample keywords for EWIS maintenance search.

“wir”	Arc	Spark	“apton”	Chaff
Tefzel®	tefzel	Connector	Relay	CB
Circuit breaker	Fuse	Terminal	Pin	Socket
Short	Crimp	Splice	Sleeve	Bundle
Harness	Clamp	Grommet	Conductor	Insulation
Button	Switch	Optic	Fiber	

If the data analysis is focused on all EWIS problems during the life of the aircraft, then no date ranges are necessary. However, if date ranges are necessary, this filter on the data should be included in the query criteria.

C.4.6 Keyword supplement.

As stated above, the keyword list is not all-inclusive. Each aircraft has a specific set of terms and shorthand when associated maintenance data is entered. This information can be gathered from aircraft maintenance personnel via direct communication or via questionnaire.

An example of a simplified questionnaire can be found on figure C-6. It is suggested that this questionnaire be expanded and modified to best match the maintenance processes for the aircraft. After review and modification, the questionnaire should be provided to multiple aircraft technicians.

C.4.7 Data selection.

When querying the data system, a large number of data fields are available, and this can be overwhelming from an analysis perspective. The data fields returned from the query can be reduced to a subset. It is recommended that, at a minimum, the following fields be selected when the analysis is performed:

a. Dates fields (date created, updated, closed, etc.)
b. Unique ID (this is the unique identifier for all maintenance records)
c. WUC
d. Narrative
e. System and/or subsystem
f. Problem description
g. Corrective action
h. Location

Other fields that may be of use include flight hours, scheduled/unscheduled maintenance, component model, and stage of operation. Note: It is easier to hide or remove data fields from a query than to add them later.

C.5 DATA REVIEW

Once the keywords have been selected and the desired data identified, run the query and store the results. An example set of results is shown in table C-II. The results are returned in a tabular form with each record on an individual line.

TABLE C-II. Example database keyword search result.

MDS	WUC	JCN	WDC	HMAL	ACFT	Discrepancy	AT	Corrective Action	MH	DATE
XXXX	XXZKD	011402041	F	255	6600008304	F/E INTERPHONE CORDS HAS FEEDBACK INOP	R	R2 STOW SWITCH	2	200105
XXXX	XXZKD	011402046	F	255	6600008304	LEFT WINGTIP AFT POSITION LIGHT OUT	R	R2 STOW SWITCH	2	200105
XXXX	XXZKD	011442166	F	255	6600008304	(X) #4 ENGINE T/R NOT LOCK LIGHT & PRESSURE LIGHT ON WITH T/R IN STOW POSITION	R	R2 STOW SWITCH THRUST REVERSER SYSTEM	2	200105

Given maintenance systems are regularly updated, it is recommended the original data be stored for further reference and the filter/review process be documented. This allows for direct traceability through the process and, if necessary, identification of possible analysis errors.

A two-tier approach is recommended to assess the entries. The first tier, performed by a junior engineer or data analyst with some familiarity of the aircraft or maintenance reports, examines each item in the data, reads the details, and tags the entries. The second tier, performed by a senior engineer or senior technician, reviews the results and makes determinations on unclear items.

C.5.1 Tier #1 data review.

The evaluation of the maintenance data requires manual data review. The manual record examination process should separate the records into one of three categories:

1. The record does not involve an EWIS component, or it was indirectly related (e.g., hydraulic failure caused damage to wires).
2. The record clearly is associated with EWIS items.
3. It cannot be deciphered whether the record is an EWIS-related event, or insufficient information was provided.

The results should be reviewed regularly to ensure the records are being accurately partitioned. This process will be able to identify 90 to 95 percent of the items, with the remaining 5 to 10 percent marked as "Unknown."

In addition to sorting, EWIS-related items should be examined for correct WUC assignment, component type, and any other fields that may be useful in the data analysis when the maintenance actions are reviewed.

Notes for Maintenance Data review:

1. Do not delete any data. If data is not applicable, then it should be filtered out, or a column should be added to identify the information as "Not Applicable."
2. Do not overwrite original data. Again, this is for traceability of the data. If the report is associated with the wrong WUC, add a new column "Correct WUC" and apply the correct code.
3. Generate a list of keywords during the data examination to be included in another query on the maintenance data. Once compiled, rerun the report and merge the data. Repeat as necessary.

C.5.2 Tier #2 data review.

The Tier #2 assessment is performed by a senior engineer or technician to review the items marked as "Unknown." These "Unknown" entries from tier 1 are to be broken into either an EWIS related issue or non-EWIS issue. At the completion of this work, the data is ready for analysis.

C.6 DATA ANALYSIS

Data analysis begins after the data has been gathered, sorted, and cleaned up. There are multiple methods for analyzing the data, and some are presented here. These methods are intended to provide insight into the EWIS related maintenance actions that are performed on the fleet.

C.6.1 Analysis techniques.

Pareto analysis: By concentrating on 20 percent of the factors (the top drivers or the biggest problems), 80 percent of the issues will be resolved.

Use scatter diagrams to correlate data. Scatter diagrams are plots of two variables used to show the relationships between the two variables, whether they are positive or negative. For example, when trying to determine the relationship between environmental exposure and connector corrosion, a scatter diagram will show a positive correlation between environmental exposure and connector corrosion.

Use cause and effect (“fishbone”) diagrams to narrow causes. When relating a Key Performance Issue (KPI) to its potential causes, a powerful method is to develop a cause and effect diagram, also known as a “fishbone” diagram. The main performance issue (or “gap”) is labeled as the fish’s head, the major categories as structural bones, and the likely specific causes as ribs. The analysis identifies the major categories of potential problem causes.

Perform trend analysis. This is merely determining the direction and/or magnitude of a trend (increasing or decreasing, strong or weak). A time-series chart can also be considered a trend measurement tool. When measuring trends on EWIS systems, various metrics such as sortie rate must be calculated and factored in when determining failure and/or cost trends.

Identify “hot spots” and/or provide solutions. The last stage of EWIS analysis is the identification of “hot spots” or failure clusters. These are areas of consistent weakness characterized by high levels of maintenance and/or operational traffic or excessive environmental exposure.

C.6.2 Partitioning of data.

In addition to the direct analysis of the data, other mechanisms for reviewing the data include the following:

1. Hot spot analysis partitioned by system, subsystem, location, zone, and device type.
2. Number of maintenance actions that are allocated to the wrong WUC.
3. If the fleet consists of multiple versions, it may be advantageous to partition the data by model. This can help identify potential issues that are experienced by a subgroup within the fleet.

C.6.3 Data fitting.

The data may also be normalized. This process helps to account for increased operations tempo or an overall increase in maintenance actions. Normalization can be based on the total number of sorties flown, hours of flight, number of total maintenance actions, or total maintenance man-hours.

C.6.4 Examples.

The following are examples of Pareto analysis performed on actual maintenance data. This analysis was conducted in multiple parts (this is dependent on the desired level of analysis). Figure C-2 through figure C-4 show a progression, starting with a review of EWIS maintenance actions on all systems, followed by progressively reviewing the top contributing factors on each level of the analysis.

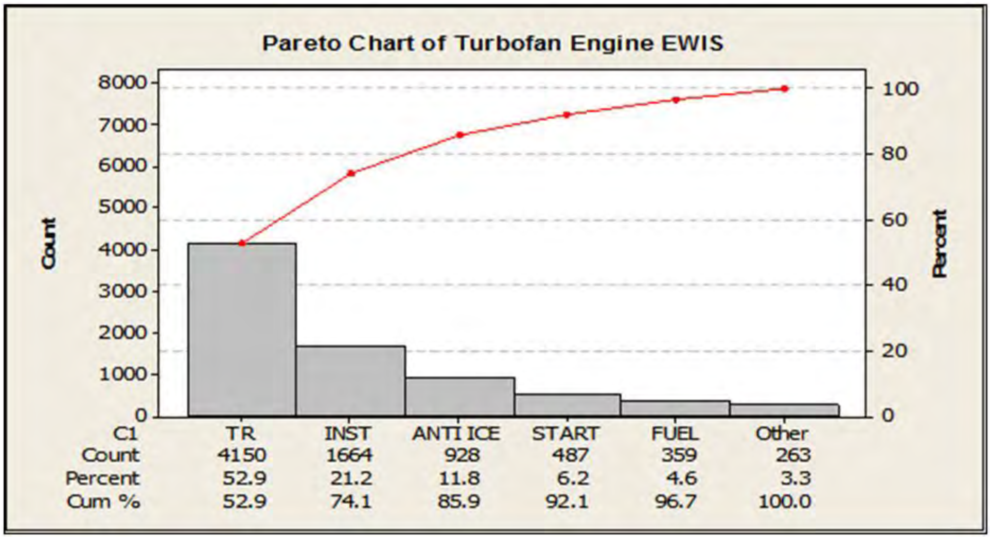


FIGURE C-2. Example of Pareto analysis of turbofan EWIS maintenance issues.

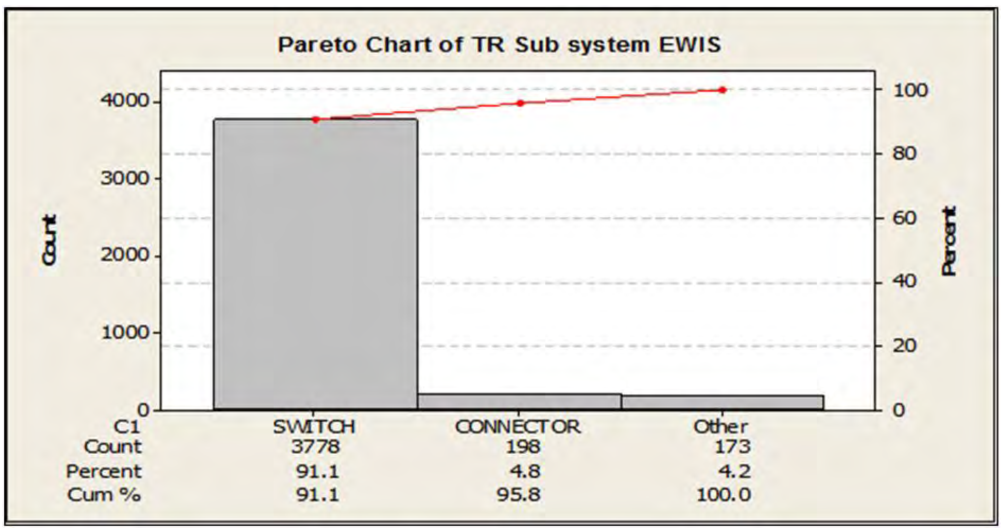


FIGURE C-3. Example Pareto analysis of TR subsystem maintenance actions.

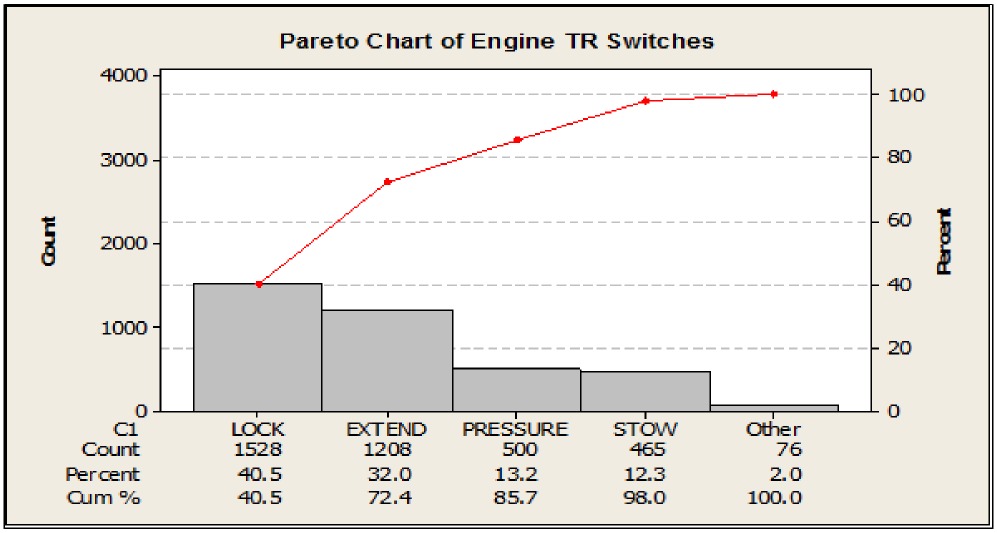


FIGURE C-4. Example Pareto analysis of engine TR switch maintenance actions.

Another method similarly identifies this issue by data partitioning. In the bar graph seen on figure C-5, the EWIS-related failures are partitioned by system and then by device type. Evidence shows the thrust reverse system switches are a significant aircraft EWIS maintenance actions contributor.

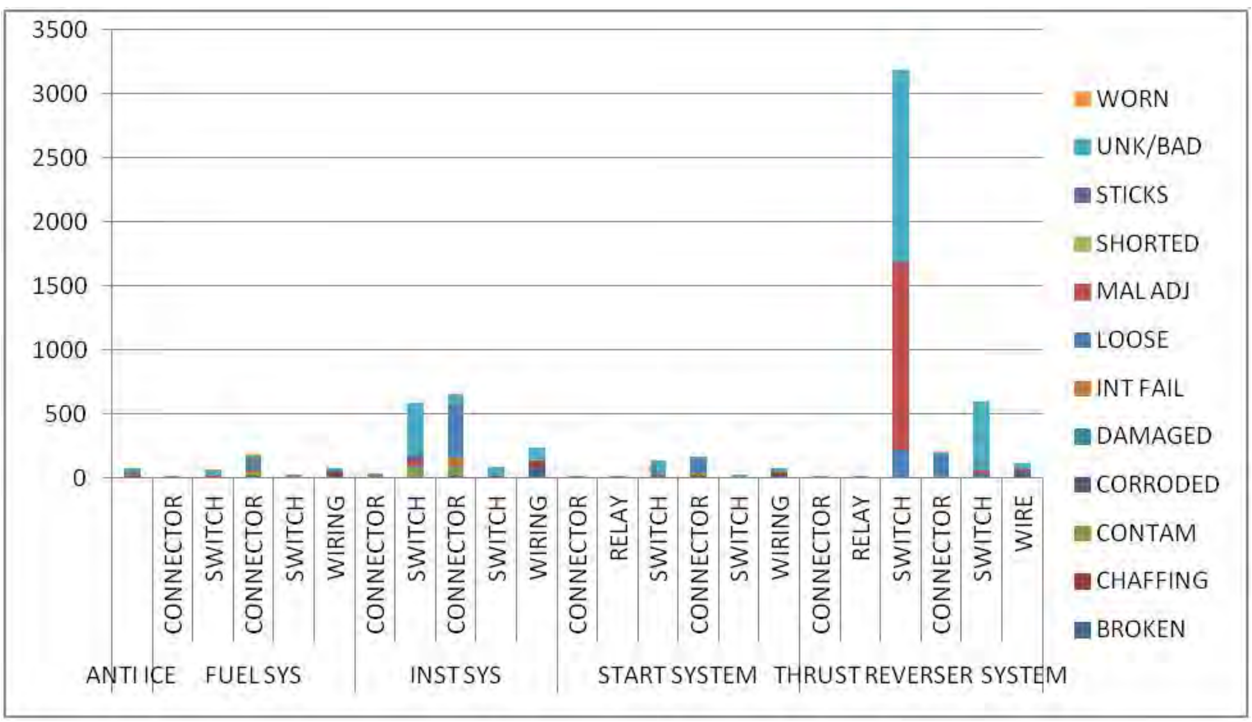


FIGURE C-5. Example of maintenance items categorized by system and device type.

Further research eventually revealed a problem with the latch and extent switches (traced to a single part number) in the TR system that was mitigated by an aircraft modification.

Upon completion of all EWIS and aircraft subsystems data analysis, a report is assembled bringing together a snapshot of all of the systems on the aircraft. This information is used to direct the on aircraft inspections (Task Three) and provide guidance on component removal for degradation analysis (Task Four), reliability data for the risk assessment (Task Five), and data to support an action plan (Task Six).

C.7 DATA ANALYSIS QUESTIONNAIRE

Figure C-6 is an example of a questionnaire that will aid in the collection and review of EWIS maintenance data. Ideally, the information should be collected by interviewing EWIS maintenance technicians.

Q #	QUESTION	ANSWER
1	Are there any shorthand notations you use (or know others have used) when entering maintenance actions related to electrical wiring system (e.g., “wr” for “wire” or “btn” for “button”)?	
2	Are there any slang terms that you use (or know others have used) when entering maintenance actions related to electrical wiring system?	
3	Are there any EWIS components that are unique or seem to be specialized for this aircraft?	
4	Is there anything else that might be helpful to someone who would review the maintenance reports for EWIS-related issues?	
5	How many years have you worked on this aircraft fleet?	
6	What is your current position?	

EXAMPLES OF EWIS COMPONENTS		
Wires	Relays	Splices
Fiber Optics	Terminals	Pins
Connectors	Buttons	Circuit Protection
Clamps	Switches	Grounds

FIGURE C-6. Example EWIS maintenance data questionnaire.

APPENDIX D

EWIS TASK THREE – PHYSICAL AIRCRAFT INSPECTION

D.1 SCOPE

The objective is to provide guidance on the physical inspection programs of all EWIS installed on aircraft and in fulfilling Task Three of this handbook. Application of this information will improve the likelihood that EWIS degradation from many causes—including environmental, maintenance-related, and age-related problems—will be identified and corrected. In addition, this information has been reviewed to ensure maintenance actions such as inspection, repair, overhaul, replacement of parts, and preservation do not (1) cause a loss of EWIS function, (2) cause an increase in the potential for smoke and fire in the aircraft, and (3) inhibit the safe operation of the aircraft. The guidance provided in this appendix is based on the information provided in MIL-HDBK-522, AC 25-27A, and AC 120-94.

The dependencies of Task Three are shown on figure D-1.

D.2 APPLICABLE DOCUMENTS (DELETED)

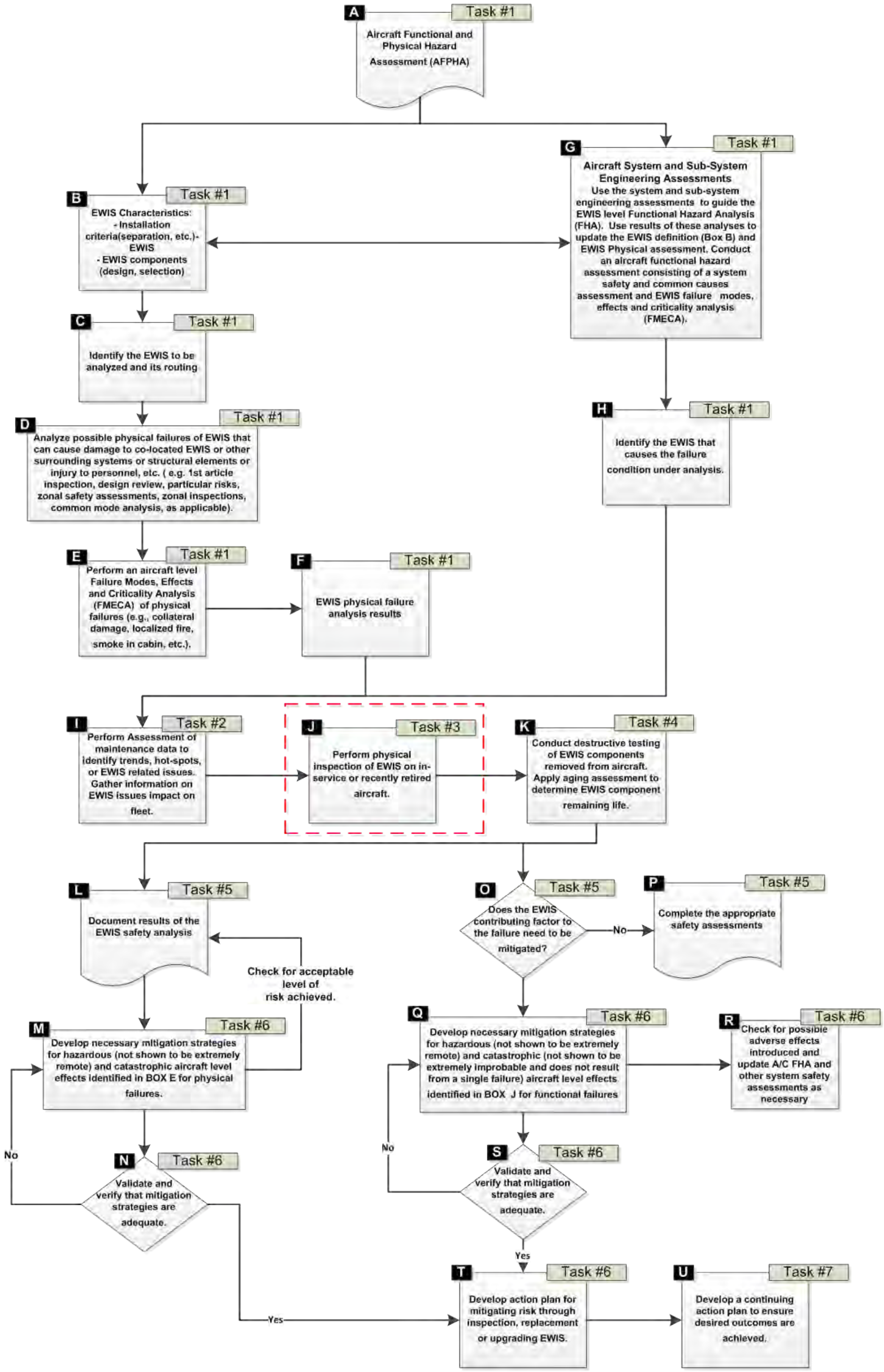
D.2.1 General. (Deleted)

D.2.2 Government documents. (Deleted)

D.2.2.1 Specifications, standards, and handbooks. (Deleted)

D.2.2.2 Other Government documents, drawings, and publications. (Deleted)

D.2.3 Non-Government publications. (Deleted)



NOTE: The red-dashed boxed area includes the Task Three efforts.

FIGURE D-1. Process flow for risk assessment.

D.3 BACKGROUND

The guidance in this task is based on recommendations generated by the ATSRAC and experience within Air Force Research Laboratory's (AFRL) Materials Integrity Branch, AFRL/RXSA. It is also drawn from maintenance, inspection, and alteration best practices identified through extensive research by ATSRAC and Federal Government working groups.

It is important to note that performance or physical degradation is not always visible. Micro-cracks in the insulation or heat damage caused by electrical overloads are difficult to see in individual wires, and even more difficult to see in large bundles. The same is true for other EWIS components. Thus, the physical inspection conclusions should not overstate the aircraft condition. This information must be combined with the data analysis, physical degradation, and system failure severity for comprehensive analysis.

D.4 CAUSES OF WIRE AND OTHER EWIS COMPONENT DEGRADATION

D.4.1 through D.4.12 describe what are considered the principal causes of wiring degradation. Anyone who conducts an inspection program or develops or performs maintenance programs should be familiar with these factors and ensure their proper emphasis. EWIS materials degraded due to the mechanisms described here should be considered when a comprehensive materials/aging analysis outlined in Task Four of this handbook is conducted.

D.4.1 Design (Added paragraph).

Poor design and initial installation are the single worst cause of EWIS system and component failure. Failure to identify, designate, and employ the correct component for the EWIS application will lead to premature failure. Examples include the use of the correct plating on a connector in a SWAMP area or using plastic RJ-45 Ethernet connectors on LRUs or WRAs. Design alignment with the application requirements is pivotal in achieving the intended mission for the life of designated life cycle of the platform/weapon system.

D.4.2 Modification and Upgrade of EWIS (Added paragraph).

EWIS modifications need to be designed with the latest design requirements (e.g. AS50881 latest published revision). Failure to cite the most current EWIS specifications leads to inducing known issues. Lack of contractual review, oversight, platform acceptance inspection, and enforcement is the same as poor or obsolete designs and components. They lead to unsafe, inefficient, and poor performing EWIS and affected systems. Thus, the next avionics system upgrade or defensive system may be unsupportable or not maintainable based on the poor installation or design.

D.4.3 Vibration.

High vibration areas tend to accelerate degradation over time, resulting in "chattering" contacts and intermittent symptoms. High vibration of cable ties or string ties can cause damage to insulation. In addition, high vibration will exacerbate any existing wire insulation cracking.

D.4.4 Moisture.

High moisture areas (above 60 percent Relative Humidity or areas with condensation) generally accelerate corrosion of terminals, pins, sockets, and conductors. Certain insulation types that contain aromatic polyimide material are susceptible to degradation from moisture. High moisture levels can also reduce the insulation resistance of materials and create conductive paths. EWIS component reliability and life is typically extended when installed in clean, dry areas with moderate temperatures.

D.4.5 Maintenance.

Scheduled and unscheduled maintenance activities, if done incorrectly, may contribute to long-term problems and degradation of EWIS. Certain repairs may have limited durability and should be evaluated to ascertain if rework is necessary. Repairs that conform to NAVAIR 01-1A-505 or USAF TO 1-1A-14, the approved aircraft TO on general wire repair practices, or manufacturers' recommended maintenance practices are generally considered permanent and should not require rework.

D.4.6 Metal shavings and debris.

Metal shavings and debris have been discovered on wire bundles after maintenance, repair, or modification has been performed. Work areas should be cleaned while the work is in progress to ensure all shavings and debris are removed. The work area should be thoroughly cleaned after work is complete, and the area should be inspected after the final cleaning.

D.4.7 Repairs.

Repairs should be performed according to the most effective, authorized methods available. Since wire splices are more susceptible to degradation, arcing, and overheating, the recommended method of repairing a wire is with an environmentally sealed splice. Use guidance from TO 1-1A-14 or the approved aircraft TO on general wire repair practices.

D.4.8 Indirect damage.

Events such as pneumatic duct ruptures or duct clamp leakage can cause damage that, while not initially evident, can later cause wiring problems. When events such as these occur, surrounding EWIS should be carefully inspected to ensure that there is no damage or potential for damage. Indirect damage caused by these types of events could be broken clamps or ties, broken wire insulation, or even broken conductor strands. In some cases, the pressure of the duct rupture could cause wire separation from the connector or terminal strip.

D.4.9 Contamination.

EWIS contamination refers to any of the following situations:

1. a. Presence of a foreign material that is likely to cause degradation of EWIS.

   b. Presence of a foreign material that is combustible or able to sustain a fire after removal of the ignition source. An EWIS contaminant may be in solid or liquid form.
2. Solid contaminants. Solid contaminants, such as the following, can accumulate on wiring and other EWIS components and could degrade or penetrate wiring or other EWIS components:
   a. Metal shavings/swarf.
   b. Debris.
   c. Livestock waste.
   d. Lint.
   e. Dust.
3. Fluid contaminants. Chemicals in fluids, such as the following, can contribute to degradation of wiring and other EWIS components:
   a. Hydraulic fluid.
   b. Battery electrolytes.
   c. Fuel.
   d. Corrosion inhibiting or preventative compounds.
   e. Waste system chemicals.
   f. Cleaning agents.
   g. De-icing fluids.

h. Paint.
i. Soft drinks.
j. Coffee/tea.

4. Contaminants requiring special consideration.
   a. Special consideration is required for the following:
      1) Hydraulic fluids.
      2) De-icing and lavatory fluids.
      3) Battery electrolyte.
      4) Engine exhaust.
      5) Engine oil/vapors.
      6) Fuel vapors.
      7) Some CPCs.
   b. These fluids, although essential for aircraft operation, can damage EWIS components, such as connector grommets and inserts, wire bundle clamps, cable ties, and wire lacing, and cause chafing and arcing. EWIS components exposed to these fluids should be given special attention during inspection. Contaminated wire insulation that has visible cracking or breaches to the core conductor can eventually arc and cause a fire. Wire and other EWIS components exposed to, or in close proximity to, any of the chemicals listed above may need to be inspected more frequently for damage or degradation.
   c. When areas or zones of the aircraft that contain both wiring and chemical contaminants are cleaned, special cleaning procedures and precautions may be needed. Such procedures may include wrapping wire connectors and other EWIS components with a protective covering prior to cleaning. This would be especially true if pressure-washing equipment is used. In all cases, the aircraft manufacturer’s recommended procedures should be followed.
   d. Lavatory (waste) system contamination. Lavatory system spills also require special attention. Service history has shown that these spills can have detrimental effects on aircraft EWIS and have resulted in smoke and fire events. When this type of contamination is found, all affected components in the EWIS should be thoroughly cleaned, inspected, and repaired or replaced as necessary. The source of the spill or leakage should be located and corrected. These fluids are typically highly conductive, alkaline (pH values above 10) and damaging to EWIS components such as relays, switches, connectors, and wire insulation containing aromatic polyimide (Kapton®).
5. Areas of the aircraft subjected to cleaning or exposed to pressure washing should be inspected for physical damage and chemical contamination.

D.4.10 Heat.

Exposure to high heat can accelerate degradation of EWIS by causing wire insulation oxidation, thermal damage, and loss of solvents, which leads to loss of mechanical properties and/or cracking. Direct contact with a high heat source can quickly damage insulation. Burned, charred, or even melted insulation is the most likely indicator of this type of damage. Low levels of heat can also degrade wiring over a longer period. This type of degradation is sometimes seen on engines, generators, in galley wiring such as in coffee makers and ovens, and behind fluorescent lights, especially ballasts. Sealed cockpits with a glass canopy in direct sunlight can reach elevated temperatures sufficient to damage EWIS components.

D.4.11 Cold.

Exposure to extremely cold temperatures, such as those found at typical cruising altitudes, or wires exposed to cold temperatures while the aircraft is parked in a cold environment, increases the rigidity of wire insulation in those wires that have little or no current flow. Vibration or other types of movement of the EWIS during this time could lead to wire faults. This is important to remember when maintenance to or around these wires is performed in a cold environment.
EWIS located outside the pressurized fuselage—such as those located in landing gear wheel wells, wing leading and trailing edges, and in the horizontal and vertical stabilizers—are routinely subjected to these extreme cold temperatures.

D.4.12 Severe Wind and Moisture Prone (SWAMP) areas.

Wheel wells, wing folds and areas near wing flaps, and areas directly and extensively exposed to weather conditions are considered SWAMP areas on aerospace vehicles. The EWIS components in these areas require special attention.

D.5 GENERAL EWIS MAINTENANCE GUIDANCE

Areas to be inspected should be cleaned to minimize the possibility that collected dirt, grease, or other contaminants might hide unsatisfactory conditions that would otherwise be undetected during inspection. Such contamination could cause EWIS component degradation and also prevent an effective General Visual Inspection (GVI) or Detailed Inspection (DET) if it were not cleaned. Additionally, depending on the type and amount present, contaminants may also be combustible and sustain a fire should electrical arcing occur. Follow the aircraft manufacturer's procedures or other methods, techniques, and practices acceptable to the maintainer to perform cleaning considered necessary. The cleaning process itself should not compromise the integrity of the EWIS. Additional guidance for cleaning and preserving EWIS is available in NAVAIR 01-1A-505 or USAF TO 1-1A-14.

D.5.1 Levels of inspection applicable to EWIS.

Though the term "detailed visual inspection (DVI)" remains valid for a detailed inspection using only eyesight, this may represent only part of the inspection required in the EWIS Instruction for Continued Airworthiness (ICA) used to establish an operator's maintenance program. The acronym "DVI" should not be used because that term may exclude tactile examination, which is sometimes needed. The following definitions are provided instead.

D.5.2 General Visual Inspection.

A general visual examination of an interior or exterior area, installation, or assembly will detect only obvious damage, failure, or irregularity. This level of inspection is made from within touching distance unless otherwise specified. A mirror may be necessary to enhance visual access to all exposed surfaces in the inspection area. This level of inspection is made under normal lighting conditions such as daylight, hangar lighting, flashlight, or droplight and may require removal or opening of access panels or doors. Stands, ladders, or platforms may be required to gain proximity to the area being checked. Use Guideline 1 of MIL-HDBK-522 for EWIS inspection procedures. Additional guidance for EWIS inspection is available in NAVAIR 01-1A-505 or USAF TO 1-1A-14.

There is usually no need to remove equipment or displace EWIS when a GVI is performed, unless the access instructions specifically call for it.

The area to be inspected should be clean enough to minimize the possibility that collected dirt, grease, or other contaminants might hide unsatisfactory conditions that would otherwise be obvious. Use the aircraft manufacturer's procedures or other methods, techniques, and practices acceptable to the FAA for any cleaning considered necessary. The cleaning process itself should not compromise the integrity of EWIS. Avoid using high-pressure cleaning and abrasive materials, which could damage wire insulation and other EWIS components.

In general, the person who performs a GVI is expected to identify degradation from wear, vibration, moisture, contamination, excessive heat, aging, and so forth and assess what actions are appropriate to address the discrepancy. This assessment should consider potential effects on adjacent system installations, particularly if those systems include wiring. Any observed discrepancies, such as chafing, broken clamps, sagging, interference, contamination, etc., should be addressed.

An EWIS stand-alone GVI applies the above inspection techniques to wires, cables, and other EWIS components identified in the inspection procedure.

D.5.3 Detailed inspection (DET).
A DET is an intensive examination of a specific item, installation, or assembly to detect damage, failure, or irregularity. Available lighting is normally supplemented with a direct source of good lighting at an intensity deemed appropriate. Inspection aids such as mirrors, magnifying lenses, or other means may be necessary. Surface cleaning and elaborate access procedures may be required. A DET can be more than just a visual inspection, since it may include tactile assessment in which a component or assembly is checked for tightness/security. It may require the removal of items such as access panels and drip shields or the moving of components. Additional guidance for EWIS inspection is available in NAVAIR 01-1A-505 or USAF TO 1-1A-14.

Detailed inspection procedures for various EWIS components and examples of preferred and unacceptable conditions with respect to SAE AS50881 are given in MIL-HDBK-522. MIL-HDBK-522 should be used to inspect aircraft EWIS and maintain it in an airworthiness condition.

Tactile assessment as used in the context of an EWIS DET does not require the disassembly of wire bundles to inspect individual wires within the bundle.

D.5.4 Zonal inspection.
This is a collective term, which describes selected GVIs and DETs applied to each aircraft zone, defined by access and area, to check the component integrity within the zone. A zonal inspection is an inspection of an area or zone to detect unsatisfactory conditions and discrepancies.

D.5.5 EWIS-related guidance for zonal inspections.
The following EWIS degradation conditions are typical of what should be detectable and addressed as a result of a zonal inspection (as well as a stand-alone GVI). Maintenance and training documentation should include these items. This list is not intended to be all-inclusive and may be expanded as appropriate. Existing inspection handbooks (such as MIL-HDBK-522) should be used to supplement the inspection information provided here.

1. Wire/wire harnesses.
    a. See MIL-HDBK-522, Guidelines 3, 4, 6, 7, 8, 12, 13, 15, 16, 17, 19, 21, 22, and 29 through 32.
    b. Wire bundle/wire bundle or wire bundle/structure contact/chafing.
    c. Wire bundles sagging or improperly secured.
    d. Wires damaged (obvious damage because of mechanical impact, overheat, localized chafing).
    e. Lacing tape and/or ties missing/incorrectly installed.
    f. Wiring protection sheath/conduit deformed or incorrectly installed.

g. End of sheath rubbing on end attachment device.
h. Grommet missing or damaged.
i. Dust and lint accumulation.
j. Surface contamination by metal shavings/swarf.
k. Contamination by liquids.
l. Deterioration of previous repairs (e.g., splices).
m. Deterioration of production splices.
n. Inappropriate repairs (e.g., an incorrect splice).
o. Inappropriate attachments to or separation from fluid lines.

2. Connectors.
   a. See MIL-HDBK-522 Guidelines 5, 6, and 33 through 41.
   b. External corrosion on receptacles.
   c. Backshell tail broken.
   d. Rubber pad or packing on backshell missing.
   e. No backshell wire securing device.
   f. Fool-proofing chain broken.
   g. Safety wire missing or broken.
   h. Discoloration/evidence of overheat on terminal lugs/blocks.
   i. Torque stripe misaligned.
   j. Broken, bent, or missing pins.
   k. Pin or socket corrosion.
   l. Contamination inside connector or on mating surfaces.
3. Switches.
   a. Rear protection cap damaged.
   b. Missing hardware (e.g., screws, washers).
   c. Loose hardware.
   d. Improper hardware.
4. Ground points.
   a. See MIL-HDBK-522, Guideline 28.
   b. Corrosion.
   c. Loose hardware.
5. Bonding braid/bonding jumper.
   a. See MIL-HDBK-522, Guideline 28.
   b. Braid broken or disconnected.
   c. Multiple strands corroded.
   d. Multiple strands broken.
6. Wiring clamps or brackets.
   a. See MIL-HDBK-522 Guidelines 14 and 18.
   b. Corroded.
   c. Broken/missing.
   d. Bent or twisted.
   e. Unstuck/detached.
   f. Attachment faulty (bad attachment or fastener missing).

   g. Protection/cushion damaged.
7. Supports (rails or tubes/conduit).
   a. See MIL-HDBK-522 Guidelines 42, 45, and 48
   b. Broken.
   c. Deformed.
   d. Fastener missing.
   e. Edge protection on rims of feed-through holes missing.
   f. Racetrack cushion damaged.
   g. Drainage holes (in conduits) obstructed.
8. Circuit breakers, contactors, or relays.
   a. See MIL-HDBK-522, Guideline 43.
   b. Signs of overheating.
   c. Signs of arcing.
   d. Missing hardware (e.g., screws, washers).
   e. Loose hardware.
   f. Improper hardware.
9. Pressure Seals.
   a. Evidence of seal loss around the bulkhead seal or internally to the connector.
   b. Debris build-up or fuel residue in the connector.
   c. Cracks or corrosion in the glass-to-metal seals around feed-through pins.
10. Shield terminations.
   a. See MIL-HDBK-522, Guidelines 20, 27, and 46.
   b. Signs of overheat/under-heated.
   c. Loose or incorrect size.
   d. Corroded.
   e. Missing/broken ground lead wire.
11. Terminal lugs.
   a. See MIL-HDBK-522, Guidelines 25 and 26.
   b. Signs of overheat.
   c. Loose lug or incorrect/missing hardware.
   d. Corroded.
   e. Missing/broken wire or strands
   f. Incorrect lug size for the size stud.

D.6 WIRING INSTALLATIONS AND AREAS OF CONCERN

Maintenance material should address the following installations and areas.

D.6.1 Wiring installations.

D.6.2 Clamping points.

Damaged clamps, migration of clamp cushions, or improper clamp installations contribute to wire chafing. Aircraft manufacturers specify clamp type and part number for EWIS throughout the aircraft. Use those specified by the aircraft manufacturer when clamps are replaced. Plastic cable ties provide a rapid method of clamping, especially during line maintenance operations, but improperly installed tie wraps can have a detrimental effect on wire insulation. Plastic ties are not approved for any military installation, unless expressly approved by the particular weapon system/platform in their maintenance manual. When new wiring is installed as part of a TCTO, AFB, or other modification, the drawings will provide wire routing, clamp type and size, and proper location. Examples of significant wiring alterations are the installation of new avionics systems, new galley equipment, and new instrumentation. Wire routing, type of clamp, and clamping location should conform to the approved drawings. Adding new wire to existing wire bundles may overload clamps and cause wire bundles to sag and wires to chafe. Raceway clamp foam cushions may deteriorate with age, disintegrate, and thus fail to provide proper clamping.

Particular attention is required where wire bundles normally flex or move when doors and panels are opened and closed. Inspect for improper usage of clamps and clamp cushions with types not compatible for the installation environment. Any evidence of loose clamps, lacing tape ties, cable ties, loose or damaged bundle clamp standoffs, distorted bundle clamp support brackets, or improper usage of clamps or clamp cushions is considered a discrepancy.

D.6.3 Connectors.

Worn environmental seals, loose connectors, missing seal plugs, missing dummy contacts, or lack of strain relief on connector grommets can compromise connector integrity and allow contamination to enter the connector and lead to corrosion or grommet degradation. Connector pin corrosion can cause overheating, arcing, and pin-to-pin shorting. Drip loops should be maintained when connectors are below the level of the harness, and tight bends at connectors should be avoided or corrected.

Inspect potting of connectors or feed-through bushings for proper sealing, cracking, or deterioration. Look for contamination tracks and burn marks across potting material to metals. Pay close attention to vertically oriented connector parts for evidence of moisture. Evidence of improper sealing, cracking, deterioration, moisture, or burn marks of potting is a discrepancy.

Inspection of connector internals (pins, internal contamination, etc.) is dependent upon where the physical inspection is performed and may not be possible in all conditions. The connector assessment level should be coordinated with the aircraft maintainer.

D.6.4 Terminations.

Terminations, such as terminal lugs and terminal boards, are susceptible to mechanical damage, corrosion, heat damage, chemical contamination, dust, and dirt. Over time, vibration can cause high-current-carrying feeder cable terminal lugs to lose their original torque value and result in arcing (see AIR 6151). One sign of this is heat discoloration at the terminal end. Proper build-up and nut torque is especially critical on high-current-carrying feeder cable lugs. Corrosion on terminal lugs and boards can cause high resistance and overheating. Dust, dirt, and other debris are combustible and could sustain a fire if ignited from an overheated or arcing terminal lug. Terminal junctions and terminal boards located in equipment power centers (EPC), avionics compartments, and throughout the aircraft need to be kept clean and free of combustibles.

D.6.5 Backshells.

Wires may break at backshells from excessive flexing, lack of strain relief, or improper build-up. Loss of backshell bonding may also occur because of these and other factors.

D.6.6 Sleeving and conduits.

Damage to sleeving and conduits, if not corrected, may lead to wire damage. Damage such as cuts, dents, and creases on conduits may require further investigation for condition of wiring within.

D.6.7 Grounding points.

Grounding points should be checked for security (i.e., finger tightness), condition of the termination, presence of corrosion, compliance with platform maximum fill requirements, and cleanliness. Grounding points that are corroded and loosened or that have lost their protective coating should be tested for suitable bonding (ARP1870), repaired, then re-potted/sealed per the application requirement. Additional guidance for EWIS bonding and grounding is available in NAVAIR 01-1A-505 or USAF TO 1-1A-14.

Harness Protection: Harness protective systems (used to protect wiring from chafing, heat, or electromagnetic interference) may become brittle or chaffed. The harness protection should be examined for wear, heat damage, or increased stiffness.

D.6.8 Pressure seals.

A pressure seal is an area where a wire bundle passes through a pressure bulkhead via a bulkhead connector. Examples would be between a pressurized and unpressurized bay or where one side of a connector is in a fuel compartment and the other side is in a dry bay area. Pressure seals may also be used when a wire bundle passes through a firewall and other openings in the structure. This is typically a hermetic connector with glass-to-metal seal in the connector pin feed-through; the feed-through may also use an elastomeric grommet cork-and-bottle type seal.

Inspection should concentrate on evidence of seal loss around the bulkhead seal and internally to the connector. There may be evidence of debris build-up or fuel residue in the connector.

These connectors typically contain feed-through pins in a glass-to-metal seal, which can crack or exhibit corrosion. A grommet based feed-through seal is less robust than a glass-to-metal seal and must be inspected periodically for evidence of seal failure.

D.6.9 Splices.

Both sealed and non-sealed splices are susceptible to vibration, mechanical damage, corrosion, heat damage, chemical contamination, and environmental deterioration. Power feeder cables normally carry high current levels and are very susceptible to installation error and splice degradation. All splices should conform to the applicable platform Technical Manual or NAVAIR 01-1A-505 or USAF TO 1-1A-14.

D.6.10 Areas of concern.

D.6.11.1 Wire raceways and bundles.

Addition of wires to existing wire raceways may cause undue wear and chafing of the wire installation and inability to maintain the wire in the raceway. Addition of wires to existing bundles may cause wire to sag against the structure, which can cause chafing.

D.6.11.2 Wings.
Wing leading and trailing edges are difficult environments for wiring installations. On some aircraft models, wing leading and trailing edge wiring is exposed whenever the flaps or slats are extended. Slat torque shafts and bleed air ducts in these areas are other potential damage sources.

D.6.11.3 Engine, pylon, and nacelle area.
These areas experience high vibration, heat, and frequent maintenance and are susceptible to chemical contamination.

D.6.11.4 Accessory compartment and equipment bays.
These areas typically contain items such as electrical components, pneumatic components and ducting, and hydraulic components and plumbing. They may be susceptible to vibration, heat, and liquid contamination.

D.6.11.5 Auxiliary power unit (APU).
Like the engine/nacelle area, the APU is susceptible to high vibration, heat, frequent maintenance, and chemical contamination.

D.6.11.6 Landing gear and wheel wells.
This area is exposed to SWAMP in addition to vibration and chemical contamination.

D.6.11.7 Electrical panels and LRUs/WRAs.
Electrical panel wiring is particularly prone to broken wires and damaged insulation when these high-density areas are disturbed during troubleshooting activities, modifications, and refurbishments. Tying wiring to wooden dowels to reduce its disturbance during modification can minimize wire damage. For some configurations, use of connector support brackets would be more desirable and cause less wire disturbance than removal of individual connectors from the supports.

D.6.11.8 Batteries.
Wires and other EWIS components near all aircraft batteries are susceptible to corrosion and discoloration and should be inspected for those problems. Inspect discolored wires and other EWIS components for serviceability.

D.6.11.9 Power feeders.
High-current wire and associated connections have the potential to generate intense heat. Vibration may cause degradation or loosening of power feeder cables, terminals, and splices. If signs of overheating are seen, splices or termination should be replaced. For both galley and engine/APU generator power feeders, depending on the design, service experience may indicate a need for periodic checks of proper torque on power feeder cable terminal ends, especially in high vibration areas.

D.6.11.10 Under galleys, lavatories, and cockpit.
Areas under the galleys, lavatories, and cockpit are particularly susceptible to contamination from such things as coffee, food, water, soft drinks, lavatory fluids, dust, and lint. Correct floor panel sealing procedures can minimize such contamination in these areas.

D.6.11.11 Fluid drain plumbing.
Leaks from fluid drain plumbing could lead to contamination of EWIS. Service experience may show a need for periodic leak checks or cleaning, in addition to routine visual inspections.

D.6.11.12 Fuselage drain provisions.
Some installations include plumbing features designed to catch leakage and drain it to an appropriate exit. Blockage of the drain path can result in contamination of the EWIS. In addition

to routine visual inspections, service experience may signal a need to check these installations and associated plumbing periodically to ensure the drain path is free of obstructions.

D.6.11.13 Cargo bay underfloor.
Damage to EWIS in the cargo bay underfloor can occur from maintenance activities in the area.

D.6.11.14 EWIS subject to movement.
Wiring and other EWIS components that are subject to movement or bending during normal operation or maintenance access, at locations such as doors, actuators, landing gear mechanisms, and electrical access panels, should be inspected at those areas where movement occurs.

D.6.11.15 Access panels.
EWIS near access panels could be accidentally damaged from repetitive maintenance access and may warrant special attention.

D.6.11.16 Under doors.
Areas under cargo, passenger, and service entry doors are susceptible to fluid entering from rain, snow, and liquid spills. Fluid drain provisions and floor panel sealing in these areas should be periodically inspected and repaired as necessary.

D.6.11.17 Under cockpit sliding windows.
Areas under cockpit sliding windows are susceptible to water entering from rain and snow. Fluid drain provisions in these areas should be periodically inspected and repaired as necessary.

D.6.11.18 Areas where EWIS is difficult to access.
Areas difficult to access, such as flight deck instrument panels and the cockpit pedestal, could accumulate excessive dust and other contaminants because of infrequent cleaning. In these areas, it may be necessary to remove components and disassemble other systems to facilitate access to the area.

D.6.11.19 Severe Wind And Moisture Prone areas.
Areas such as wheel wells, wing folds and areas near wing flaps, and areas directly exposed to extended weather conditions are considered SWAMP areas on aerospace vehicles.

D.6.11.20 Separation distance from structure and hydraulic/fuel lines.

Inspect wiring for the minimum clearance (one-half inch) from structure, surfaces, and equipment. Where a minimum clearance (one-half inch) cannot be maintained, a tighter minimum clearance (three-eighths inch) is acceptable where anti-chafing material is used. Ensure a minimum clearance (2 inches) between wiring and fluid-carrying lines, tubes, and equipment is maintained. When there is less than acceptable clearance between wiring and fluid-carrying lines, there must be a positive means (clamp) to maintain a minimum (one-half inch) clearance. Improper clearance between wiring, fluid-carrying lines, tubes, and equipment or lack of or improperly installed anti-chafing material is a discrepancy.

D.6.11.21 Separation from other components.
Inspect for proper wiring clearance from linkages, throttle controls, boxes, covers, structures, control cables, and component mounting hardware. Improper wiring clearance from linkages, throttle controls, boxes, covers, structures, control cables, and component mounting hardware is a discrepancy.

D.6.11.22 EWIS component identification.
Inspect all wiring for secure and legible connector identifications in accordance with SAE AS50881, NAVAIR 01-1A-505, or USAF TO 1-1A-14. Illegible or missing identification is a discrepancy.

D.7 SELECTION OF AIRCRAFT

The representative aircraft is the configuration of each series aircraft model that incorporates all variations of EWIS used in production on that series aircraft and all designed modifications mandated. For example, a particular aircraft model may be offered in various configurations depending on mission requirements. For a given aircraft model, the resultant EWIS examination must account for any differences between configurations. The placement of galleys, lavatories, equipment, and other interior furnishings might affect the type inspections identified. The resultant EWIS inspection plan must reflect such differences.

Ideally, the physical EWIS inspection should be performed when a representative aircraft is at the heavy maintenance level, when many of the aircraft panels have been opened or removed. Inspections performed on in-service aircraft are likely to be more access and time limited, which limits the inspection detail possible.

D.8 SELECTION OF EWIS COMPONENTS FOR INSPECTION

All EWIS components should be physically examined to the best of the inspection team's ability. A plan should be developed prior to the aircraft inspection to identify which equipment, floor boards, and/or panels will need to be removed to provide inspection access. High-failure EWIS components identified in Task Two should be specifically included in the inspection plan. A checklist should be developed for each area to ensure all identified components are properly inspected.

D.9 ELECTRICAL CHARACTERIZATION

The use of electrical characterization tools can supplement the physical assessment of EWIS components. Some of these tools provide the capability to assess circuit breaker boxes and relay panels, identify hard shorts and opens and high resistance in wiring or connections, and measure impedance. It can be advantageous to coordinate the physical inspection with a scheduled automatic test system characterization of the electrical system.

Intermittent Fault Testing, Detection and Location: Testing to identify and locate intermittent faults in an EWIS requires a comprehensive understanding of the materials and components under test as well as the failure mechanisms involved. Intermittent faults can be very difficult to detect and often are non-recurring. They can vary significantly in duration from several milliseconds to less than a few nanoseconds. Reproducing intermittent faults through testing is highly dependent on recreating the operating environment where intermittent problems are suspected and testing over a period sufficient to capture faults and identify potential fault locations occurs. If intermittency testing successfully detects faults during environmental testing, visual inspection of areas under test must be conducted to identify the location and root cause of the fault. This includes inspection of all tested interconnections and wiring for cracked/broken solder joints, the presence of conductive contaminants such as solder flux residues from manufacturing or earlier repairs, corrosion products, whiskers, dendrites, electro-migration, and FOD and/or other failure evidence associated with aging or manufacturing. MIL-PRF-32516 offers requirements for intermittent test equipment capable of testing longer duration intermittent events between 500 µseconds and 5 milliseconds. The standard does not identify the environmental test conditions required of the items under test to detect intermittency or the test time needed to detect any related fault in EWIS or associated interconnects.

D.10 INSPECTION REPORT

After completion of the physical examination, a report should be prepared which details the findings from the inspection. Each reported discrepancy should have an associated criticality level in keeping with the service's accepted norms (e.g. Class I=Major, II=intermediate, III=minor, IV=superficial; see NAVAIR 01-1A-505-1, WP 004 01). The report should include photographs of discrepancies found during the inspection. Any items identified during the inspection process that may affect aircraft airworthiness should be addressed immediately with corrective actions.

D.11 SKILLS OF PERSONNEL PERFORMING INSPECTION

The following skills and knowledge of specifications that govern them are necessary to conduct an aircraft wiring assessment:

a. Wiring, Aerospace Vehicle: SAE AS50881 (version applicable to aircraft).
b. Wiring, Aerospace Vehicle: MIL-W-5088 (version applicable to aircraft).
c. NAVAIR 01-1A-505 Wiring Maintenance Manual (Volumes -1, -2, -3, and -4).
d. Aircraft Electric Power Characteristics, MIL-STD-704 (version applicable to aircraft).
e. Fiber Optic Cabling Systems Requirements and Measurements, MIL-STD-1678-1.
f. Selection and Installation of Aircraft Electric Equipment, MIL-STD-7080.
g. Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety, SAE ARP1870.
h. FAA Airworthiness Certification; FAR Part 21, Part 23, Part 26, Part 121, Part 123.
i. Acceptable Methods, Techniques, and Practices - Aircraft Inspection and Repair; FAA AC-43.13-1B, Ch. 11.
j. Flight Clearance Policy for Air Vehicles and Aircraft Systems, NAVAIRINST 13034.1C.
k. Airworthiness Certification Criteria, MIL-HDBK-516.
l. Governing Wiring Specifications, SAE AS22759 and ANSI/NEMA WC27500; Platform Detailed Specification (SD), etc.

Knowledge and demonstrated experience with the following:

a. EWIS component, configuration, and materials.
b. Aircraft Ground Operations/Safety.
c. Systems/Structures Terminology.
d. Electrical Drawing Interpretation.
e. Installation Drawing Interpretation.
f. Airworthiness Training.
g. FAA Functions and requirements leading to Airworthiness Approval (applicable for commercial derivative aircraft).

Enhanced Zonal Analysis - Details of Zone

Zone Number ☐ **Zone Description** ☐

	COMMENTS
☐ Hydraulic Plumbing	
☐ Hydraulic Components (Valves, Actuators, Pumps)	
☐ Pneumatic Plumbing	
☐ Pneumatic Components (Valves, Actuators)	
☐ EWIS - Power Feeder (High Voltage, High Amperage)	
☐ EWIS - Motor-Driven Devices	
☐ EWIS - Instrumentation and Monitoring	
☐ EWIS - Data bus	
☐ Electrical Components	
☐ Primary Flight Control Mechanisms	
☐ Secondary Flight Control Mechanisms	
☐ Engine Control Mechanisms	
☐ Fuel System Components	
☐ Insulation	
☐ Oxygen System Components	
☐ Potable Water System Components	
☐ Waste Water System Components	

FIGURE D-2. Inspection worksheets.

Enhanced Zonal Analysis - Hostility of Environment and Likelihood of Accidental Damage

Zone Number		Zone Description	

Hostility of Environment	
1 - Passive / 2 - Moderate / 3 - Severe	
Temperature	
Vibration	
Chemicals (toilet fluids, de-icing fluid, etc.)	
Humidity	
Contamination	
Shock	
Other	
Enter the Highest Number.	

Likelihood of Accidental Damage	
1 - Passive / 2 - Moderate / 3 - Severe	
Ground Handling Equipment	
Foreign Object Debris (FOD)	
Weather Effects (hail, rain, etc.)	
Frequency of Maintenance Activities	
Fluid Spillage	
Crew Traffic	
Other	
Enter the Highest Number.	

		Zone Size		
		Small	**Medium**	**Large**
Density	**Low**	1	2	3
	Medium	2	2	3
	High	2	3	3

FIGURE D-2. Inspection worksheets – Continued.

Aircraft Physical Inspection Log

Date ____________ **Name(s) of assessor(s)** ____________ **Aircraft ID** ____________

Location ____________ **Configuration** ____________ **Page #** ____________

Line #	Zone	Subzone/ Area/ Access Panel	Harness ID	Wire ID(s)	Discrepancy Description	Notes	Criticality (Class: I - Major, II - Intermediate, III - Minor, IV - Superficial)	Ease of access (1 - Low, 2 - Mid, 3 - High)	Photo #'s
1									
2									
3									
4									
5									
6									
7									
8									
9									

FIGURE D-2. Inspection worksheets – Continued.

APPENDIX E

EWIS TASK FOUR – COMPONENT ASSESSMENT

E.1 SCOPE

Selective sampling of EWIS devices becomes necessary to determine the current and future health condition of the fleet's EWIS. The health assessment of a component may be limited to pass/fail conditions or provide information on the future system reliability, depending on the device type and industry research on the particular component. This task focuses on a destructive materials/aging analysis of wiring and electrical components removed from the aircraft based on information gathered in earlier tasks. Guidance is provided on processes and sampling techniques associated with EWIS component assessment and is based on information provided in MIL-DTL-5757, MIL-STD-202, MIL-STD-1678-1, and DOT/FAA/AR-08/2.

E.2 APPLICABLE DOCUMENTS

E.2.1 GENERAL.

The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

E.2.2 Government documents.

E.2.2.1 Specifications, standards, and handbooks.

The following specifications, standards, and handbooks form a part of this document to the extent specified herein.

DEPARTMENT OF DEFENSE SPECIFICATIONS

MIL-DTL-17	-	Cables, Radio Frequency, Flexible and Semirigid, General Specification for
MIL-DTL-3950	-	Switches, Toggle, Environmentally Sealed, General Specification for
MIL-DTL-5757	-	Relays, Electromagnetic, General Specification for

DEPARTMENT OF DEFENSE STANDARD

MIL-STD-202	-	Electronic and Electrical Component Parts

(Copies of these documents are available online at https://quicksearch.dla.mil/.)

E.2.2.2 Other Government documents, drawings, and publications.

The following other Government documents, drawings, and publications form a part of this document to the extent specified herein.

FEDERAL AVIATION ADMINISTRATION (FAA)

DOT/FAA/AR-08/2	-	Aircraft Wiring Degradation Study

(Copies of this document are available online at www.faa.gov.)

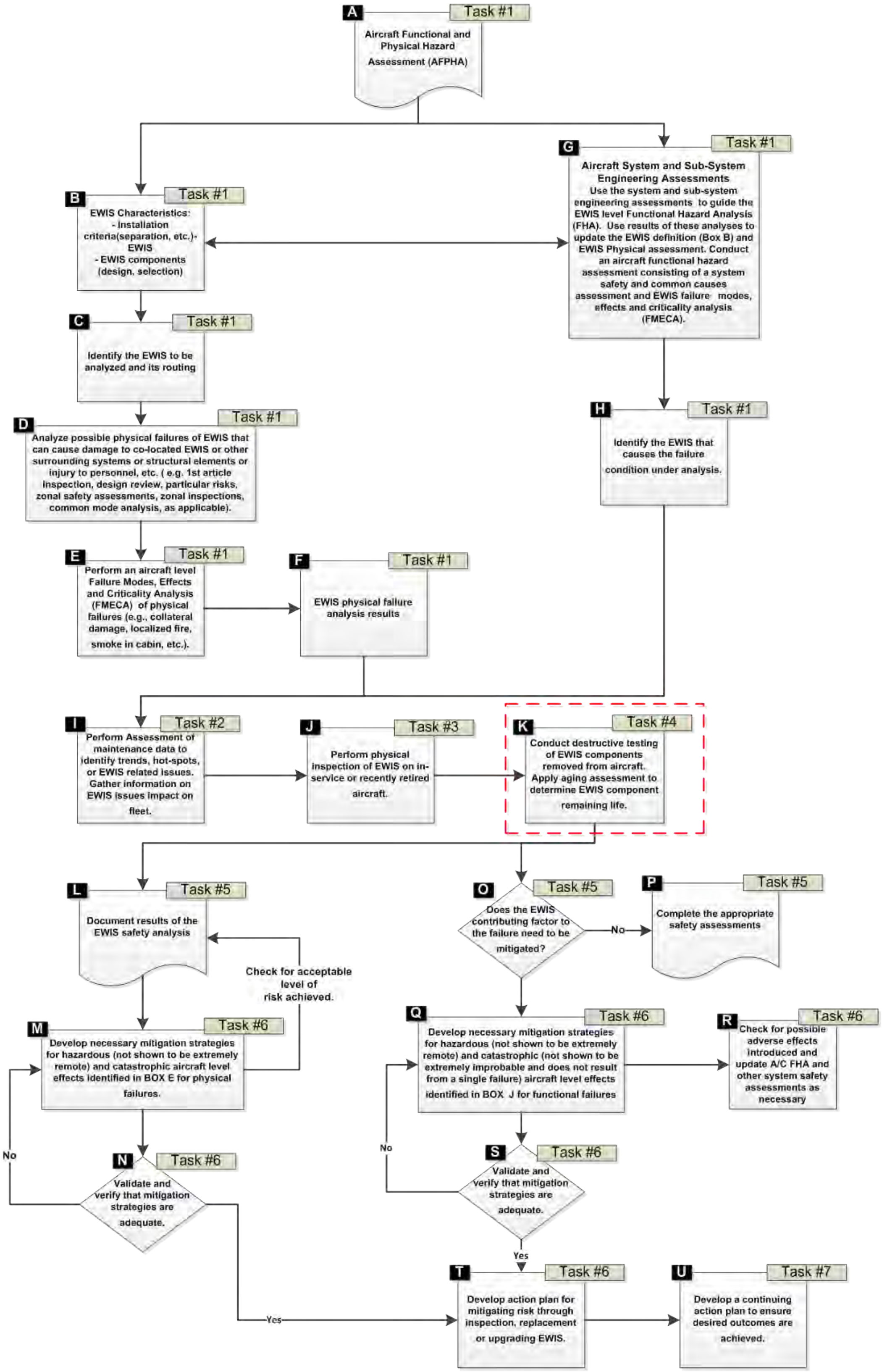
E.3 OVERVIEW

There are two main goals for the EWIS component assessment:

1. Determine the current condition of the EWIS components.
2. Determine the remaining component service life.

This process, with regard to the current EWIS component condition, seeks to identify whether the equipment is currently able to meet the performance requirements for the platform (cases in which the component does not meet minimum specifications may require immediate action to assess the susceptibility of the fleet).

The term “remaining life” used herein refers to the time remaining in the device’s life cycle before age-related failures (wear-out failures) begin to emerge. When EWIS components are tested to failure, the degradation and remaining cycles (or years of service) can be assessed and used in the overall risk assessment outlined in Task Five. Frequently, in-situ component testing provides information on only the component's current health and no information to predict future performance and reliability. Thus, destructive testing is emphasized in this handbook. The integration of the component assessment performed in Task Four is shown on figure E-1.



NOTE: The red-dashed boxed area includes the Task Four efforts.

FIGURE E-1. Process flow for risk assessment.

E.4 EWIS DEVICES TO BE CONSIDERED FOR ASSESSMENT

The following is a list of devices included in the EWIS degradation assessment. Information gathered from either the data analysis (Task Two) or inspection (Task Three) should be used to add or remove devices from this list as applicable to the specific platform. Compare condition of components with new (unused) components. Apply aging assessment techniques and aging/degradation models to determine remaining life of EWIS components.

1. Wire insulation, cable jacket, and conductor integrity (E.5.5)
2. Protective harness materials (E.5.6)
3. Shield and ground terminations (E.5.7)
4. Connector contact integrity and shield effectiveness (E.5.8)
5. Circuit breaker contact integrity and the trip curve verification (E.5.9)
6. Relay contact integrity and actuation performance (E.5.10)
7. Switch contact integrity and actuation performance (E.5.11)
8. Electrical distribution panels (E.5.12)
9. Terminal boards, ground studs, and connector back shells (E.5.13)

E.5 DEVICE ASSESSMENT METHODS

The assessment methods described herein for the devices listed are not all-inclusive, but are representative of the factors that should be considered through EWIS degradation assessment tests. Additional technologies and assessment methods may be available. These should be evaluated prior to selection of a particular assessment technique.

Further, many of the assessment methods described herein require specialized equipment and should be performed by a laboratory or organization with knowledge and experience of the component degradation.

E.5.1 General assessment techniques.

There is commonality between the devices and the assessments that are recommended through the EWIS component evaluation process. The following are standard evaluations that should be performed on all components selected for testing.

E.5.2 Visual Inspection.

Conduct a laboratory visual and optical inspection to document condition of components and follow with a detailed materials and aging analysis of selected EWIS components. Any anomalies (e.g., discoloration, deformation, wear, etc.) should be noted. This inspection should be performed on all components selected for testing.

E.5.3 Corrosion.

All points on EWIS components that conduct electricity should be examined for corrosion. This includes connection and contact points for devices and the conductors for wiring.

E.5.4 Contact resistance.

The contact points on devices that make and break electrical current—such as switches, relays, and circuit breakers—can create resistance points through use and wear. These resistance points can slow device activation and create a source for heat generation.

A common method to determine contact integrity and measure contact resistance is with a Kelvin Bridge or four-point probe. The method to measure contact resistance is discussed in MIL-STD-202, Method 307 (Contact Resistance).

E.5.5 Wire insulation and conductor integrity.

The wiring examined during these evaluations is the wire that runs in the chassis of the aircraft, not wiring in LRUs/WRAs. There are several common wire types on aircraft. A brief description of methods for their assessment follows.

Note: Additional details on the degradation of these materials is available in the FAA report DOT/FAA/AR-08/2 located at http://www.tc.faa.gov/its/worldpac/techrpt/ar082.pdf.

E.5.5.1 Aromatic polyimide insulations (common name, Kapton®).

This is a common wire insulation type on many older platforms. This material has been extensively researched and several testing techniques have been developed for its degradation assessment. The following techniques have been found as means to assess the wire condition.

1. Force hydrolysis: This technique has been found to work with periodic dielectric testing to forecast the remaining life of the polyimide wire.
2. Inherent viscosity: As polyimide ages, the polymer chains break down and make the polymer more susceptible to crack growth from mechanical strain. Inherent viscosity testing identifies polymer chain reduction and has been used to forecast remaining life.
3. Tensile elongation and elongation to break: Research has shown these tests track with the polymer degradation and reduction of physical properties.

Note: Based on numerous studies, safety incidents, and a better understanding of the failure mechanisms of this insulation material (e.g. M81381, M22759/28 thru /31), every effort should be made to remove it and replace it with suitable approved M22759 general wire types (i.e. AS50881 Appendix A1 or A2).

E.5.5.2 XL-ETFE (common name, Tefzel®).

Current research suggests the primary cause for wire degradation is exposure to heat. Failure models have been developed for XL-ETFE and are based on examination of the insulation tensile and elongation mechanical properties discovered primarily through tensile elongation test.

E.5.5.3 Composite insulations (common name, Teflon-KAPTON-Teflon® (TKT).

The particular degradation mechanisms for this wire construction are still not well understood despite this insulation's use on aircraft for more than 20 years. The insulation consists of an extruded Teflon® (which is chemically inert) layer on top of polyimide tape. The Teflon® layer provides the moisture barrier and the polyimide tape provides the abrasion strength and insulation resistance.

Degradation of the insulation has been identified through inherent viscosity and tensile elongation tests.

E.5.5.4 Fiber optic cable.

Methods to assess the condition of fiber optic cabling may include specification tests and/or measurement of signal attenuation.

E.5.5.5 Coax cables.

There is not yet a well-established degradation model for coaxial cables. Test performed may include specification tests and/or measurement of impedance or signal attenuation. (See MIL-DTL-17.)

E.5.5.6 Seamless composite wire construction (e.g. AS22759/180 thru /192) using tin-plated conductor (e.g. AS22759/185). (Added paragraph)

Sintering heat applied in the construction of the wire assembly degrades the tin-plated conductor, rated to only 150 degrees Celsius. The conductor will be visually discolored and plating degraded, resulting in excessive impedance at the crimp joint (contact or terminal). The negative effects of sintering are doubled if the wire is part of a multi-conductor cable such as M27500 with a tin plated shield and seamless PTFE outer jacket. The second heat exposure further degrades the conductor plating (ANSI/NEMA 27500 and SAE AS50881).

E.5.6 Protective harness materials.
There are a variety of protective sleeving materials with different chemical compositions. There may be degradation models developed for these materials, but examination of these materials should focus on physical inspection for wear and stiffening.

E.5.7 Shield and ground terminations.
The shielding for cables and ground terminations should be visually examined for physical damage and corrosion. Where applicable, the contact resistance should also be measured.

E.5.8 Connector contact integrity and shield effectiveness.
The contact resistance should be measured as discussed in the general test section.

E.5.9 Circuit breaker contact integrity and the trip curve verification.
There are five areas that should be considered for evaluation of circuit breakers. These include:

1. pull force,
2. thermal degradation,
3. corrosion,
4. contact resistance, and
5. trip curve and response time conformance.

E.5.9.1 Pull force.
Pull force evaluation will determine if the circuit breaker is operating within specification and will also provide information as to whether the circuit breaker contacts were welding or corroded together. For example, the circuit breaker pull test results in figure E-2 indicate both were operating within the operation specifications.

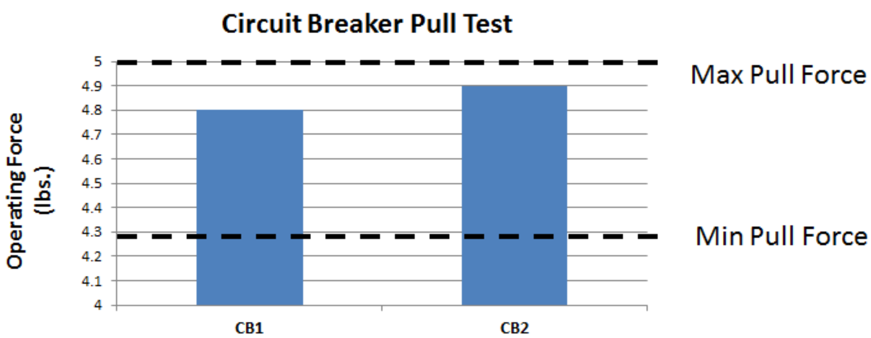


FIGURE E-2. Circuit breaker pull tests.

E.5.9.2 Thermal degradation.
Examine circuit body and terminals for discoloration.

E.5.9.3 Corrosion.
The terminals should be examined for any visible signs of corrosion.

E.5.9.4 Contact resistance.
The contact resistance should be measured as discussed in the general test section.

E.5.9.5 Trip curve and response time.
The response time testing for the circuit breakers evaluates the reaction time to overload conditions. An example of two circuit breaker response times for four over-current conditions is depicted in figure E-3. The figure shows the typical thermal circuit breaker trip curve with the response times of two circuit breakers overlaid. Circuit breaker #1 (blue) was found to operate within the specified limits for all tests, whereas circuit breaker #2 (orange) response time is outside the specified operating limits for this circuit breaker. A quick method to evaluate the functional performance of a circuit breaker is through use of a 200-percent overload test.

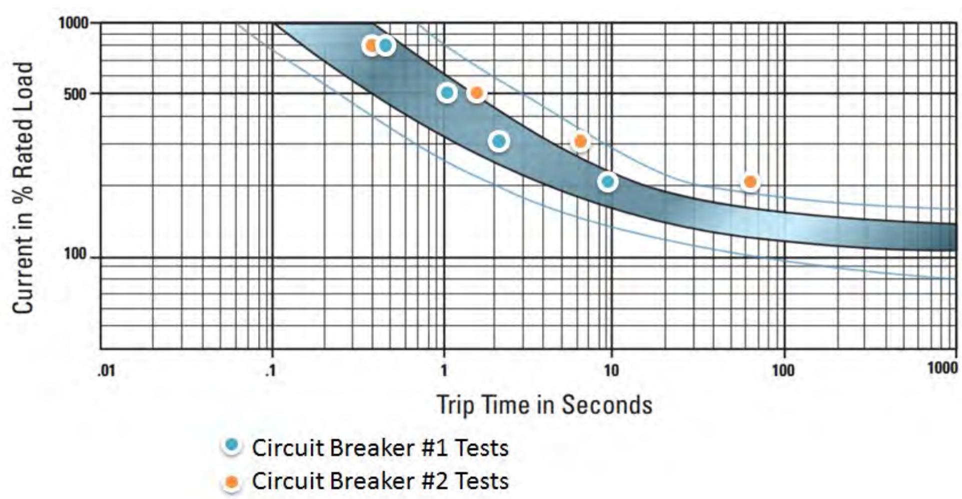


FIGURE E-3. Test results of circuit breaker trip tests.

E.5.10 Relay contact integrity and actuation performance.
Relays should be visually examined and contact resistance checked for all positions. Furthermore, the relay activation should be tested to failure via the method similar to one described in MIL-DTL-5757J, section 4.6.20, “Life test.” This test sets an expected life of the relay at 100,000 or 50,000 cycles depending on type of activation device test condition. These can be used as a basis to develop pass-fail criteria.

E.5.11 Switch contact integrity and actuation performance.
Switches should be visually examined and the contact resistance checked for all positions. Furthermore, the actuation performance should be examined in testing similar to MIL-DTL-3950H, method 4.8.6, “Strength of toggle lever, pivot, and lever stop.”

E.5.12 Electrical distribution panels.
Junction boxes should be securely mounted to the aircraft structure; examine for broken attachment hardware. Check for chafing of wire harnesses associated with the junction box and ensure connectors are securely tightened. Examine for thermal damage and corrosion or evidence of water or fluid contamination.

E.5.13 Terminal boards, ground studs, and connector back shells.
Check for loose or damaged connections, residues between electrically isolated terminals, and presence of corrosion. Note thermal damage or arcing evidence on terminals or ground studs.

E.6 COMPARE CONDITION OF COMPONENTS WITH NEW (UNUSED) COMPONENTS

The components, where possible, should be tested and compared against test data of new (unused) components. This validation provides additional check on the results of the degradation analysis and expected limits on the device performance.

E.7 COMPONENT SELECTION

The selection of how many components are required for a degradation assessment and the environment the component is removed from are important considerations. Because there can be variability between aircraft models and devices, care should be taken to gather information on the variability of the component (make, model, manufacturer, etc.). Where practical, logical groupings of aircraft and components should be made to reduce the necessary test sample size. Selection of components should also consider samples with varying degrees of age, exposure to environment, and maintenance. See section D.5 for additional guidance.

E.8 AIRCRAFT SELECTION

While it would be ideal to test only one aircraft for representative sampling of a fleet, this is not representative of an entire fleet. The impact of the operational history and service locations can greatly affect the degradation of EWIS components. This requires an understanding of the fleet usage history to allow for logical aircraft grouping. Just as grouping of aircraft zones reduced the number for testing, the logical grouping of fleet aircraft identifies the selective sampling partitions. This process ensures the validity and applicability of risk assessment results.

After the groups have been created, the next step is to determine which aircraft within these groups should be selected for testing. The aircraft within these groups are typically those that are most available for wire removal (e.g., depot-level maintenance or recently retired).

E.8.1 Selection factors.
The selection of aircraft for sample selection should be based on the criteria described in E.8.1.1 through E.8.1.4.

E.8.1.1 Availability.
A requirement to remove samples from in-service aircraft should coincide with depot-level maintenance actions. Sufficient time should be allotted for removal and replacement of any components. Care should be taken to limit testing of obsolete or long lead-time components. Recently retired aircraft may also serve as a viable option for sample selection. Advanced degradation models are able to remove extended aging accumulated since end of service.

E.8.1.2 Accessibility.
Some EWIS components can be located or routed in areas not often accessed during the aircraft's life; the removal of components or structure to access the areas may be high-cost actions. The location of the equipment should be considered prior to removal and can drive the selection of components for removal.

E.8.1.3 Age.
As this effort is part of a service life extension program, the aircraft selected should be those that are among the oldest in the fleet with consideration of flight and calendar time.

E.8.1.4 Service locations.
The EWIS components can degrade differently based on different service locations. Hot, humid environments will affect the degradation of components more than cool, dry environments. As such, the aircraft service locations should also be a contributing factor about which aircraft are selected.

E.8.2 Sample size.
Sample size is important when degradation analysis and destructive testing of system components are performed. A proper sample size is selected to reflect the variability of conditions on the aircraft accurately.

A sound sample size provides sufficient information about the system without the need to test every component. Considerations for determination of the sample size should include:

1. variability between environments within the aircraft,
2. component age, and
3. aircraft age.

Representative sampling assessment should be coordinated with the testing body to ensure a sufficient number of samples are taken. At a minimum, at least three components should be tested for each degradation assessment. The degradation assessment for the wiring should acquire at least twelve test samples per environmental zone.

E.9 TEST PERFORMANCE

The particular type of testing is based on the component tested, and a variety of test options may be available within each component class. Different methods to determine the degradation of components were identified in section E.5.

E.10 TEST RESULTS

The results will be presented differently dependent on the type of degradation model available for the given component. Pass/fail criteria should be established if no degradation model has been developed. The pass/fail criteria should be set such that, at a minimum, the component will likely continue to function in the worst-case environment until the next depot-level maintenance. A Subject Matter Expert should help define the pass/fail threshold.

If a simplified degradation model has been developed, then this may include multiple levels of life condition. The following is an example of this partitioning:

Like new (greater than 75 percent of life remaining)

Limited wear (between 45 percent – 75 percent)

Near end of life (between 15 percent – 45 percent)

End of life (less than 15 percent of life remaining)

These partitioning should be changed based on the available component degradation data and fleet sustainability needs.

More advanced degradation models can, with the aid of destructive testing data, identify the component degradation and the remaining years of continued service before age-related failures will start to emerge. These models are often specialized to one particular type of component.

E.11 TASK REPORT

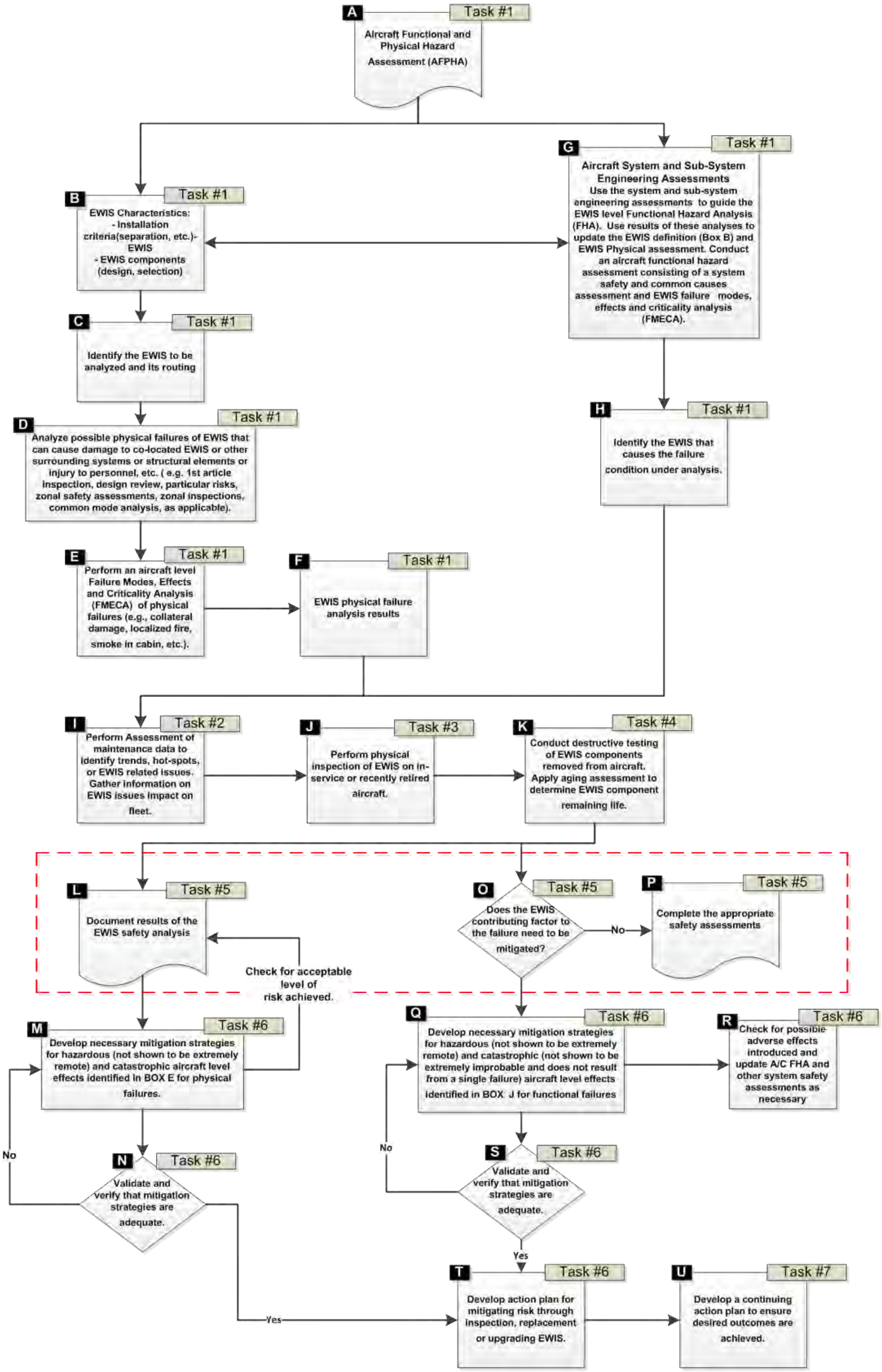
The final task for the component degradation assessment is the delivery of a final report. This report should describe condition of EWIS components and available life forecast data. This data may be reported at the device, system, or zonal level.

APPENDIX F

EWIS TASK FIVE – RISK ASSESSMENT

F.1 SCOPE

This task combines the results of the previous four tasks for the development of an EWIS risk assessment. If unsafe conditions are identified during this task, this task may be revisited pending the determination of risk tolerance in Task Six. In the subsequent Task Six, mitigation strategies may be developed and require re-evaluation of the aircraft (or system) risk. In such a case, only a subsection of this task may need to be repeated to determine a modification in risk. The integration of the Task Five with the overall EWIS risk assessment effort is shown on figure F-1. The guidance provided in this appendix is based on the information provided in AC 25-27A, AC 25.1701-1, AC 120-97A, and MIL-STD-882.



NOTE: The red-dashed boxed area includes the Task Five efforts.

FIGURE F-1. Risk assessment process flow.

F.2 DOCUMENTATION OF EWIS RESULTS

Box L: Document EWIS assessment (figure F-1): Document the results of the risk assessment after mitigation strategies have been validated and verified. Update, as necessary, the aircraft-level FHA that has been developed.

F.2.1 Assignment of failure probability.

The failure probability ranking for the fleet combines the maintenance and degradation data previously generated (Tasks Two and Four, respectively) and an assigned simplified numeric value. The failure ranking from this will be combined with the failure severity generated in Task One.

F.2.2 Maintenance data numeric assignment.

Table F-I is an example stratification used to determine the impact of the maintenance data on the risk assessment.

TABLE F-I. Maintenance action category assignment.

MAINTENANCE CATEGORY	DESCRIPTION
1	The occurrence of maintenance actions is very common and component replacement is regularly required on much of the fleet.
2	Maintenance is often required and is necessary on most of the fleet.
3	Limited maintenance is necessary throughout the entire fleet.
4	Maintenance actions have been performed on this device and are limited to a small part of the overall fleet.
5	Limited maintenance actions have been performed on this device but remain an unlikely occurrence.
6	No maintenance actions have been performed on this or similar devices.

The separation between the maintenance category levels is platform dependent. The maintenance actions can be averaged per aircraft per year to provide a comparison of the results and maintenance actions between fleets.

Caution should be taken not to associate automatically the maintenance actions of the worst device/component with the most severe maintenance category, as this may unnecessarily highlight an area or device. If possible, the maintenance actions of failure rates should be compared to the same or similar devices on similar platforms.

F.2.3 Degradation assessment numeric assignment.
Similar to the maintenance data partitioning, the degradation assessment generated in Task Four should be converted to a degradation category. Table F-II depicts an example partitioning of the degradation results for components both with and without degradation models.

TABLE F-II. Degradation forecast numerical assignment.

DEGRADATION CATEGORY	DESCRIPTION WHEN USED WITH COMPONENT DEGRADATION MODEL	DESCRIPTION WHEN USED WITH "PASS/FAIL" DEGRADATION CRITERIA
1	The devices are at end of life.	The components have reached end of life.
2	The equipment is showing severe degradation. Remaining in-service life is limited. Attrition of existing equipment replacement has begun.	
3	The equipment is degrading. Continued equipment use may lead to wear-out near next depot-level maintenance cycle.	
4	The equipment is showing some degradation. Wear-out is not likely to occur by next depot-level maintenance cycle.	The components are still functioning within specification.
5	Equipment is in good condition. Only marginal signs of performance degradation.	
6	The equipment is like new. No signs of degradation.	

It is recommended that the degradation categories associated with these components be limited to values 1 and 4 for components that had only "pass/fail" degradation analysis criteria, unless additional information can be gathered.

F.2.4 Degradation forecast.
Similar to the degradation assessment assignment above, the assignments should also be made for future intervals, if possible. An example of the degradation forecasting intervals can be seen in table F-III. This table depicts the forecast using the degradation analysis on wire taken from three aircraft zones and a set of circuit breakers.

TABLE F-III. Example degradation forecast for four example devices.

DEVICE TYPE	DEGRADATION CATEGORY		
	CURRENT	5-YEAR FORECAST	10-YEAR FORECAST
Leading Edge Wiring	3	3	2
Trailing Edge Wiring	3	2	2
Flight Deck Wiring	5	5	5
DC Circuit Breakers	4	4	3

In this example, the continued equipment use will lead to degradation of the more exposed wire in the leading and trailing edge of the wing. The forecast indicated the trailing edge would start to experience age-related failures of the equipment after 5 years of service. This forecast may affect subsequent plans for replacement scheduling and the development of directed maintenance inspection actions (Task Six).

Depending on the degradation methods for particular components (or the platform needs), this information can also be presented utilizing flight hours. In that case, the “5-Year Forecast” and “10-year Forecast” in table F-III would be replaced with flight hour levels that best represent the use of the fleet.

F.2.5 Combine degradation assessment with maintenance data.
The risk assessment reporting may be reported using the maintenance data and degradation data independently or by combining the two into a single value. This may be done as a summary of the system risk or in the case that there are conflicting failure probability projections between the maintenance and degradation data.

Table F-IV provides a lookup chart for combining the degradation categorization of component with the maintenance assessment.

TABLE F-IV. Degradation assessment categories combined with maintenance data analysis categories.

MAINTENANCE CATEGORY	DEGRADATION CATEGORY					
	1	2	3	4	5	6
1	1	1	1	1	1	1
2	1	2	2	2	2	2
3	1	2	3	3	3	3
4	1	2	3	4	4	4
5	1	2	3	4	5	5
6	1	2	3	4	5	6

The results of combining the maintenance categories with the degradation categories may indicate that component maintenance is more of an issue than indicated by the degradation assessment. Thus, this can affect the component degradation forecast results. For example, in table F-III, the DC circuit breakers showed a value of “4” for the current degradation category and were forecast to show no degradation until year 10. However, if the maintenance actions associated with the circuit breakers had a maintenance category of “3,” a disparity between the maintenance and degradation values of “1” should revise the forecasted value and reduce the “10-year forecast” to “2.”

F.3 FAILURE SEVERITY

The failure severity information for the assessment should come from the work performed in Task One. The physical inspection performed in Task Three should be reviewed to determine if the system assumptions made in Task One were accurate. If changes are necessary (e.g., shorter separation distances, lack of physical protection, different routing), the system data used in Task One should be updated and the failure severity reassessed. After review and, if necessary, update of the assessment, the results should include physical EWIS failure assessment and the functional failure assessment (both aircraft-level effects).

The results of the failure probability index for the equipment from section 4 and Task One can be combined to form a risk index based upon the guidance of MIL-STD-882. Table F-V depicts the risk assessment matrix.

TABLE F-V. Risk assessment matrix.

PROBABILITY	SEVERITY			
	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (1)	High	High	Serious	Medium
Probable (2)	High	High	Serious	Medium
Occasional (3)	High	Serious	Medium	Low
Remote (4)	Serious	Medium	Medium	Low
Improbable (5)	Medium	Medium	Medium	Low
Eliminated (6)	Eliminated			

This assessment can be generated and applied to the individual EWIS device level, wiring harness, system, and/or aircraft level. It may be possible to identify the sources for system risk if this assessment is performed at each of these levels. For example, the risk assessment may show a high-risk value for the landing gear system. Upon examination, the source of the high failure probability was the system wiring routed in the wheel well. The action plans developed in Task Six can be directed to the source of issues by identifying the source of risk in the system.

F.4 ASSESSMENT OF MITIGATION

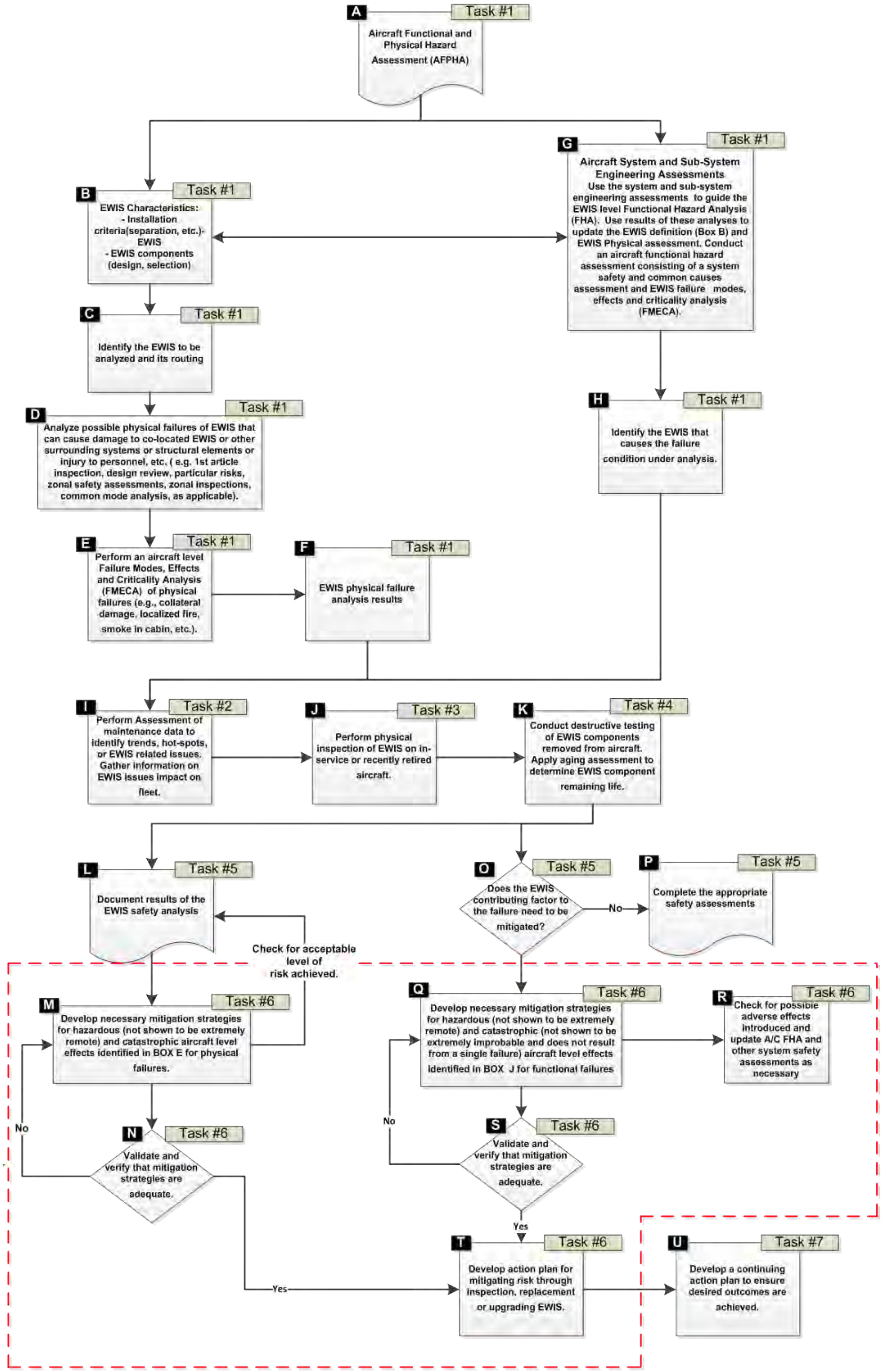
Box O: Contributing factor mitigation (figure F-1): Use the analyses to determine if the EWIS associated with the system under analysis can contribute (in whole or in part) to the failure condition under study. Determine whether the EWIS failure needs to be mitigated. If so, develop, validate, and verify a mitigation strategy (Task Six). Complete the appropriate safety assessment if no mitigation is needed.

APPENDIX G

EWIS TASK SIX – ACTION PLAN

G.1 SCOPE

Once the EWIS risk assessment is completed (Task Five), actions must be taken to address those zones and components that pose a risk to aircraft airworthiness. This task centers on the actions that can be taken to address identified issues. The integration of the Task Six workflow is shown on figure G-1. The guidance provided in this appendix is based on the information provided in AC 25.1701-1, AC 120-97A, and MIL-STD-882.



NOTE: The red-dashed boxed area includes Task Six efforts.

FIGURE G-1. Risk assessment process flow.

G.2 DETERMINATION OF ACTIONS TO BE TAKEN

The actions selected for implementation are dependent upon multiple factors including project, platform, engineering, and risk tolerance constraints. The selection of a mitigation strategy must consider each of these. The following sections highlight some available methods to address the risks identified during the assessment.

G.2.1 Design changes.

Boxes M & N: Development and validation of physical failure mitigation strategies (figure G-1): Components or harnesses that create unacceptably high failure severity values may need to be considered for design changes (e.g., a high-current wiring harness routed too close to a hydraulic line). Identify and develop a mitigation strategy for those components deemed to have too high a risk index if the failure severity was associated with physical failure identified in Boxes E and F.

If a redesign or component changes are considered, the risk assessment for the affected components should be re-evaluated with different solutions to determine how the risk reduction will have different impacts on the system (see Table B-IX for further details). Validation and verification of the mitigation solution should ensure the following:

1. Hazardous failure conditions are extremely remote.

   Catastrophic failure conditions are extremely improbable and do not result from a single common cause event or failure.
2. This mitigation solution does not introduce any new potential failure conditions.

G.2.2 Reduction of physical failure risk.

A reduction in physical failure risk can be achieved by implementation of one or more strategies. Methods to reduce physical failure risk include but are not limited to the following:

1. Physical separation: The wiring may be rerouted or separated from the wiring harness in instances where the critical or redundant systems are routed in the same harness or connector. Increasing the physical separation between the harnesses could reduce the likelihood of arcing damage in collocated harnesses.
2. Segregation: The use of segregation materials may be employed where physical separation is not possible or practical. These physical barriers (e.g., harness sleeving) can limit the area affected by an electrical failure. The objective of segregation materials is to achieve equivalent separation.
3. Limit the fault current: A large factor in EWIS failure is the current available during a fault. Limiting the fault current in the circuit (the electrical current available at the fault location—in a single-phase fault this is quantified as the short circuit current at the location) can reduce the potential damage to other wires in the harness, damage to nearby components, and fire ignition.
4. Change circuit protection devices: Standard thermal circuit protection devices are not adequate to prevent damage from electrical arcing events. Circuit protection devices such as arc fault circuit breakers or solid-state power systems can limit the energy released in electrical arcing failure.
5. Change wire type: No wire type can fully eliminate damage from electrical arcing; some are better at reducing the damage level.

The damage assessment and associated risk should be reexamined following the selection of a mitigation strategy. This process can be performed multiple times or until an acceptable level of risk has been achieved.

G.2.3 Reduction of functional failure risk.

Boxes Q & S: Development and validation of functional failure mitigation strategies (figure G-1): Identify and develop mitigation strategies for those components with a high functional failure severity. For EWIS components associated with hazardous or catastrophic events, these events should be shown to be improbable and not the result of a single failure, with the aircraft-level effects identified for functional failures.

Once mitigation plans have been developed, the validation and verification of the mitigation solution should ensure the following:

1. Hazardous failure conditions are extremely remote.
2. Catastrophic failure conditions are extremely improbable and do not result from a single common cause event or failure.
3. This mitigation solution does not introduce any new potential failure conditions.

G.2.4 Replacement.

If design changes are not possible or an acceptable level of risk has not been achieved, replacement should be considered for EWIS components that have reached end of life criteria. If EWIS components are not replaced, they may soon experience performance degradation or reach risk targets. The need for replacement is based on the individual platform needs and constraints.

G.2.5 Forecasting replacement.

The results of the component degradation assessment performed in Task Four provide a means to forecast EWIS reliability. The benefit of this is that degrading components can be scheduled for replacement in advance. EWIS components that are not in an immediate need for replacement and are not projected to impact aircraft safety or reliability can be scheduled for future maintenance cycles.

G.2.6 Maintenance changes.

The risk assessment identifies safety-critical EWIS components and correlates them with aging and maintenance hot spots. This information, combined with the aircraft zone breakdown and inspection checklist developed, provides a framework to generate or augment an existing EWIS inspection program. Maintenance efforts can be directed to do the following:

a. Monitor components that are exhibiting deterioration through periodic inspection. Corrective actions can be taken more quickly if failures occur sooner and in higher numbers than predicted by the degradation models.
b. Monitor maintenance hot-spot areas.

The worksheets completed during Task One provide some guidance on how to build an EWIS scheduled inspection plan. The zonal breakdown and analysis should be supplemented with the risk assessment results if additional details would be beneficial for the maintenance program. The inspection checklist and lessons learned in Task Three provide a basis for the development of periodic inspection tasks. The development of these tasks is described in section G.2.

G.3 EWIS ENHANCED ZONAL ANALYSIS PROGRAM DEVELOPMENT

Figures G-2 and G-3 and the narratives on the following pages describe the Enhanced Zonal Analysis Procedures (EZAP) process. The development of EZAP should be performed by those familiar with the risk assessment process. The process below is provided for general information and reflects a process originally designed for commercial aircraft but has been tailored for better applicability to military aircraft.

The objective is to improve maintenance and inspection programs for all EWIS installed on aircraft. Applying the information and lessons learned from the EWIS risk assessment will improve the likelihood that EWIS degradation from many causes, including environmental, maintenance-related, and age-related problems, will be identified and corrected. In addition, this information has been reviewed to ensure maintenance actions, such as inspection, repair, overhaul, replacement of parts, and preservation, do not:

a. cause a loss of EWIS function,
b. cause an increase in the potential for smoke and fire in the aircraft, or
c. inhibit safe operation of the aircraft.

The inspection program should be scheduled at regular intervals based on system criticality, maintenance information, and normally scheduled maintenance actions. The results should generate inspection intervals such that areas exposed to harsher environmental and maintenance conditions are checked more regularly than benign areas.

G.3.1 Enhanced Zonal Analysis Procedure.
The EZAP will allow the user to determine the appropriate general or detailed inspections and any cleaning tasks (also referred to as restoration tasks by some manufacturers) needed to minimize the presence of combustible material. An EZAP can be used to develop new wiring cleaning and inspection tasks for both zonal and non-zonal inspection programs.

Use of this procedure to develop a maintenance program will help ensure proper attention is given to EWIS components during maintenance. The EZAP provides a logical procedure for selection of inspections (either general or detailed) and other tasks to minimize combustibles and identify EWIS degradation. An EZAP will identify new wiring inspection tasks for aircraft without a structured zonal inspection program.

G.3.2 Guidance for a General Visual Inspection.
This clarifies the definition of a GVI and provides guidance on what is expected from such an inspection, whether performed as a stand-alone GVI or as part of a zonal inspection.

G.3.3 Protections and cautions.
Guidance is developed for actions and cautionary statements to be added to maintenance instructions for the protection of wire and wire configurations. Maintenance personnel will use these enhanced procedures to minimize contamination and accidental damage to EWIS while working on aircraft.

G.3.4 "Protect and Clean as You Go" philosophy.
This philosophy is applied to aircraft wiring through inclusion in its operators' maintenance and training programs and stresses the importance of protective measures when working on or around EWIS components. It stresses how important it is to protect EWIS during structural repairs, modifications, or other alterations by making sure metal shavings, debris, and contamination resulting from such work are removed. The "Protect and Clean as You Go" philosophy is translated into specifics by the protection and caution recommendations.

G.3.5 Consolidation with fuel tank requirements.
Fuel tank systems contain EWIS that may be routed independently or integrated with other aircraft systems' EWIS. Aircraft fuel system documents typically address EWIS fuel tank safety, maintenance, and inspection and should be followed accordingly. If no guidance is available, use FAA AC 120-97 to develop guidelines for proper EWIS fuel tank design and installation, maintenance practices, and inspection protocols.

G.3.6 Enhanced Zonal Analysis Procedure—general guidance.
Current approaches to aircraft wiring and systems platform maintenance will need to be redefined and altered to realize fully the objectives of the EWIS risk assessment. This redefinition must reach both overall philosophy and specific maintenance tasks. This may require more than simply updating maintenance manuals and work cards and improving training. Maintenance personnel need to be aware that aircraft EWIS must be maintained in an airworthy condition. They also need to recognize that visual inspection of wiring has inherent limitations. Small defects such as breached or cracked insulation, especially in small-gage wire, may not always be apparent. Therefore, effective wiring maintenance combines good visual inspection techniques with improved wiring maintenance practices and training.

An EZAP will result in safety improvements for aircraft operated with a maintenance or inspection program that includes a zonal inspection program (ZIP). It is unlikely that ZIPs developed in the past considered wire or other EWIS components, except for the most obvious damage that could be detected by a GVI.

The EZAP logic is likely to identify a large number of EWIS-related tasks that will need to be consolidated into the existing systems maintenance or inspection program for platforms without a ZIP. Those without a ZIP may find it worthwhile to develop a ZIP in accordance with an industry-accepted method in conjunction with an EZAP.

When the EZAP is performed, evaluate items such as plumbing, ducting, control cables, and other system installations located in the zone for possible contributions to wiring or other EWIS component degradation or failures. The results of the analysis will indicate whether a restoration task, a zonal GVI, a stand-alone GVI, or a DET inspection are required to inspect the EWIS in the zone. The type of inspection is determined by completion of EZAP worksheets.

New tasks identified by the EZAP logic should be compared against existing tasks in the maintenance program to ensure they are compatible with each other. Also, existing maintenance task type and frequency should not affect the outcome of the EZAP analysis. The analysis for a particular zone should be completed to identify appropriate EWIS tasks and their frequency. After the analysis is complete, these new EWIS tasks should be compared to existing maintenance program tasks to assess where the new tasks and the existing maintenance program tasks can be logically combined. The EZAP analysis should not be “tweaked” to make the tasks and intervals fit the existing maintenance program just for the sake of tasks alignment.

Platforms may want to use the EZAP logic to identify additional inspection and cleaning tasks for any design changes on their aircraft for which EZAP ICA are not available. An original EWIS ICA developed by a manufacturer (if it exists) may not have taken into account modifications made to the platform by someone other than the OEM.

Each step in the EZAP logic is explained in G.3.6.1 through G.3.6.11. Performers of the EZAP analysis should use the information gathered from the tasks performed during the EWIS assessment on a “representative aircraft.” Whenever possible, verify the results of the analysis through use of an actual aircraft (typical aircraft that has not been cleaned) to ensure the inspectors fully understand the zones being analyzed. When the information from the onsite inspection is combined with the risk assessment information, a basis to make determinations on zone density, size, environmental issues, and failure consequence for each zone results.

Further details of developing an EZAP are included in AC25-27A.

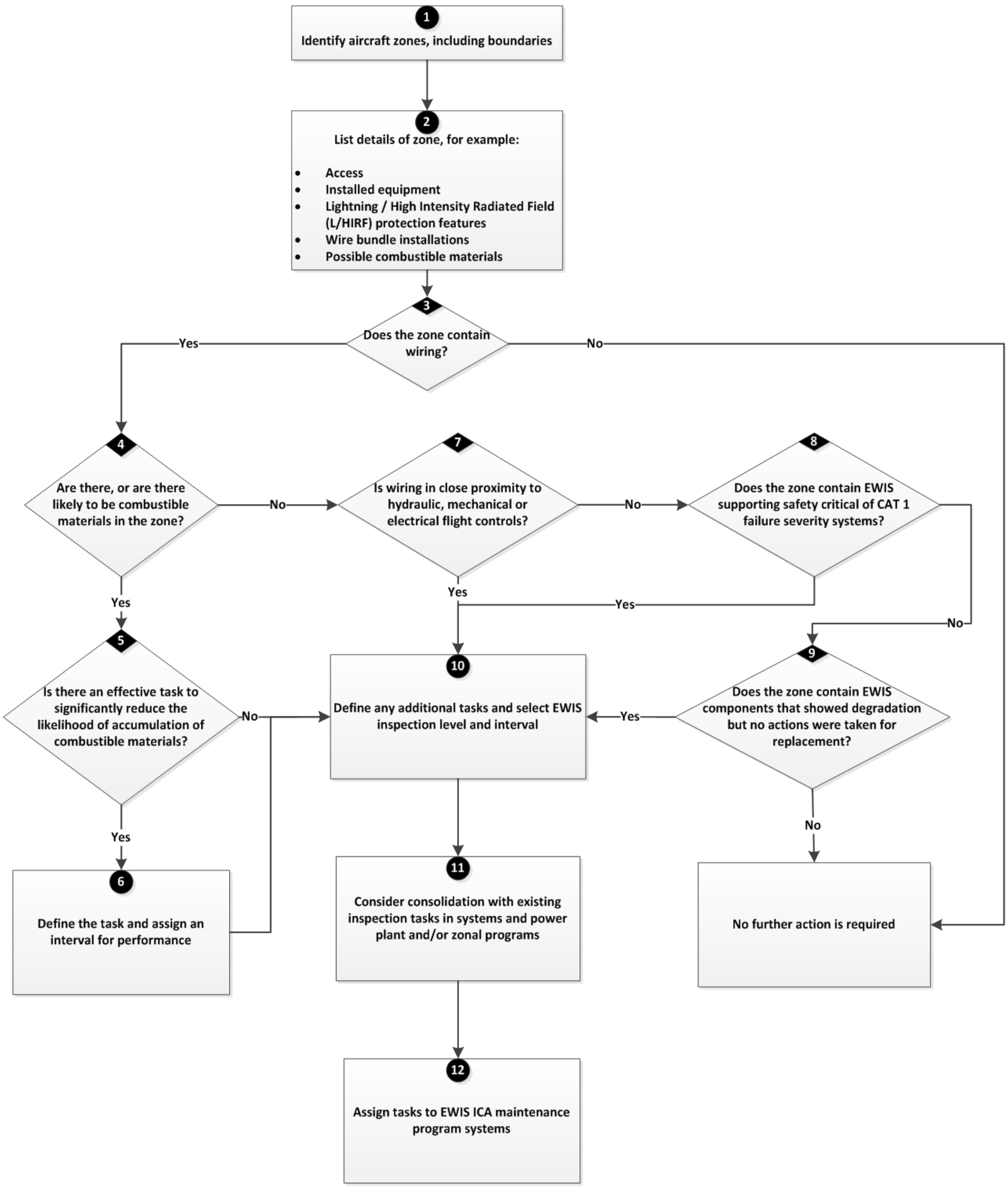


FIGURE G-2. EZAP process.

G.3.6.1 STEP 1: Identify aircraft zones, including boundaries.
The boundaries used for development of the EZAP should be the same, or similar to, those used in the assessment of Task One and Task Three. Where possible, these zones should be defined by actual physical boundaries such as wing spars, major bulkheads, cabin floor, control surface boundaries, skin, etc., and include access provisions for each zone.

G.3.6.2 STEP 2: List details of zone.
Within the zone, identify system installations, significant components, lightning and high intensity radiated field (L/HIRF) protection features, typical power levels in any installed wiring bundles, combustible materials (present or with the potential for accumulation), and any other features that may affect wiring integrity or accumulation of combustibles.

With respect to power levels, the physical damage analysis completed in Task One should be used as a basis to determine the potential physical effects of deterioration.

Identify any locations where both primary and back-up flight controls are routed in close proximity. This information is required to answer the question in STEP 7.

G.3.6.3 STEP 3: Does zone contain wiring?
This question eliminates from the EZAP those zones that do not contain wiring.

G.3.6.4 STEP 4: Are there, or are there likely to be, combustible materials in zone?
This question requires evaluation of whether the zone might contain combustible material that could cause a fire to be sustained in the event an ignition source arises in adjacent wiring. Examples include the presence of fuel vapors, conductive water-based fluids, dust/lint accumulation, and contaminated or flammable insulation blankets.

a. With respect to commonly used liquids (e.g., oils, hydraulic fluids, corrosion prevention compounds), refer to the product specification to assess potential for combustibility. The product may be readily combustible only in vapor mist form. If so, an assessment is required to determine if conditions might exist in the zone for the product to be in this state.
b. Liquid contamination of wiring by most synthetic oil and hydraulic fluids (e.g., Skydrol®) may not be considered combustible. It is a concern, however, if it occurs in a zone where dust and lint are present because wet or oily surfaces attract dust and lint.
c. Avionics and instruments located in the flight compartment and equipment bays tend to attract dust, dirt, and other contamination. Because of the heat generated by these components and their relatively tightly packed installations, these zones have the potential for accumulation of combustible material. Forced-air ventilation is often used in these areas, which causes lint and dust to be blown about the area and often results in a buildup of dust and lint on component surfaces. Always use the EZAP logic for these zones. The answer to the question in this STEP 4 should be, “YES” for flight compartment and equipment bays.

Although moisture (whether clean water or otherwise) is not combustible, its presence on EWIS components increases the probability of electrical conduction and arcing from small breaches in the insulation. This could cause a localized fire in the wire bundle. The fire could spread if there are combustibles in close proximity. The risk of a sustained fire caused by EWIS failure is considered in the aircraft-level assessment in Task One. This information can be used here to supplement the effects of failure.

G.3.6.5 STEP 5: Is there an effective task to reduce significantly the likelihood of accumulation of combustible materials?

Many maintenance programs do not include tasks directed toward removal of combustible materials from wiring or adjacent areas or prevention of their accumulation. Evaluate whether accumulation on or adjacent to wiring can be significantly reduced.

Though restoration tasks such as cleaning are the most likely applicable tasks, the possibility of identifying other tasks is not eliminated. For example, a detailed inspection of a hydraulic pipe might be appropriate if high-pressure mist from pinhole corrosion could impinge a wire bundle and the inherent zone ventilation is low. Task effectiveness criteria should include consideration of the potential for damage to wiring.

G.3.6.6 STEP 6: Define the task and assign an interval for its performance.

This step will define an EWIS ICA task to reduce accumulation of combustible materials and an effective interval for performance of that task. The defined task should be included as a dedicated task in the systems & power plant section of the maintenance program. It may be introduced within Maintenance Review Board Reports (MRBRs) under the standard practices section (ATA chapter 20 of the MRBR) with no failure effect category assigned.

Restoration tasks should not be so aggressive that they damage wiring but should be performed at a level that significantly reduces the likelihood of combustion.

For fuel system EWIS components, critical design configuration control limitations (CDCCL), inspections, or other procedures must be established as necessary. These provisions will help prevent development of ignition sources within the fuel tank system, which will increase fuel tank flammability conditions. They also help prevent degradation and improve overall reliability of the fuel tank system. Visible means to identify critical features of the design must be available in areas of the aircraft where foreseeable maintenance actions, repairs, or alterations may compromise the CDCCL (e.g., color-coding of wire to identify separation limitation). These visible means must also be identified as CDCCL.

G.3.6.7 STEP 7: Is wiring close to both primary and backup hydraulic, mechanical, or electrical flight controls?

This question is asked to ensure STEP 10 logic is applied where wiring is in close proximity to both primary and backup hydraulic, mechanical, or electrical flight controls, even in the absence of combustible materials in the zone.

Proximity is addressed in the inspection-level definition portion of STEP 10. This question does need not be asked for zones where combustible materials are present (as determined in STEP 4).

This step addresses the concern that segregation between primary and back-up flight controls may not have been consistently achieved. Even in the absence of combustible material, a localized EWIS failure could prevent continued safe flight and landing if hydraulic pipes, mechanical cables, or wiring for fly-by-wire controls are routed in close proximity to a wiring harness. In consideration of the redundancy in flight control systems, this question should be answered “YES” if both the primary and back-up system might be affected by wire arcing.

On all aircraft type designs, regardless of design date, alterations performed by TAA or a field-approved repair or alteration may not have taken into account the aircraft’s design specification criteria. It is recommended that the TAA assess whether their design changes route wires within 2 inches or 50 mm of both primary and back-up hydraulic, mechanical, or electrical flight control cables and lines. Similarly, air carriers and air operators should assess any field-approved repairs, alterations, or other modifications that have been made to their aircraft to identify any added or altered wiring that may be close to flight control cable and lines.

G.3.6.8 STEP 8: Does the zone contain EWIS supporting safety-critical CAT 1 failure severity systems?

CAT 1 critical systems, circuits, and devices identified in Task One of this assessment (see Severity Categories identified in table B-IX) provide the information to determine where these can be found. The inspection tasks should include information on the system and the EWIS components to be checked within the zone.

G.3.6.9 STEP 9: Does the zone contain EWIS components that showed degradation but no actions were taken for replacement?

The EWIS components identified in Task Four which show degradation but are not selected for replacement (Task Six) should be periodically inspected to identify and preempt the onset of further degradation. Each identified discrepancy should have an associated criticality level in keeping with the service's accepted norms (e.g. Class I = Major, II = Intermediate, III = Minor, IV = Superficial; see NAVAIR 01-1A-505-1, WP 004 01).

G.3.6.10 STEP 10: Select wiring inspection level and interval.

G.3.6.10.1 Inspection level.

At this point, it has been confirmed that wiring has been installed in a zone where the presence of combustible materials may exist. It is located near the primary and backup hydraulic or mechanical flight controls, a CAT 1 component, and/or degradation has been identified. Therefore, some level of inspection of the wiring in the zone is required. This step details how to select the proper level of inspection and interval.

The proper inspection level and interval can be selected through use of ratings tables that rate characteristics of the zone and how the wiring is affected by, or can affect, those attributes. Each platform will determine the precise format of such a rating table, but example-rating tables appear on figure G-3. Inspection-level characteristics, which may be included in the rating system, are identified in G.3.6.10.1.1 through G.3.6.10.1.4.

G.3.6.10.1.1 Zone identification.

According to ATA Specification iSpec 2200, "Manufacturer's Technical Data," zones are identified by the aircraft manufacturer "to facilitate maintenance, planning, preparation of job instructions, location of work areas and components, and a common basis for various maintenance tasks." The specification iSpec 2200 contains guidelines to determine aircraft zones and their numbering. The EZAP process uses these manufacturer-identified zones. The zones are not created uniquely for EZAP.

G.3.6.10.1.2 Zone size.

Zone size determination is based on a comparison of all the zones in a given aircraft model and assessing them in relation to each other. For the purposes of the EZAP analysis, zone sizes are identified as "small," "medium," or "large." For example, the aft cargo bay on a large transport category aircraft would be considered a "large" zone, but the radome on the same aircraft would be considered a "small" zone. The smaller and less congested a zone, the more likely EWIS degradation will be identified by GVI.

G.3.6.10.1.3 Zone density.

The density of installed equipment, including wiring and other EWIS components, within the zone is assessed in relation to the size of the zone. Zone density is identified as "low," "medium," or "high" for the purposes of the EZAP analysis.

Typical factors to consider are the number of components, their relative closeness to one another, and the complexity of these components (e.g., multiple electrical, mechanical, or hydraulic connections). For example, the electrical and electronics compartment located in the forward nose section below the flight deck of most large transport category aircraft could be considered a "high"-density zone. This is because the relatively small physical area is crowded with avionics equipment and a large number of wires and other EWIS components. An example of a “low”-density zone on some aircraft is the cargo compartment (as defined by the cargo compartment walls and forward and rear bulkheads). Although this is a large zone relative to other zones on the aircraft, it has relatively few systems or EWIS components installed in it.

G.3.6.10.1.4 Failure severity.
This determination should be based on the failure severity assessment performed in Task One. The aircraft-level physical and functional EWIS failures should be considered when the failure severity is assigned. This assessment should include consideration of the potential for loss of multiple functions and the resultant effect on continued safe aircraft operation. The presence of flammable fluids should also be considered, although design features such as shrouds over the fuel line can be considered to mitigate the likelihood of fuel being a source of fuel for a fire. The determination of potential effects of a fire on adjacent wiring and systems should be based on knowledge of what aircraft systems are in the area under analysis (i.e., what is in the zone) and how loss or degradation of these systems could affect safe operation. The rating system developed should consider these potential effects.

If a zone does not have mitigating design features that would reduce the adverse effects of a fire, then the potential effects of a fire should be rated higher (e.g., “medium” or “high”). Credit for fire mitigation capability can be given to zones that contain a fire detection and suppression system or a zone that is designated a “fire zone.” Potential effects of a fire in such zones could then possibly be rated at a lower level. Consideration can also be given to whether the fire could be easily detected by crewmembers or passengers and to whether, if there was a fire, it could be extinguished or controlled by available means. Fire can result in severe outcomes, such as wire-to-structure or wire-to-wire shorting and arcing in areas such as the flight deck, electrical power centers, and those that contain power feeder cables, which are subject to chafing if they have flammable materials close by. A fire in these areas could present a high risk to continued safe flight and landing.

Potential effects of fire must also be considered when wiring is near both primary and backup flight controls. A GVI alone may not be adequate if a fire caused by failure of the wiring poses a risk to aircraft controllability.

At minimum, all wiring in the zone will require a GVI at a common interval.

The logic for platforms without a ZIP, asks: “Is a GVI of all wiring in the zone at the same interval effective for all wiring in the zone?” This step calls for consideration of whether there are specific items or areas in the zone more vulnerable to damage or contamination than others and thus may warrant a closer or more frequent inspection.

Such a determination could result in selection of a more frequent GVI, a standalone GVI (for operators with a zonal inspection program), or even a DET. The intent is to select a DET of wiring only when it is determined that a GVI will not be adequate. The one who performs the EZAP should avoid unnecessary selection of a DET where a GVI is adequate. Over-use of DET dilutes the effectiveness of the inspection.

The level of inspection required may be influenced by tasks identified in STEP 5 and STEP 6. For example, if a cleaning task is selected in STEP 5 and STEP 6 that will minimize accumulation of combustible materials in the zone, this may justify selecting a GVI instead of a DET for the wiring in the zone.

G.3.6.10.2 Selecting an inspection interval.
A rating system can be used to select an effective inspection interval. The characteristics for wiring to be rated should include:

a. Likelihood of accidental damage.
b. Environmental factors.

Rating tables should be designed to define increasing inspection frequency based on increasing risk of accidental damage and increasing severity of the local environment within the zone.

The sample "Interval Determination" table on figure G-3's EZAP Worksheet 4 provides a range of intervals from which to choose. The choice of interval should be based on the reasons for specific rating values assigned for "Hostility of Environment" and "Likelihood of Accidental Damage."

As an example, the table provides a range of inspection intervals for a "Hostility of Environment" rating of "3" and a "Likelihood of Accidental Damage" rating of "3." It depicts the inspection should occur as frequently as every "A-check," but the interval could be as long as once every "1C-check." The choice should be based on the reasons a "3" rating was assigned.

a. The importance of a likelihood of accidental damage assessment is that the higher the likelihood of accidental damage from multiple sources, the more frequent the inspection task should be. If, on the other hand, all of the factors except one have been rated as a "1," then the inspection interval could be somewhat longer.
b. The choice of the inspection interval should also be based on what type of environment the EWIS is located in and the condition of the EWIS components. Just as with the ratings for likelihood of accidental damage, the more the EWIS is exposed to various harsh environmental conditions, the more frequent the inspection interval should be. The "Hostility of Environment" and "Likelihood of Accidental Damage" should be considered when the inspection task interval is assigned.

G.3.6.10.3 Inspection-level guidance.
The FAA Continuous Airworthiness Maintenance Program (CAMP) outlines the amount of time between aircraft inspections and how often aircraft components need to be inspected, overhauled, or replaced and includes EWIS components. There are four levels of maintenance checks under FAA FAR Part 91:

1. "A-checks" are performed at around 500 flying hours (FH). This is a routine check, to make sure everything is functioning safely and efficiently. It can usually be completed overnight at an airport gate and can even be delayed if an aircraft meets certain predetermined conditions.
2. "B-checks" are more extensive than "A-checks" but can also be completed overnight.
3. "C-checks" require aircraft to be docked at a hangar or repair station for detailed inspections. These are generally performed every 12-18 months, depending on the type of aircraft and the manufacturer's specifications.
4. "D-checks" are done approximately every 4 to 5 years and are the most intensive, time-consuming aircraft inspection. The aircraft needs to have every fastener, nut, wire, hinge, and component inspected, repaired, maintained, or replaced.

"A/B-checks" are considered minor inspections and are usually performed at the operational station. "C/D-checks" are considered major inspections and are usually performed at a Depot facility.

EWIS inspections are best conducted during planned aircraft inspections and should be more detailed at the "C/D-checks." Military operations have similar inspection intervals with the times based on flight hours and/or calendar times with the details determined by program requirements.

G.3.6.11 STEP 11: Consider consolidation with existing inspection tasks in systems and power plant and/or zonal programs.

This step in the procedure examines the potential for consolidation between the tasks derived from the EZAP and inspections that already exist in the maintenance program. Consolidation would require that the inspections in the existing maintenance program be performed in accordance with the inspection definitions.

Compare new tasks identified by the EZAP logic against existing tasks in the maintenance program to ensure:

1. Tasks are compatible with each other. Existing maintenance tasks and EZAP-generated inspection or maintenance tasks (such as a restoration task) should not compromise or negate each other. For example, an EZAP-generated task should not compromise existing fuel tank system wire maintenance requirements such as separation or configuration specifications.
2. Task intervals are aligned to the maximum extent possible so undue disturbance of EWIS and other systems located within the zone do not occur. However, the inspection interval chosen must ensure the intent and reason for the EWIS inspection is not compromised.
3. Redundant (or duplicate) tasks are consolidated into a single task.
4. Although some non-zonal inspection programs may already include some dedicated inspections of wiring that may be equivalent to new tasks identified by an EZAP, it is expected that a significant number of new wiring inspections will be identified for introduction as dedicated tasks in the system & power plant program. All new tasks identified by an EZAP should be uniquely identified to ensure they are not deleted during future program development.

The following guide can be used to determine proper consolidation between EZAP-derived inspections and existing inspections of the same item or area. When an EZAP task is selected for consolidation, the documentation should include a record identifying it for traceability purposes.

a. If the EZAP inspection interval and existing inspection interval are equal, but the inspection levels are different, the more detailed inspection takes precedence (e.g., a 1C DET takes precedence over a 1C GVI.
b. If the EZAP inspection interval and existing inspection interval are different, but the inspection levels are equal, the more frequent inspection interval takes precedence (e.g., a 1C GVI takes precedence over a 2C GVI).
c. If the EZAP inspection interval and level are different from the existing inspection interval and level, these tasks may be consolidated using the more frequent inspection and at the more detailed level (e.g., a 1C DET takes precedence over a 2C GVI). The tasks should not be consolidated when the more frequent inspection is less detailed.

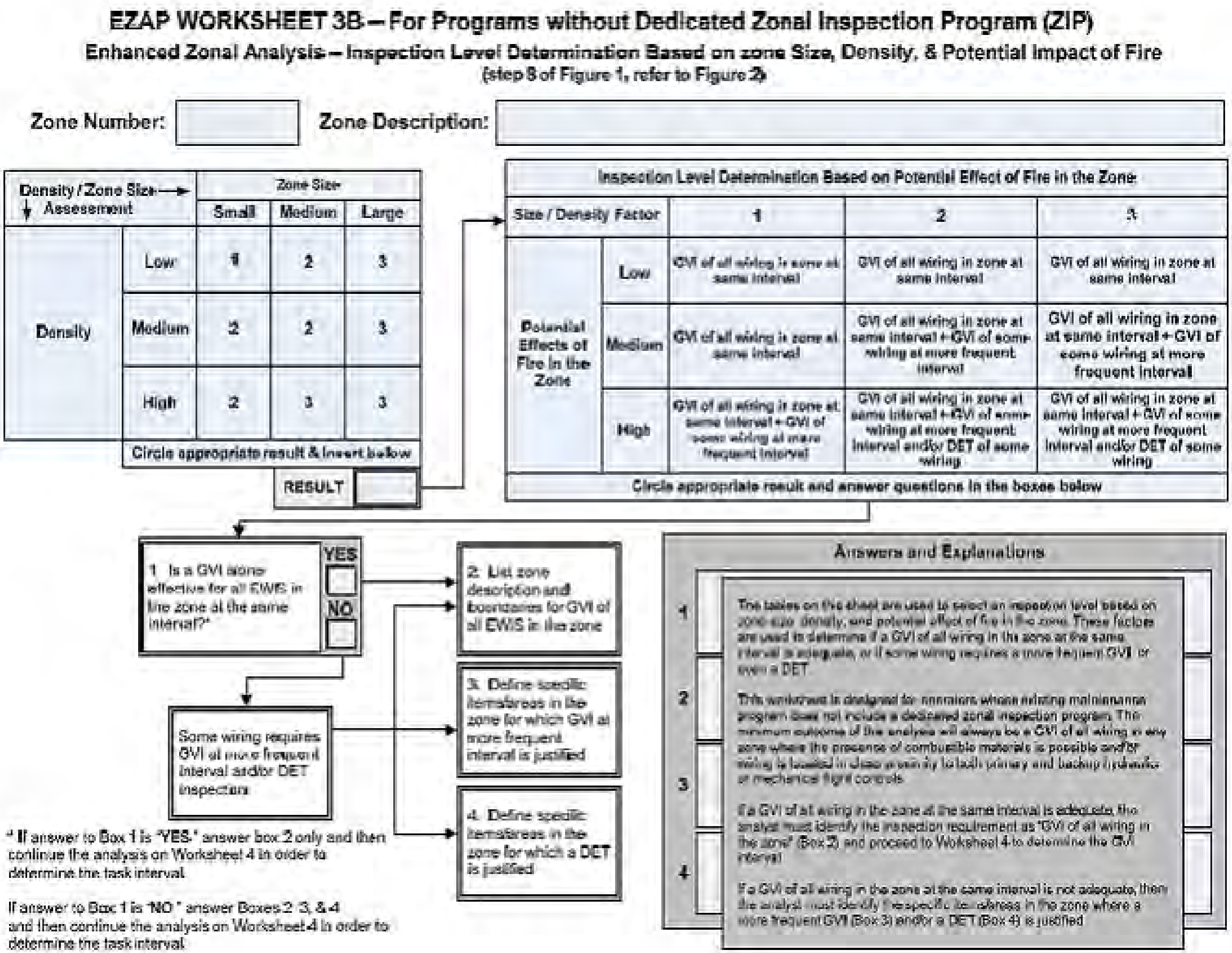


FIGURE G-3. EZAP worksheet for dedicated Zonal Inspection Program (ZIP).

EZAP WORKSHEET 4 – Intervals Based on "A" and "C" Checks

Enhanced Zonal Analysis – Interval Determination Based on Hostility of Environment and Likelihood of Accidental Damage

(step 8 of Figure 1, refer to Figure 2)

Zone Number: ______ **Zone Description:** ______

Hostility of Environment	
1 – Passive / 2 – Moderate / 3 - Severe	Enter Number Here
Temperature	
Vibration	
Chemicals (toilet fluids, de-icing fluid, etc)	
Humidity	
Contamination	
Other	
Enter the Highest Number Here →	

Likelihood of Accidental Damage	
1 – Passive / 2 – Moderate / 3 - Severe	Enter Number Here
Ground handling equipment	
Foreign object debris (FOD)	
Weather effects (hail, rain, etc)	
Frequency of maintenance activities	
Fluid spillage	
Passenger Traffic	
Other	
Enter the Highest Number Here →	

Interval Determination		Likelihood of Accidental Damage 1	2	3
Hostility of Environment	1	4C – 8C 14,400 - 21,600 FH 60 – 90 M	2C – 4C 7,200 – 14,400 FH 30 – 60 M	1C – 2C 3,600 – 7,200 FH 15 – 30 M
	2	2C – 6C 7,200 – 21,600 FH 30 – 90 M	1C – 4C 3,600 – 14,400 FH 15 – 60 M	A – 1C 450 – 3,600 FH 1 – 15 M
	3	1C – 6C 3,600 – 21,600 FH 15 – 90 M	1C – 4C 3,600 – 14,400 FH 15 – 60 M	A – 1C 450 – 3,600 FH 1 – 15 M
RESULT Upon completion, enter all task and interval selections onto Worksheet 5, Task Summary				

Examples of task interval ranges

Interval selection is specific to each task identified on Sheet 3A or 3B. For GVI of entire zone, consider overall zone environment and likelihood of damage. For stand-alone GVI or DET, consider environment and likelihood of damage only in respect to the specific item/area defined for inspection.

NOTE: Interval ranges are quoted in the rating table to explain a typical arrangement of values. For a particular application, these must be compatible with the interval framework used in the existing maintenance or inspection program (as detailed in the current MRB Report). They may be expressed in terms of usage parameter (e.g. flight hours or calendar time) or in terms of letter check.

FIGURE G-3. EZAP worksheet for dedicated Zonal Inspection Program (ZIP) – Continued.

Zonal Task Summary

Zone Number		Zone Description	

Task Summary			
Task #	Access	Task Interval	Task Description

FIGURE G-3. EZAP worksheet for dedicated Zonal Inspection Program (ZIP) – Continued.

APPENDIX H

EWIS TASK SEVEN – ITERATIVE EWIS ASSESSMENT

H.1 SCOPE
This task objective is for the continuing application of the risk assessment action plan and lessons learned through the aircraft active duty life cycle. This includes necessary tailoring and iterative application in response to changes in platform-specific program direction and changes to operational requirements such as service life, mission, etc.

H.2 EWIS MONITORING
It is important to track the progress and the fleet-level impacts once Tasks One through Six are completed. To do this, the following actions should be considered.

H.2.1 EWIS component reassessment.
Determine if/when additional fleet inspection and EWIS component comprehensive materials/electrical properties assessment should be performed. This may be based on the remaining reliable service life limits determined in Task Four, the risk thresholds established in Task Five, or other factors.

H.2.2 Develop assessment metrics.
The overall goal of the assessment is to improve the aircraft's EWIS. This should be measured and tracked to determine if there has been a noticeable improvement based on the changes implemented from the action plan. The data gathered in Task Two should be used as a baseline to determine improvements in EWIS safety and reliability. Comparisons should be normalized to fleet size and usage to provide relevant analyses.

H.2.3 Action plan implementation assessment.
Review the action plan that was established and determine the implementation of mitigation strategies, maintenance plans, and other actions defined in Task Six.

H.3 PERIODIC REASSESSMENT
Continued aircraft use will lead to additional aging and possible degradation of EWIS components. The following are possible circumstances under which additional iterations through the EWIS risk assessment process may be performed.

H.3.1 Change in risk tolerances.
The action plan formed in Task Six is based on project-specific objectives and constraints; over time, these may change. Periodic reassessment will determine if the risk tolerances made in the original assessment are still valid or if changes are needed to satisfy current objectives.

H.3.2 Design life review.
An aircraft EWIS service life extension assessment can be evaluated using this handbook and Task Five. Reassessments should be scheduled prior to projected impact on aircraft airworthiness.

H.3.3 System upgrades.

Upgrade or modification to aircraft systems (such as avionics, hydraulics, etc.) can impact the EWIS risk assessment assumptions. Changes in the electrical loads, routing, and/or separation distance may affect EWIS physical or functional failures on the aircraft during these upgrades or modifications. The proposed changes should be integrated with the EWIS risk assessment model. This would require gathering of EWIS data as outlined in Task One (EWIS documentation), risk assessment performance in Task Five (risk assessment), and the evaluation of risk and mitigation strategy action in Task Six (action plan).

H.3.4 Mission change.

This may include changes in equipment. Furthermore, a change in aircraft mission profile may also affect the risk tolerance. The decisions made on risk mitigation strategies proposed during the original risk assessment effort may need to be re-examined to determine if the actions will be necessary to achieve risk level for the new mission profile.

CONCLUDING MATERIAL

Custodians:
Army – AV
Navy – AS
Air Force – 20
DLA – CC

Preparing activity:
Air Force – 20
(Project SESS-2019-053)

Review activities:
Army – AR, CR, MI, TE
Navy – EC, OS, SH
Air Force – 19, 70, 71, 84, 85, 170

Agent:
Air Force – 110

NOTE: The activities listed above were interested in this document as of the date of this document. Since organizations and responsibilities can change, you should verify the currency of the information above through use of the ASSIST Online database at https://assist.dla.mil.

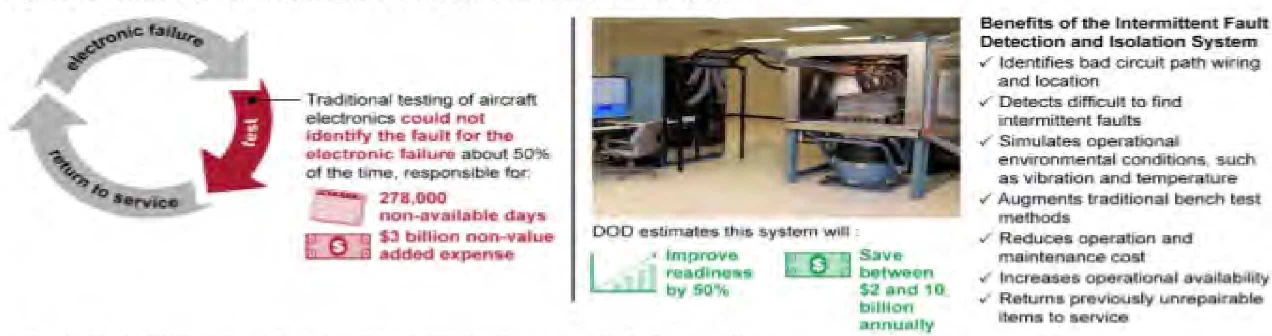
IFDIS focused Executive Highlights GAO-20-116 Report - MILITARY DEPOTS Can Benefit from Further Sharing of Best Practices and Lessons Learned

GAO Highlights of GAO-20-116, a report to congressional committees
Date: January 2020

Preface:
. . . DOD is experiencing benefits and taking steps to mitigate challenges with implementing best practices and lessons learned among the depots. Depots reported that implementing some best practices and lessons learned has led to benefits, including time and cost savings. For example, Navy Fleet Readiness Center Southwest, California, implemented an intermittent fault detection system from Ogden Air Logistics Complex, Utah, on its F/A-18 aircraft generators. According to officials, the depot reduced repair time from 90 days to 30 days and quadrupled the generators' time between failures. . . .

Page 20-21:
Inter-service collaboration. . . . example, the Navy's Fleet Readiness Center Southwest implemented a best practice learned from Ogden Air Logistic Complex to improve testing of electrical circuits. Specifically, according to depot officials, a maintainer at Ogden created a method—Intermittent Fault Detection and Isolation System—which tests systems and software to detect, isolate, and repair intermittent problems due to open circuits, short circuits, and poor wiring by replicating the environment of the aircraft in flight (See fig. 8.). According to Ogden officials and program documentation, by implementing this best practice, they have recovered out-of-service assets and generated about $62 million in cost savings. For example, after testing its F-16 chassis, Ogden officials recovered 138 out-of-service assets—amounting to $42 million of flight hardware returning to service

Figure 8: Benefits of the Intermittent Fault Detection and Isolation System



Source: GAO analysis of Department of Defense (DOD) and military service documentation; DOD (photos). | GAO-20-116

Moreover, officials at Fleet Readiness Center Southwest visited Ogden during a benchmarking trip to discuss the process of implementing the Intermittent Fault Detection and Isolation System to test their systems. According to officials from the Office of the Secretary of Defense, the intermittent faults due to aircraft electrical systems amounted to more than $300 million in operating and support costs in fiscal year 2014. The Fleet Readiness Center Southwest used the Intermittent Fault Detection and Isolation System to test its F/A-18 aircraft generators, which provide electrical power to the aircraft. As a result of testing these generators using the Intermittent Fault Detection and Isolation System, the mean time between failures for the generators has increased, according to officials, from 104 flight hours to over 400 flight hours, and the Navy anticipates a reduction of about 30 to 90 days of repair time.[30]

Page 26-27:
Approval process. . . . time-sensitive engineering decisions for one of its new weapon system reside at another location, which has caused delays in making timely decisions. In another example, depot officials told us that they had to get approval from individual program managers to implement the cold spray technology and the Intermittent Fault Detection Isolation System.
. . . Finally, the Office of the Assistant Secretary of Defense is providing specific guidance in implementing best practices and lessons learned, such as the memorandum issued in April 2019 on the Intermittent Fault Detection and Isolation System directing the military services to adopt this best practice.[33]

United States Government Accountability Office

Report to Congressional Committees

January 2020

MILITARY DEPOTS

DOD Can Benefit from Further Sharing of Best Practices and Lessons Learned

GAO-20-116

GAO Highlights

Highlights of GAO-20-116, a report to congressional committees

January 2020

MILITARY DEPOTS

DOD Can Benefit from Further Sharing of Best Practices and Lessons Learned

Why GAO Did This Study

DOD operates depots nationwide to maintain complex weapon systems and equipment through overhauls, upgrades, and rebuilding. These depots are crucial to sustaining military readiness by ensuring that the military services can regularly maintain critical weapon systems and return them to the warfighter for use in training and operations. For fiscal year 2018, DOD reported $19 billion in total maintenance expenditures and about 84,000 personnel performing depot-level maintenance.

In June 2018, the Senate Armed Services Committee, in a report accompanying a bill for the National Defense Authorization Act for Fiscal Year 2019, included a provision for GAO to review DOD's sharing and implementation of best practices and lessons learned among the depots.

GAO evaluated the extent to which DOD experiences benefits and has challenges with (1) sharing and (2) implementing best practices and lessons learned among the depots. GAO reviewed agency guidance; surveyed 17 depots; conducted site visits at five depots; and interviewed DOD, military service, and depot officials.

What GAO Recommends

GAO is making two recommendations to improve the depots' ability to share best practices and lessons learned by creating a comprehensive list of sharing venues, including points of contact, and re-establishing and maintaining materiel lessons learned organizations. DOD concurred with the recommendations.

View GAO-20-116. For more information, contact Diana Maurer at (202) 512-9627 or maurerd@gao.gov

What GAO Found

The Department of Defense (DOD) experiences benefits from sharing best practices and lessons learned among its depots, but communication and organization challenges exist. Best practices and lessons learned are shared among the depots through a variety of venues, including networking, working groups, and benchmarking trips to other depots. However, DOD has communication challenges, such as the lack of awareness of venues for sharing information. While Office of the Secretary of Defense officials reported posting a list of working groups, the list only contains three of the more than 60 working groups GAO identified. Without a centralized list of sharing venues and points of contact, it is unclear what groups exist and who to contact to participate, which may impede sharing of best practices and lessons learned. Further, while the Army stated it established lessons learned organizations for sharing maintenance best practices and lessons learned, it did not maintain them due to organizational restructuring and resource constraints. Establishing and maintaining effective organizations dedicated to sharing materiel best practices and lessons learned would encourage knowledge sharing among the Army depots.

Department of Defense's Benefits and Challenges with Sharing and Implementing Best Practices and Lessons Learned among the 17 Military Depots

Source: GAO analysis of Department of Defense information. | GAO-20-116

DOD is experiencing benefits and taking steps to mitigate challenges with implementing best practices and lessons learned among the depots. Depots reported that implementing some best practices and lessons learned has led to benefits, including time and cost savings. For example, Navy Fleet Readiness Center Southwest, California, implemented an intermittent fault detection system from Ogden Air Logistics Complex, Utah, on its F/A-18 aircraft generators. According to officials, the depot reduced repair time from 90 days to 30 days and quadrupled the generators' time between failures. Depots reported a variety of challenges to implementing lessons learned and best practices, including a lack of resources, lengthy approval processes, and acquisition and technology restrictions. DOD is taking steps to mitigate challenges to implementation, such as creating a new technology tool for viewing metrics on weapon systems' cost and availability which will allow senior leaders to steer resources to needed programs.

Contents

Figures

Abbreviations

CJCS	Chairman of the Joint Chiefs of Staff
DOD	Department of Defense

U.S. GOVERNMENT ACCOUNTABILITY OFFICE
441 G St. N.W.
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Congressional Committees

The Department of Defense (DOD) operates depots nationwide to maintain complex weapon systems and equipment through overhauls, upgrades, and rebuilding.[1] These depots are crucial to sustaining military readiness by ensuring that the military services can regularly maintain critical weapon systems and return them to the warfighter for use in training and operations. For fiscal year 2018, DOD reported $19 billion in total maintenance expenditures and about 84,000 personnel performing depot-level maintenance. However, our prior work shows that DOD is continually experiencing challenges at its depots, including deteriorating equipment and facility condition, filling critical personnel skills, and meeting service repair needs.[2] These challenges can lead to delays in the maintenance of weapon systems, which ultimately affects readiness by impeding the military services' ability to conduct training and to provide forces with sufficient equipment to perform operations around the world. According to DOD officials, these challenges could be better addressed within a culture of collaboration that shares best practices as well as leaders and processes that foster a culture of assessment and feedback.

To address these challenges and learn more about DOD's efforts to share best practices and lessons learned, the National Defense Authorization Act for Fiscal Year 2018 directed the Secretary of Defense to submit to the congressional defense committees a ‘‘comprehensive plan for the sharing of best practices for depot-level maintenance among

[1]The term "depots" will refer to 17 installations reviewed in this report that perform depot-level maintenance, including the Army's depots, the Navy's shipyards and fleet readiness centers, the Marine Corps' production plants, and the Air Force's air logistics complexes. Depot maintenance includes inspection, repair, overhaul, or the modification or rebuild of end items, assemblies, subassemblies, and parts that, among other things, require extensive industrial facilities, specialized tools and equipment, or uniquely experienced and trained personnel that are not available in other maintenance activities. Depot maintenance is independent of any location or funding source and may be performed in the public or private sectors.

[2]See, for example, GAO, *Military Depots: Actions Needed to Improve Poor Conditions of Facilities and Equipment That Affect Maintenance Timeliness and Efficiency*, GAO-19-242 (Washington, D.C.: Apr. 29, 2019) and *DOD Depot Workforce: Services Need to Assess the Effectiveness of Their Initiatives to Maintain Critical Skills*, GAO-19-51 (Washington, D.C.: Dec. 14, 2018).

the military services.''[3] In March 2018, DOD submitted a report to Congress describing a number of groups, committees, and activities related to a governance framework of joint collaboration.[4] In June 2018, the Senate Armed Services Committee, in a report accompanying a bill for the National Defense Authorization Act for Fiscal Year 2019, stated that it is not clear if DOD is effectively sharing and implementing best practices and lessons learned identified by its individual depots.[5] As such, the Senate Armed Services Committee report included a provision for us to review DOD's sharing and implementation of best practices and lessons learned among the depots. In this report, we examine the extent to which DOD experiences benefits and has challenges with (1) sharing and (2) implementing best practices and lessons learned among the depots. This report is the first in a series of reports examining depot maintenance requirements and timeliness for aviation, ground vehicles, and naval shipyards.

To address these objectives, we reviewed relevant laws and DOD and military service guidance that govern depot maintenance. We conducted a survey of 17 DOD depots performing depot-level maintenance to gain an understanding of how each depot shares with each other and implements best practices and lessons learned.[6] The response rate for the survey was 100 percent. To gather detailed examples of DOD's efforts to share and implement best practices and lessons learned, we visited a non-generalizable sample of five depots. To select our sample, we considered variation in geographic location, military service representation, and types of weapon systems maintained. At these sites, we conducted group discussions with depot officials and maintainers to gain insight into their roles in sharing and implementing best practices and lessons learned.

Additionally, we interviewed officials from the Office of the Secretary of Defense, military headquarters, military logistics or materiel components, and military lessons learned centers. We reviewed our prior reports related to challenges experienced at DOD depots and DOD's report to

[3]Pub. L. No. 115-91 (2017).

[4]DOD, *Report to Congress on Sharing of Best Practices for Depot-Level Maintenance Among the Military Services* (March 2018).

[5]S. Rep. No. 115-262, at 147 (2018).

[6]To capture the full range of activities surrounding best practices and lessons learned, our unit of analysis for each survey was the depot as a whole. As such, our results will be reported by number of depots, rather than depot commanders or other metrics.

Congress on the sharing of best practices for depot-level maintenance among the military services. We obtained and analyzed documentation of sharing, such as working group charters and trip reports documenting results from visiting another depot, as well as benefits experienced from implementing a best practice or lessons learned, including time and cost savings. We assessed the documentary and testimonial evidence we collected against DOD and military service guidance, as well as the *Standards for Internal Control in the Federal Government* related to information and communication.[7] A detailed discussion of our scope and methodology is in appendix I.

We conducted this performance audit from January 2019 to January 2020 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

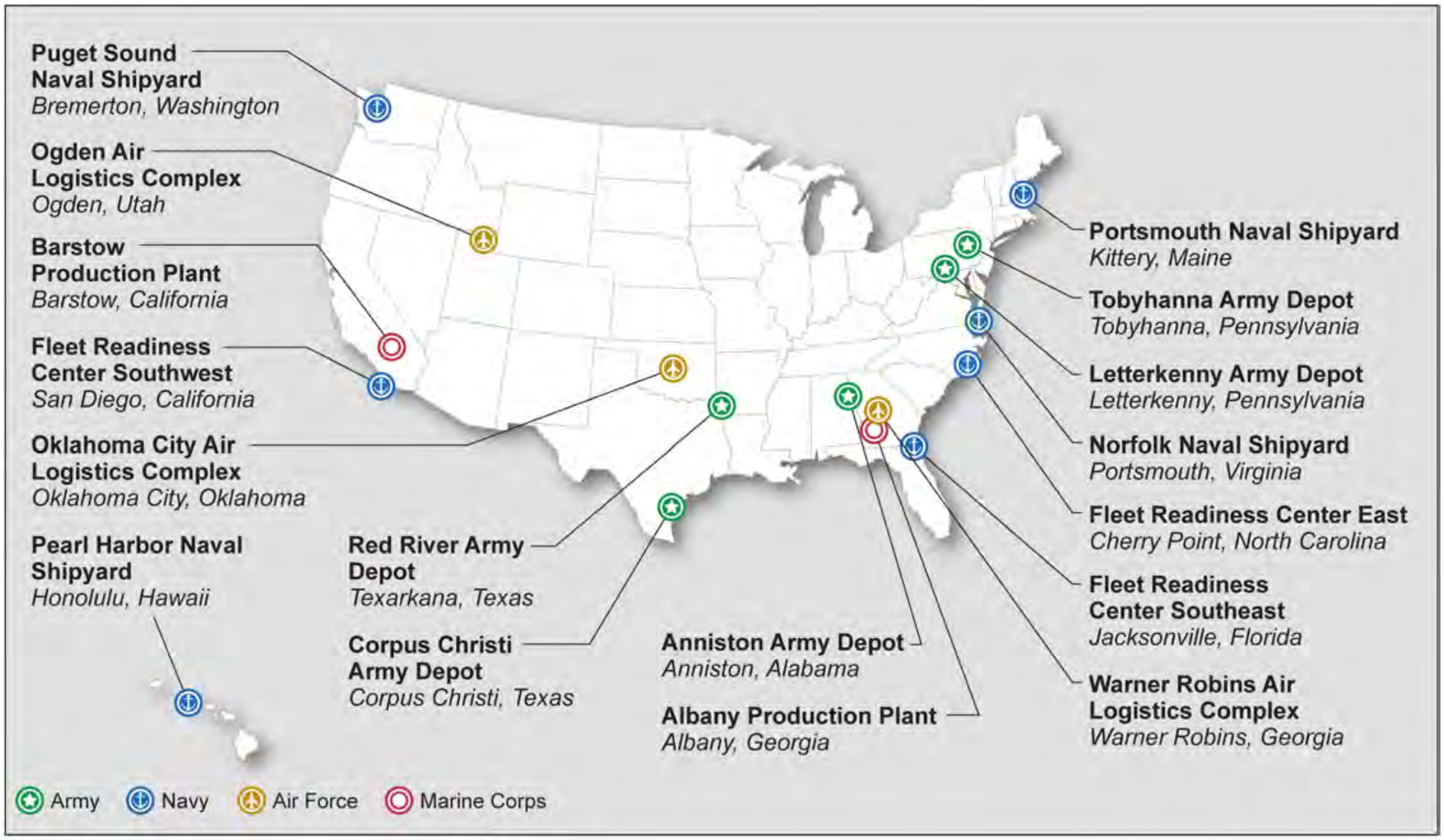
DOD's Depots

Depots are government-owned, government-operated industrial installations that maintain, overhaul, and repair a multitude of complex military weapon systems and equipment for the Department of Defense. Depots are essential to maintaining readiness for DOD and play a key role in sustaining weapon systems and equipment in meeting operational, contingency, and training requirements. There are 17 depots operated by the military services that perform depot-level maintenance on a wide range of vehicles and other military assets, including aircraft, engines, helicopters, combat vehicles, ships, and software. Five are Army depots, four are Naval shipyards, three are Navy fleet readiness centers, two are Marine Corps production plants, and three are Air Force air logistics complexes.[8] Figure 1 below shows the location of these 17 depots across the United States.

[7]GAO, *Standards for Internal Control in the Federal Government*, GAO-14-704G (Washington, D.C.: September 2014).

[8]The Navy's fleet readiness centers are primarily focused on aviation-related repairs.

Figure 1: Department of Defense's 17 Depots where Depot-Level Maintenance on Weapon Systems Is Performed



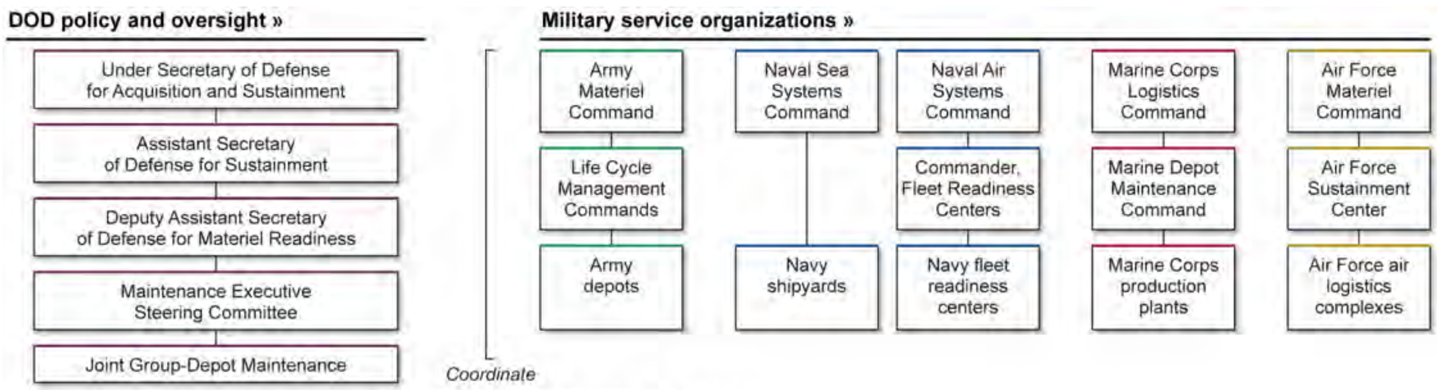
Source: GAO analysis of Department of Defense documents. | GAO-20-116

Note: Depots are government-owned, government-operated industrial installations that maintain, overhaul, and repair a multitude of complex military weapon systems and equipment.

Roles and Responsibilities

The depots are part of a larger, DOD-wide logistics enterprise that involves a number of different organizations (See fig. 2.).

Figure 2: DOD and Military Service Organizations Related to Depot Management



Source: GAO analysis of Department of Defense (DOD) and military service documentation. | GAO-20-116

Office of the Under Secretary of Defense for Acquisition and Sustainment. This office is responsible for, among other things, ensuring the defense industrial base, including depots, is robust, secure, resilient and innovative.

Office of the Assistant Secretary of Defense for Sustainment. This office serves as the principal assistant and advisor to the Under Secretary of Defense for Acquisition and Sustainment on material readiness. Among other responsibilities, the Assistant Secretary of Defense for Sustainment prescribes policies and procedures on maintenance, materiel readiness, and sustainment support.

Office of the Deputy Assistant Secretary of Defense for Materiel Readiness. This office establishes and maintains maintenance policies and programs to maintain the desired levels of weapon systems and military equipment readiness to accomplish the Department's missions. Further, according to DOD officials as well as DOD's March 2018 report to Congress on sharing best practices, the Office of the Deputy Assistant Secretary of Defense for Materiel Readiness has established a governance framework for materiel maintenance at DOD depots.[9] There are a number of stakeholders involved in this framework, including the Maintenance Executive Steering Committee (Committee) and the Joint Group-Depot Maintenance.

[9]DOD, *Report to Congress on Sharing of Best Practices for Depot-Level Maintenance Among the Military Services* (March 2018).

Maintenance Executive Steering Committee. This Committee consists of senior maintenance and logistics representatives from the Office of the Secretary of Defense, the Joint Staff, the Defense Logistics Agency, and the military services. According to DOD, this Committee advises the Deputy Assistant Secretary of Defense for Materiel Readiness on initiatives affecting efficiency, effectiveness, and affordability of maintenance management and operations. The Committee also serves as a forum for a coordinated review of maintenance policies, systems, programs and activities and helps optimize and steer DOD enterprise maintenance practices and strategy.

Joint Group–Depot Maintenance. As a standing committee of the Maintenance Executive Steering Committee, the mission of the Joint Group–Depot Maintenance is to promote and review depot maintenance functions at the enterprise level to achieve effective and affordable depot maintenance support for weapon systems and to execute responsibilities assigned in DOD maintenance of military materiel policy.[10]

Military service organizations. Each military service has its own logistics or materiel command component, which provides day-to-day management and oversight of the military services' depots.

DOD Guidance for Sharing Best Practices and Lessons Learned

The Chairman of the Joint Chiefs of Staff is responsible for formulating policies for gathering, developing, and disseminating joint lessons learned for the armed forces.[11] Chairman of the Joint Chiefs of Staff (CJCS) Instruction 3150.25G, *Joint Lessons Learned Program*, defines:

- best practice as "a validated method or procedure which has consistently shown results superior to those achieved with other means, and appears to be worthy of replication," and
- lesson learned as "a resolved issue or best practice that improves operations or activities and results in an internalized change to capability, process, or procedure."[12]

[10]DOD Directive 4151.18, *Maintenance of Military Materiel* (March 31, 2004) (Incorporating Change 1, Aug. 31, 2018). DOD materiel maintenance includes maintenance of weapon systems, hardware, equipment, software, or any combination.

[11]10 U.S.C. § 153(a)(6)(E).

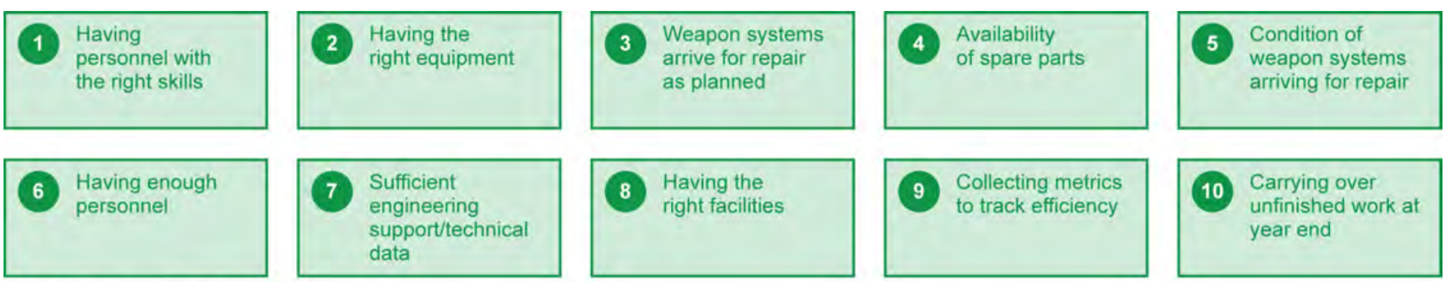
[12]CJCS Instruction 3150.25G, *Joint Lessons Learned Program* (Jan. 31, 2018).

The Joint Staff's Joint Lessons Learned Program collects, validates, and disseminates lessons learned to support sustainment and improvement of joint force readiness and effectiveness via refinements in doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy.[13] Specific military service guidance on their respective lessons learned programs share the same purpose.[14] Best practices and lessons learned are captured in the Joint Lessons Learned Information System—DOD's system of record for lessons learned—and are generally focused on sharing operational information from after-action reports and joint training exercises, rather than maintenance-related lessons learned. The DOD maintenance community, including the military service logistics or materiel command component and depots, do not typically coordinate with the military services' lessons learned centers or enter lessons learned into the Joint Lessons Learned Information System.

GAO's Prior Work on Depot Maintenance

Our prior work has identified multiple challenges that can affect depot performance, including having the right facilities and having personnel with the right skills, among other challenges (See fig. 3.).

Figure 3: Challenges Experienced at Department of Defense Depots That Can Affect Depot Performance



Source: GAO. | GAO-20-116

Note: Depots are government-owned, government-operated industrial installations that maintain, overhaul, and repair a multitude of complex military weapon systems and equipment.

[13]CJCS Manual 3150.25B, *Joint Lessons Learned Program* (Oct. 12, 2018).

[14]Army Regulation 11-33, *Army Lessons Learned Program* (June 14, 2017); Office of the Chief of Naval Operations (OPNAV) Instruction 3500.37D, *Navy Lessons Learned Program* (June 20, 2018); Marine Corps Order 3504.1, *Marine Corps Lessons Learned Program (MCLLP) and the Marine Corps Center for Lessons Learned (MCCLL)* (July 31, 2006); Air Force Instruction 90-1601, *Air Force Lessons Learned Program* (Dec. 18, 2013).

Specifically, in April 2019 we reported on the condition of facilities at DOD depots, such as the condition of these depots are poor and the age of equipment is generally past its useful life, and the military services do not consistently track the effect that these conditions have on depot performance. To address these challenges, we recommended that DOD improve its data collection on the effect of facilities and equipment condition on depot performance, among other things.[15] DOD concurred, and stated, in general, that the Service Chiefs for the Army, Navy, Air Force, and Marine Corps will ensure that their respective material commands take actions to implement the recommendations for their respective service. Also, in December 2018 we reported on depot workforce challenges, such as hiring personnel in a timely manner and providing inexperienced personnel with the training necessary to become proficient in skilled operations. According to DOD officials, these workforce challenges contributed to delays in the maintenance of some weapon systems. To address these workforce challenges, we recommended that the military services assess the effectiveness of the actions they have taken to maintain critical skills in the depot workforce.[16] DOD concurred, and stated that each of the four services will take action to assess the effectiveness of the hiring, training, and retention programs at their respective depots, shipyards, fleet readiness centers, and air logistics complexes. The Related GAO Products page at the end of this report provides a list of our depot-related reports and testimonies.

[15]GAO-19-242.

[16]GAO-19-51.

DOD Experiences Benefits from Sharing Best Practices and Lessons Learned among the Depots, but Communication and Organization Challenges Exist

DOD Experiences Benefits from Sharing Best Practices and Lessons Learned among the Depots through a Variety of Venues

DOD shares best practices and lessons learned among the depots through a variety of venues, including networking, working groups, and benchmarking.

Networking. DOD shares best practices and lessons learned through informal networking, such as personal contacts and conferences. All 17 depots reported engaging in networking to share best practices and lessons learned and coordinating with their materiel commands, program managers and/or program offices, and academia. The majority of the depots also coordinated with industry, other depots, and/or a point of contact or group within the Office of the Secretary of Defense (see table 1 below).

Table 1: Department of Defense's (DOD) 17 Depots' Selected Responses on Coordination to Share Best Practices and Lessons Learned

Does your depot coordinate with any of the following groups regarding best practices and lessons learned?	
	Yes
Your materiel command/systems command	17
The Program Manager and/or Program Executive Office for items serviced at your depot	17
Academia	17
Other depots within your service	15
Other depots outside of your service	15
Industry–i.e., commercial depots, original equipment manufacturers, industry sponsored conferences/working groups	14
An Office of the Secretary of Defense-level point of contact or group	11

Source: GAO analysis of GAO survey of 17 DOD depots performing DOD-depot level maintenance. | GAO-20-116

Note: Depots are government-owned, government-operated industrial installations that maintain, overhaul, and repair a multitude of complex military weapon systems and equipment.

Fleet Readiness Center Southwest Learns and Implements Training Lab Concept from Depot Maintenance Awards Winner, Portsmouth Naval Shipyard

It is DOD policy to enhance maintenance awareness and encourage maintenance excellence by providing appropriate recognition through an annual maintenance awards program. After Portsmouth Naval Shipyard won the Robert T. Mason Award for Depot Maintenance Excellence in 2016, Fleet Readiness Center Southwest officials visited the Portsmouth Naval Shipyard on a benchmarking trip. Benchmarking is when depot officials visit another depot to compare performance and find improvement ideas. During this trip, Fleet Readiness Center Southwest officials learned about Portsmouth Naval Shipyard's apprenticeship program. Upon their return, Fleet Readiness Center Southwest officials worked to establish their own apprenticeship program, which includes labs and courses to train artisans in sheet metals, paint, and electronics.

This success has been shared with Fleet Readiness Centers East and Southeast, which are both implementing similar systems. Successfully training new artisans is particularly important for depot performance, as our prior work has shown that this workforce is aging and the Department of Defense faces challenges in hiring and retaining workers with key skills. Officials cited examples of maintenance taking months or years longer than expected, in part due to shortages in skilled personnel.

Source: GAO analysis of Department of Defense (DOD) information and GAO-19-51. | GAO-20-116

All 17 depots reported that the DOD Maintenance Symposium (Symposium), an annual department-wide conference addressing the maintenance of weapon systems and equipment, is the most regularly attended and most beneficial venue for networking. All 17 depots reported attending the Symposium regularly or occasionally, with depot officials stating in the survey and interviews that the Symposium provides opportunities to build relationships and network with peers in DOD and external contacts in industry. Depots reported in our survey that the Symposium was valuable because it offered opportunities to make contacts with equipment vendors and other services, as well as break-out sessions and informal discussions to exchange ideas. During the Symposium, a number of maintenance awards, including the Robert T. Mason Award for Depot Maintenance Excellence, are awarded to recognize maintenance excellence (see sidebar).[17] Three depots reported that the recognition of the award-winning depots gives other depots the opportunity to reach out to the award-winning depots for relevant information.

Working Groups. DOD depots' leadership and staff use working groups and communities of practice as venues for the DOD maintenance community to collaborate and to share expertise on specific topics.[18] When surveyed, 13 of 17 depots reported they share best practices and lessons learned in working groups, and they identified more than 60 such working groups.[19] Our analysis of survey responses shows that depots value working groups because they improve depot support to the warfighter by allowing the depot to evaluate best practices, review new technology, exchange data, initiate relationships, and gain stakeholder support. In our interviews, depot officials affirmed the value of working

[17]The Robert T. Mason Award for Depot Maintenance Excellence is presented annually to one program from a depot-level maintenance activity. The competition is for programs having more than 400 DOD civilian and U.S. uniformed military employees engaged in depot-level maintenance operations.

[18]DOD defines a working group as an enduring or ad hoc organization within a headquarters consisting of a core functional group and other staff and component representatives whose purpose is to provide analysis on the specific function to users. DOD defines a community of practice as a group of people who share a common craft and/or professions and learn how to do it better through regular interaction. DOD Joint Publication 1-02, *Department of Defense Dictionary of Military and Associated Terms* (Nov. 8, 2010) (as amended through Feb. 15, 2016); CJCS Instruction 3150.25G. For the purposes of this report, we use the term working groups to refer to working groups and communities of practice.

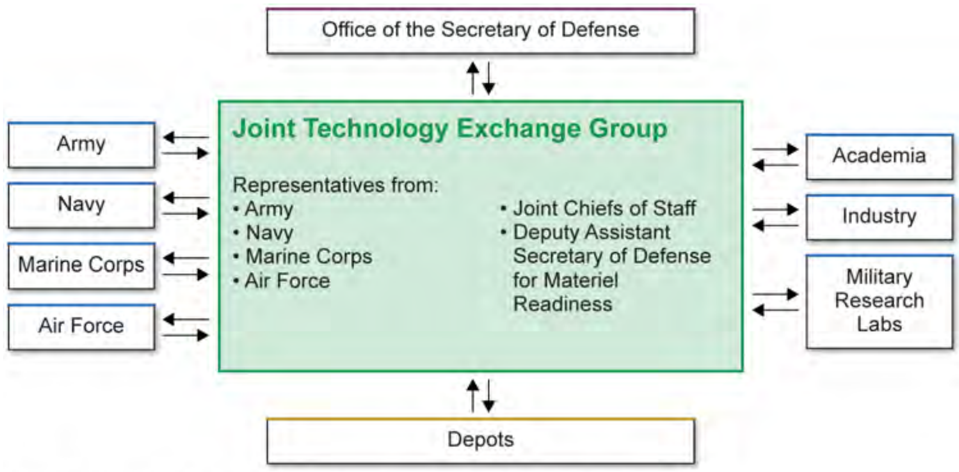
[19]See appendix II for a list of all working groups identified by the depots in our survey.

groups to promote collaboration and open discussions among peers focused on specific topics of common interest.

We found that the working groups fall into three topic areas: new technologies, specific weapon systems, and depot management. For example:

- **New technologies**. The Joint Technology Exchange Group was chartered to improve coordination in the introduction of new or improved technology, new processes, or new equipment into DOD depot maintenance activities. To do this, the Joint Technology Exchange Group facilitates a number of forums and working groups centered on specific technologies, which allow representatives from the depots to learn from other services, academia, and industry (See fig. 4.). One example of this is cold spray, a new technology that sprays high velocity metal particles to repair worn surfaces and damaged parts that are unrepairable by traditional processes. Working groups facilitated by the Joint Technology Exchange Group have shared the usefulness of cold spray technology, and 12 depots from all service branches reported that they have begun adopting the technology. One depot estimates that its annual savings from using cold spray will be $202,000 annually, as well as additional time savings.

Figure 4: Department of Defense's Joint Technology Exchange Group Participants



Source: GAO analysis of Joint Technology Exchange Group participants. | GAO-20-116

Note: The Joint Technology Exchange Group was chartered to improve coordination in the introduction of new technology into Department of Defense depot maintenance activities.

- **Weapon systems**. According to Navy officials, depot officials and maintainers for the CH-53E/MH-53E heavy lift helicopter participate in the H-53 Fleet Support Team working group. Fleet Readiness Center East reported that its production team was able to implement lessons learned from this group for repairing misalignment in a piece of the helicopter's tail. As a result, the safety of the helicopter was increased. See figure 5 for details on this heavy lift helicopter.

Figure 5: The CH-53E and MH-53E Heavy Lift Helicopters

CH-53E
Marine Corps

MH-53E
Navy

Source: Defense Visual Information Distribution Service. | GAO-20-116

- **Depot management.** Depot commanders participate in the Industrial Base Commanders' monthly teleconference to share best practices and lessons learned related, in part, to management of depot operations. Twelve of the 17 depots indicated that the Industrial Base Commanders' monthly teleconference is beneficial. The depots reported that the Industrial Base Commanders' monthly teleconference allows base commanders time to share and to work on specific depot maintenance problems and is particularly productive in the areas of personnel and policy.

Benchmarking. To benchmark, depot officials visit another depot to compare performance and find improvement ideas, particularly best practices and lessons learned related to weapon systems and depot management.[20] Our analysis of site visit and survey data shows 10 of the 17 depots reported benchmarking trips. For example, in 2018 the Marine Corps Albany Production Plant sent a team of managers and technicians from their electronics and fabrications branches on a benchmarking trip to learn best practices from the team at Tobyhanna Army Depot. They visited six areas, where they observed processes and ideas that they could take back to their plant. In its trip report, the Marine Corps Albany Production Plant team highlighted a number of processes that increased efficiency in the electronics shop at Tobyhanna Army Depot, such as steps to eliminate unnecessary travel in sheet metal processes and updated electronics workstations.

According to our prior work, benchmarking is useful for reducing internal resistance to change—a barrier to sharing best practices and lessons learned cited by the depots—because knowing what others actually are accomplishing changes perceptions of what can be done and what should be attempted.[21] One depot told us that it intentionally brings maintainers and depot officials together on benchmarking trips so that the maintainers can benefit firsthand from seeing the best practices and lessons learned.

[20]Benchmarking helps define specific reference points for setting goals for improving performance. It leads an organization to compare the performance of its processes and the way the processes are conducted with either (1) internal organizational pockets of excellence or (2) relevant peer organizations to obtain ideas for improvement. *See* GAO, *Managing for Results: Critical Actions for Managing Performance*, GAO/T-GGD/AIMD-95-187 (Washington, D.C.: June 20, 1995).

[21]GAO/T-GGD/AIMD-95-187.

DOD Has Communication Challenges That May Hinder Ability of the Depots to Share Best Practices and Lessons Learned

DOD has communication challenges, such as the lack of awareness of venues, that may hinder the ability of the 17 depots to share best practices and lessons learned. While many sharing venues exist, such as working groups, the depots' knowledge of them has gaps. According to our survey, 12 of the 17 depots reported being unaware of the existence of some venues where best practices and lessons learned can be shared. Additionally, 7 of the 17 depots reported not knowing who to contact to participate in some venues for sharing best practices and lessons learned. Moreover, in our interviews officials explained that staff turnover is also a challenge. Specifically, officials from one depot said that when the depot representative to a venue leaves, the institutional knowledge of the venue and its point of contact can be lost. They recounted having to resort to cold-calling other depots for information. Depots also reported that their staff did not attend best practices and lessons learned venues because they believed that those venues were for higher command levels. For example, one depot expressed confusion about the Industrial Base Commanders' meeting and reported that while the depot officials were aware of the meeting, they believed that it was for officials at a higher level, such as their Materiel Command.[22]

Department of Defense Instruction 4151.18 states that DOD materiel maintenance programs should adopt business practices and quality management processes to continuously improve maintenance operations and maintenance production, achieve cost savings and avoidance, and realize process cycle time reduction.[23] Further, GAO's *Standards for Internal Control in the Federal Government* states that management should communicate quality information down and across reporting lines to enable personnel to perform key roles in achieving objectives.[24] However, the Office of the Secretary of Defense has not created, shared, or maintained a comprehensive and updated list of all depot-specific DOD sharing venues (i.e., working groups) that includes points of contact. Officials from the Office of the Secretary of Defense stated that the Joint Technology Exchange Group maintains a list on its website. However, the list is incomplete, only containing three of the over 60 working groups we identified in our analysis of our interview and survey data. Moreover, we found that not all depot officials were aware of the Joint Technology

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[22]The Industrial Base Commanders' meeting is a monthly teleconference for depot commanders to share best practices and lessons learned regarding depot management.

[23]DOD Instruction 4151.18, *Maintenance of Military Materiel* (Mar. 31, 2004) (incorporating Change 1, Aug. 31, 2018).

[24]GAO-14-704G.

Exchange Group and so would not be familiar with the Joint Technology Exchange Group's website. Without a centralized list of venues and points of contact, it is unclear what groups exist and who to contact to participate, which may impede sharing of best practices and lessons learned.

The Army Has Not Maintained Lessons Learned Organizations, Potentially Hindering the Ability of the Depots to Share Best Practices and Lessons Learned

Each military service has initiatives or organizations to encourage the sharing of best practice and lessons learned; however, the Army has not maintained its lessons learned organizations. The depots from the Navy, Marine Corps, and Air Force reported, in our survey and interviews, that their military services have initiatives and organizations that encourage knowledge sharing regarding best practices and lessons learned among the depots. For example:

- **Navy's Fleet Readiness Center's Naval Sustainment System.** The Naval Sustainment System is an initiative to increase maintenance capacity and readiness among the Navy's fleet readiness centers by process reviews and benchmarking. The depots reported in our survey that it improves production by encouraging them to identify constraints and to share lessons learned. The Naval Sustainment System is also in the process of being adopted by the shipyards.
- **Navy's "One Shipyard" Concept.** The "One Shipyard" concept is a Navy workforce initiative in which maintainers are exchanged among the shipyards to ensure that the shipyards will have the required number of workers and skill sets to meet current and planned maintenance requirements. A Navy depot stated that as a result of the communication required by this concept, they are better able to share best practices.
- **Marine Corps' Marine Depot Maintenance Command.** Based on responses to our survey, Marine Corps officials stated that the Marine Corps depots have a single command structure. With this structure, all process improvement meetings are held with both depots in attendance, resulting in the sharing of best practices and lessons learned between the two depots.
- **Air Force's Art of the Possible.** The Air Force Sustainment Center created this management program to focus attention on restrictions in workflow in the depots. Depots report that it creates a culture of collaboration and sharing of best practices and lessons learned because it focuses on process improvement and creates a culture in which it is acceptable to discuss problems with other depots.

Competition for Workload

To determine which depot will receive new workload, the Department of Defense (DOD) Instruction 4151.24, *Depot Source of Repair Determination Process* (Oct.13, 2017) outlines a process under which workloads necessary to sustain core logistics capabilities are assigned to DOD depots that have the requisite competencies. Two Army depots reported that this process created competition for workload that hinders sharing for them. Depot officials stated that they fear that other depots will take workload from them if they share weapons system maintenance best practices. In one such instance, Marine Corps depot officials stated they visited an Army depot and observed a best practice for repairing 50-caliber machine gun receivers. However, when the Marine Corps depot reached out for technical details, the Army depot was not inclined to share, for a variety of reasons including competition for the same workload. Then, the Marine Corps depot asked Marine Corps Logistics Command to facilitate, and they resolved the issue by finding a Navy depot that had similar technology and was willing to share.

Senior Army officials concurred that competition between depots for jobs can be a barrier for sharing, particularly when it involves the preservation of specific depot workloads. However, depots in other services did not report competition for workload to be a barrier to sharing.

Source: GAO Analysis of DOD Information. Defense Visual Information Distribution Service (photos). | GAO-20-116

In contrast, the Army does not have similar initiatives or organizations. Army regulations direct the establishment and maintenance of two organizations for sharing depot best practices and lessons learned. First, Army Regulation 750-1 directs the Army Materiel Command to establish and maintain the Army Materiel Lessons Learned Analysis Program to identify potential systemic materiel sustainment issues and examine root and contributing causes.[25] Second, Army Regulation 11-33 directs Army Materiel Command to establish and maintain the Center for Army Acquisition and Materiel Lessons Learned to provide support in the collection, analysis, dissemination, and archiving capability of materiel lessons learned, with the objective of creating a knowledge sharing culture within the Army.[26] Moreover, the *Standards for Internal Control in the Federal Government* states that management should establish an organizational structure, assign responsibility, and delegate authority to achieve the entity's objectives.[27]

The Army stated it established these organizations for sharing materiel best practices and lessons learned; however, Army Headquarters, Army Materiel Command, and Army depot officials stated that they were not aware of analysis or knowledge sharing of depot best practices and lessons learned that were performed by these organizations. Further, the Army did not maintain these organizations for sharing materiel best practices and lessons learned. First, officials from Army Futures Command confirmed that the Army Materiel Lessons Learned Analysis Program was transferred from Army Materiel Command to Army Futures Command in July 2018 and no longer focuses specifically on materiel lessons learned. Second, the officials confirmed that the Army ceased to maintain the Center for Army Acquisition and Materiel Lessons Learned in early 2017 due to direct funding limitations. In addition, some Army depots reported being unable to identify peers in other depots to share with, and they reported that competition hinders sharing (see sidebar). Senior Army officials concurred that there are cultural challenges, which result in the depots being less open to sharing and implementing best practices and lessons learned. Establishing and maintaining effective organizations dedicated to sharing materiel best practices and lessons learned would encourage knowledge sharing among the Army depots.

[25]Army Regulation 750-1, *Army Material Maintenance Policy* (Aug. 3, 2017).

[26]Army Regulation 11-33, *Army Lessons Learned Program* (June 14, 2017).

[27]GAO-14-704G.

DOD Is Experiencing Benefits and Taking Steps to Mitigate Challenges with Implementing Best Practices and Lessons Learned among the 17 Depots

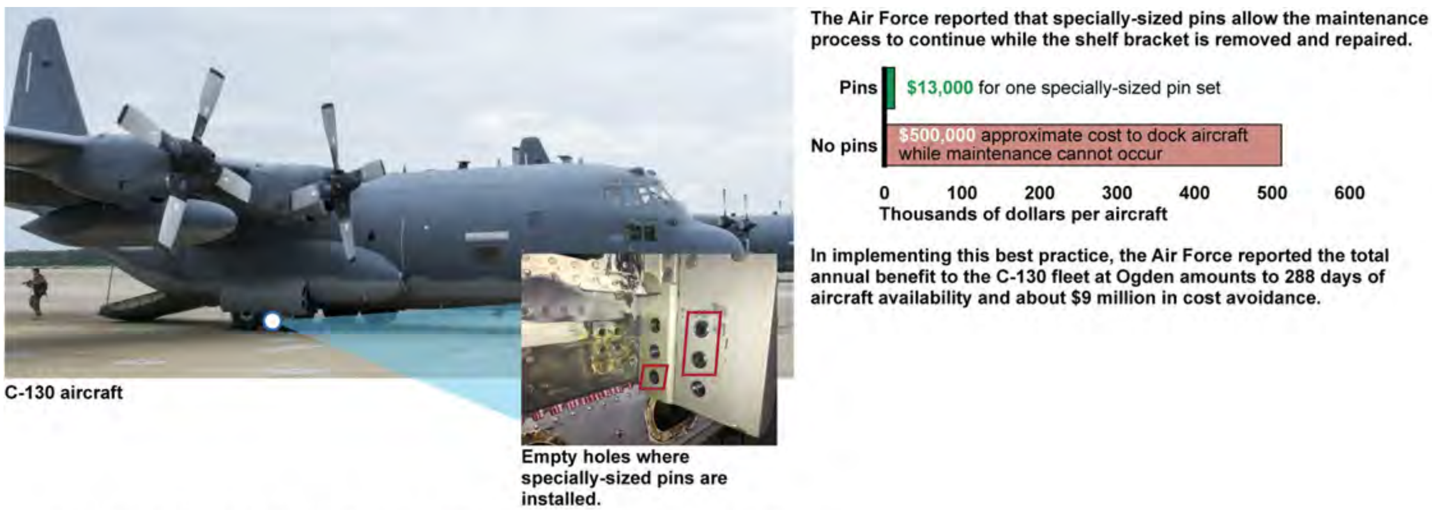
DOD Is Implementing Some Best Practices and Lessons Learned That Has Led to Benefits

DOD is implementing some best practices and lessons learned among the 17 depots that have led to benefits, including cost and time savings. In response to our survey, 16 of the 17 depots reported benefits from successfully implementing best practices and lessons learned, such as sharing technology to reduce costs and improving maintenance processes to repair parts and systems. These implemented best practices and lessons learned can be defined as intra-service (within a military service), inter-service (between two or more military services), or DOD and external entities (between a military service and private industry).

Intra-service collaboration. Depots within each military service are collaborating to implement best practices and lessons learned to improve depot management processes and repairs related to weapon systems. For example, Red River Army Depot implemented a best practice learned from Anniston Army Depot to improve its depot management process in meeting its production schedule. The production schedule is a plan that identifies, among other things, working hours for maintainers, available storage, and parts supply. To facilitate the implementation of this best practice, Army Tank-Automotive and Armaments Command, which oversees these two depots, hosted a joint event for the purpose of Anniston's sharing how a small group of individuals at its depot is responsible for maintaining visibility of all end-item (i.e., components and parts ready for their intended use) production schedules. According to Army officials, Red River did not have an organization that performed a similar function, and during the joint event, depot officials from Red River saw this as a lesson learned that they could take back to their depot and implement. Additionally, Anniston shared how it conducts its risk assessments, or program reviews, and weekly execution meetings, among other processes, in meeting its production schedules. As a result, Army officials told us that Red River implemented the best practices they thought would be beneficial in helping them make progress in meeting their production schedules.

In another example, two Air Force depots that maintain the Navy's C-130 aircraft are working together to implement a best practice, which, according to program documentation, has led to cost and time savings (See fig. 6.).[28]

Figure 6: Benefits of Using Specially-Sized Pins on Shelf Brackets for C-130 Aircraft at Ogden Air Logistics Complex, Utah



Source: GAO analysis of Air Force data; Defense Visual Information Distribution Service (photos). | GAO-20-116

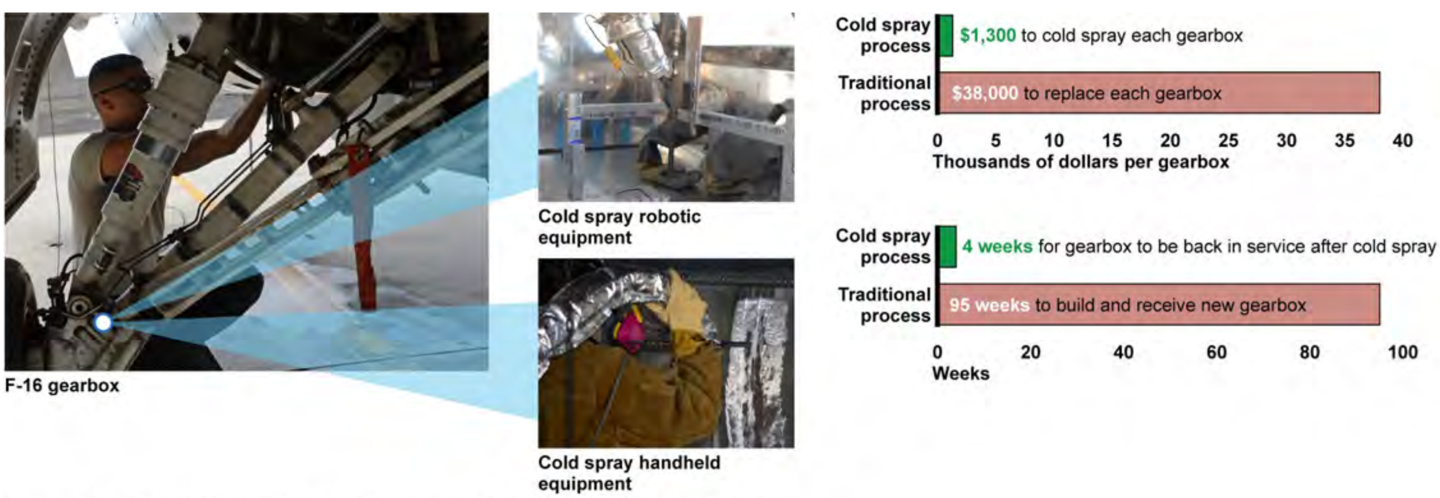
Specifically, the Navy's C-130 aircraft, which, according to Ogden officials, is maintained at Ogden Air Logistics Complex and Warner Robins Air Logistics Complex, contains a shelf bracket, which holds the pieces of the aircraft together. The aircraft becomes structurally vulnerable and unfit for operations and training if the shelf bracket is removed. The process of blasting, inspecting, plating, and reinstalling the shelf bracket takes an average of 63 days. During this time, some maintenance activities cannot occur until the shelf bracket is reinstalled. To address this issue, engineers at Ogden told us they created a series of specially-sized pins to lock the Navy's C-130 aircraft in place to help maintain the structural integrity of the airframe while other areas of the aircraft are being repaired. As a result of this best practice, maintainers

[28]The C-130 Hercules is a transport aircraft operated by the Navy, Marine Corps, and Air Force and maintained by the Air Force.

have eliminated 16 days in the maintenance process for the C-130. Also, depot officials told us for a one-time cost of $13,000 for one set of specially-sized pins, eliminating 16 days in the maintenance process in turn generates a cost avoidance of $32,000 per day (the cost to dock the aircraft) or more than $500,000 per aircraft. In implementing this best practice, the total annual benefit to the C-130 fleet at Ogden amounts to 288 days of aircraft availability and about $9 million in cost avoidance. Officials at Ogden told us they have implemented this new process and are discussing this best practice with maintainers at Warner Robins for implementation at their depot as well.

Further, Air Force depots are partnering to further implement another best practice, cold spray technology, which allows depots to repair damaged parts instead of replacing them. Replacing these damaged parts can be expensive or difficult if they are low in supply. Also, limited parts and long lead times can cause delays in the supply system, and existing repair processes have a long turnaround time. Cold spray technology has not been fully implemented; however, even with its limited implementation, cold spray technology has yielded cost and time benefits (See fig. 7.).

Figure 7: Benefits of Cold Spray Technology for the F-16 Gearbox



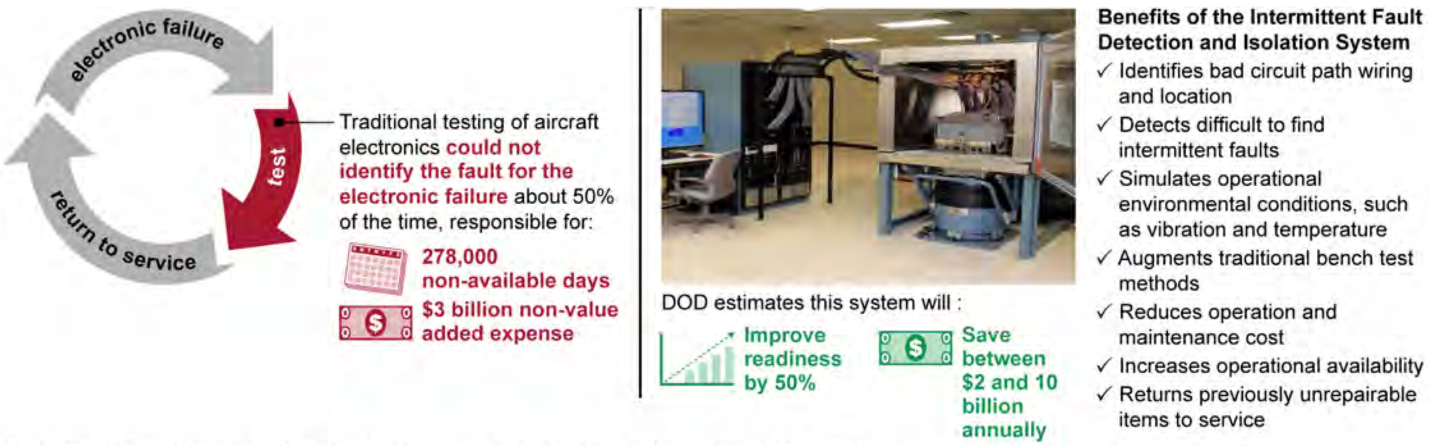
Source: GAO analysis of Air Force data; Defense Visual Information Distribution Service (photos). | GAO-20-116

According to Air Force officials, Ogden has been collaborating with the Oklahoma City Air Logistics Complex to cold spray its F-16 gearboxes until Ogden can obtain adequate workload to sustain the cold spray technology. According to Ogden officials and program documentation, cold spraying each gearbox costs about $1,300 whereas replacing each gearbox costs about $38,000; at 13 units per year, this amounts to almost $500,000 in annual cost avoidances. Additionally, it would take 95 weeks to build and receive a new gearbox unit; however, with the cold spray repair the unit is back in service in 4 weeks. Ogden officials are currently working to include cold spraying gearboxes for the F-15, C-5 and E-3 weapon systems to its workload.[29]

Inter-service collaboration. Depots from two or more military services are collaborating to implement best practices and lessons learned which has led to benefits. For example, the Navy's Fleet Readiness Center Southwest implemented a best practice learned from Ogden Air Logistic Complex to improve testing of electrical circuits. Specifically, according to depot officials, a maintainer at Ogden created a method—Intermittent Fault Detection and Isolation System—which tests systems and software to detect, isolate, and repair intermittent problems due to open circuits, short circuits, and poor wiring by replicating the environment of the aircraft in flight (See fig. 8.). According to Ogden officials and program documentation, by implementing this best practice, they have recovered out-of-service assets and generated about $62 million in cost savings. For example, after testing its F-16 chassis, Ogden officials recovered 138 out-of-service assets—amounting to $42 million of flight hardware returning to service.

[29]The F-16 Fighting Falcon, F-15 Eagle, C-5 Galaxy, and E-3 Sentry are aircraft operated and maintained by the Air Force. The F-16 and F-15 are tactical fighter aircraft; the C-5 is a transport aircraft; and the E-3 is a warning and control system aircraft.

Figure 8: Benefits of the Intermittent Fault Detection and Isolation System



Source: GAO analysis of Department of Defense (DOD) and military service documentation; DOD (photos). | GAO-20-116

Moreover, officials at Fleet Readiness Center Southwest visited Ogden during a benchmarking trip to discuss the process of implementing the Intermittent Fault Detection and Isolation System to test their systems. According to officials from the Office of the Secretary of Defense, the intermittent faults due to aircraft electrical systems amounted to more than $300 million in operating and support costs in fiscal year 2014. The Fleet Readiness Center Southwest used the Intermittent Fault Detection and Isolation System to test its F/A-18 aircraft generators, which provide electrical power to the aircraft. As a result of testing these generators using the Intermittent Fault Detection and Isolation System, the mean time between failures for the generators has increased, according to officials, from 104 flight hours to over 400 flight hours, and the Navy anticipates a reduction of about 30 to 90 days of repair time.[30]

DOD and external entities. Depots are also partnering with private industry to implement best practices and lessons learned, which has led to time-savings benefits (See fig. 9.).

[30] The mean time between failures predicts, in hours, the average amount of time the part will operate before a failure occurs.

Figure 9: Benefits of Overhauling Generator Kit for U-2 Aircraft

Source: GAO analysis of Air Force data; Defense Visual Information Distribution Service (photo). | GAO-20-116

For example, according to program officials, the Air Force, Navy, original equipment manufacturer, and contractor collaborated to implement a best practice for the U-2 aircraft. Specifically, in 2018, generators for the Air Force's U-2 aircraft had decreased their mean time between failures from 1,000 hours to 400 hours. To sustain the fleet, the Air Force was cannibalizing—removing parts from one aircraft to another—generators from aircraft in depot maintenance to those preparing for deployment. The U-2 program office identified the Navy's F/A-18 A/B generator as similar to the U-2 generator and learned valuable information on the repair and overhaul process, root cause analysis of failure of critical parts, and the Navy's recommendation for procuring and building overhaul generator kits. In order to implement the Navy's processes, the Air Force program office, working with the original equipment manufacturer and contactor, incorporated the Navy's best practices in overhauling its generator kit concept. As a result, the Air Force is no longer cannibalizing these generators and the mean time between failures has returned to about 1,000 hours of flight time.

DOD Has Not Been Able to Implement Some Best Practices and Lessons Learned among the 17 Depots, but Is Taking Steps to Mitigate Challenges

DOD has not been able to implement some best practices and lessons learned among the 17 depots, but DOD is taking steps to mitigate challenges to implementation. In its March 2018 *Report to Congress on Sharing of Best Practices for Depot-Level Maintenance Among the Military Services,* DOD noted some of the challenges in implementing best practices such as differing military service priorities, strategies, and resourcing of technologies and infrastructure.[31] In responding to our survey, 15 of the 17 depots reported challenges in implementing best practices and lessons learned, including insufficient resources, restrictions related to information technology, approval process, and acquisition and contracting policies, among others (See table 2.).

Table 2: Challenges Affecting the Implementation of Best Practices and Lessons Learned at Department of Defense (DOD) Depots

Implementation challenges	Army depots	Navy fleet readiness centers	Navy shipyards	Air Force air logistics centers
Insufficient resources	✓	✓	✓	✓
Restrictions related to information technology	✓	✓	✓	✓
Approval process	✓	✓	✓	✓
Acquisition and contracting policies	✓	✓		✓

Source: GAO analysis of GAO survey of 17 DOD depots performing DOD depot-level maintenance. I GAO-20-116

Note: Individual depot survey responses were aggregated to represent the military service as a whole. In responding to the survey, Marine Corps depots at Albany, Georgia, and Barstow, California, reported that best practices that are beneficial to its production plants and can easily be implemented at low cost and with limited to no impact on production. However, officials from the Marine Corps Logistics Command, which provides day-to-day management and oversight of the Marine Corp depots at Albany and Barstow, stated that they also experience these four challenges when implementing best practices and lessons learned at their depots.

Insufficient resources. Ten of the 17 depots reported insufficient resources as a challenge to implementation for various reasons. First, depots reported not having adequate time, staff, or funding to attend knowledge sharing activities or to analyze data from best practices and lessons learned. According to depot officials, not being able to attend knowledge sharing activities has made networking more difficult because these activities allowed them to discuss best practices and lessons learned with colleagues from other depots and industry. Second, in addition to not having adequate funding, depots also reported identifying sources of funding as a challenge to implementing best practices and

[31]The *National Defense Authorization Act for Fiscal Year 2018*, Pub. L. No. 115–91 (2017) directed the Secretary of Defense to submit to the congressional defense committees a ‘‘comprehensive plan for the sharing of best practices for depot-level maintenance among the military services.’’ In March 2018, the Secretary submitted the report, *Sharing of Best Practices for Depot-Level Maintenance Among the Military Services*.

lessons learned for specific weapon systems. For example, according to officials from one depot, they have been unable to identify a funding source to implement the laser de-painting system for the F-16, which would allow the aircraft to stay in service longer and would produce less hazardous materials than the current blasting process to remove paint from the aircraft. Third, depots reported insufficient equipment to implement a best practice. For example, one depot reported not having enough hand-held tablets, which contain electronic technical data and best practices from private industry to assist maintainers working on a weapon system. Another depot reported that it has not implemented the tablets and are relying on paper documentation to maintain its weapon systems. According to depot officials, the lack of tablets has had direct effects at the depot, such as delays in standing-up new capability and maintainers waiting on available tablets to perform their work.

To mitigate challenges with insufficient resources, DOD, military service, and depot officials have taken a variety of steps. For example, officials from the Office of the Secretary of Defense held an event through the Joint Technology Exchange Group to discuss available funding sources for new and emerging technologies, such as the funding sources for the cold spray technology. According to officials at a Navy depot, depots can petition the Office of Naval Research for federal laboratory designation. With this designation, depots can partner with private industry to evaluate technology in any area that is consistent with the federal laboratory's mission and may receive funds from private industry for technology research and development. Specific to the tablets, depot officials told us that the materiel command has taken responsibility for managing the funding of these assets and the depots will receive a technical upgrade every 4 years. Moreover, in February 2019 the Office of the Secretary of Defense launched the Enterprise Sustainment Dashboard (Dashboard), a web-based tool that will provide access to an online central repository of sustainment data for the military services and will allow senior leaders to steer resources to needed programs. The Dashboard will allow users to analyze metrics such as materiel availability (condition of a weapon system to perform an assigned mission), operational availability (availability of active inventory to conduct military service operations), and cost per day availability (maintenance cost per day for a population of weapon systems by type, model, and series). The Dashboard will also consolidate inventory, availability, and cost data systems from each of the military services. This Dashboard is in its early phase and the implementation plan includes milestones extending into fiscal year 2020.

Restrictions related to information technology. Ten of the 17 depots reported restrictions related to information technology as a challenge to implementation of best practices. Specifically, depots reported having outdated and incompatible software systems and a lack of a consolidated database for departments and product lines, which may hinder their ability to connect computer systems to automate a repair process. Additionally, depots stated that it may take years to obtain authority and approval to operate information technology systems, making data collection, sharing, and implementation of best practices difficult. For example, one depot reported a technology tool was not user friendly and had a rigid infrastructure, making it difficult for maintainers to use to analyze metrics to improve depot maintenance. Specifically, depot officials told us that this technology tool performs its functions as designed but is limited in its scope of meeting depot requirements, such as identifying bottlenecks in the maintenance process. In another example, one depot reported cybersecurity concerns with commercial off-the-shelf products, which may not be compatible with the depot's information technology system.

To mitigate challenges related to information technology, depots reported using information systems, such as SharePoint, as a primary source for collecting, storing, organizing, sharing, and accessing information via a web browser. For example, Navy officials told us that there are SharePoint sites for different departments within their organization, including portals dedicated to training, aircraft, and business processes and procedures, which capture best practices and lessons learned from subject matter experts. In another example, an Air Force depot reported that its SharePoint portal includes a section focused on practical problem solving methods for some of its continuous process improvement projects, such as balancing weight on an aircraft and issues related to the wings of the C-130T. Further, depot officials told us they conducted an analysis to mitigate concerns about a technology tool, mentioned above, that was not user friendly and had a rigid infrastructure. Based on this analysis, depot officials found a modeling and simulation tool that would help resolve challenges in several key areas, including projecting workload and personnel required to perform depot maintenance and determining the depot's capability for the volume of work that can be inducted into the depot, among other areas. The modeling and simulation tool has not been implemented yet because it was recently funded in September 2019.

Moreover, in 2018, we reported on steps that DOD is taking to improve its information technology systems.[32] Specifically, the Secretary of Defense asked the Defense Business Board to provide actionable recommendations that DOD could adopt to transform its six core business processes, including acquisition and procurement, logistics and supply, and real property management, and their supporting information technology systems. We recommended, in part, that DOD identify timeframes and deliverables for identifying and adopting optimal information technology solutions. DOD concurred with this recommendation and is taking steps to improve its information technology systems, such as issuing its initial plan for business operations reform in April 2019, collecting federal and private industry benchmarks, and reviewing information technology costs.

Approval process. Eight of the 17 depots reported that the approval process and guidance for implementing best practices is challenging. Specifically, depots reported that the layers of leadership approval prevent timely implementation of best practices and, at times, can cause enthusiasm for a project's implementation to wane. Depot officials also told us that implementing new ideas for maintaining or repairing weapon systems is challenging because they have to get multiple approvals from their chain of command as well as the program manager for a specific weapon system, thus making implementation more difficult and less timely. For example, depot officials told us that implementing best practices at the depot from one weapon system to another requires retesting of the practice and approval from each program manager. Additionally, in response to the survey, a depot reported that many of the essential, time-sensitive engineering decisions for one of its new weapon system reside at another location, which has caused delays in making timely decisions. In another example, depot officials told us that they had to get approval from individual program managers to implement the cold spray technology and the Intermittent Fault Detection Isolation System.

To mitigate challenges in the approval process, such as these, depot officials told us it is beneficial when technological development that affect the DOD-wide logistics enterprise or an entire military service occurred at a higher organizational level, making it easier for new ideas to be implemented at the lower levels. For example, one depot reported on the Navy's approach of implementing a best practice across its platforms to

[32] GAO, *Defense Management: DOD Needs to Address Inefficiencies and Implement Reform across Its Defense Agencies and DOD Field Activities*, GAO-18-592 (Washington, D.C.: Sept. 6, 2018).

eliminate corrosive plating on its weapon systems. Navy officials told us that these decisions are made at the headquarters level and implemented across the depots. Moreover, one depot reported allowing decision authority for specific weapon systems to reside within the depot, rather than at another location, to help the depot make timely decisions on implementing new ideas. Finally, the Office of the Assistant Secretary of Defense is providing specific guidance in implementing best practices and lessons learned, such as the memorandum issued in April 2019 on the Intermittent Fault Detection and Isolation System directing the military services to adopt this best practice.[33]

Acquisition and contracting policies. Five of the 17 depots reported acquisition and contracting policies as a challenge to implementation. Specifically, depots reported that current acquisition and contracting policies are complex and time consuming, which causes government to lag behind industry in implementing best practices. For example, officials from one depot told us that even when two depots need the same item to repair a weapon system, each depot was encouraged to pursue a separate contract. Depot officials described this as an inefficient and burdensome process, which sometimes resulted in an inferior item. Similarly, officials from another depot told us that they started an initiative to make equipment and software more similar across their service's depots; however, they were unable to implement this initiative for similar reasons. Further, officials from one depot told us that the procurement of a weapon system does not always include access to all data necessary to maintain the system.[34] According to depot officials, this limits their ability to implement a best practice or lesson learned from a similar weapon system because the contractor retains ownership of the intellectual property needed to repair or optimize the system.

[33]Deputy Assistant Secretary of Defense for Materiel Readiness Memorandum, *Addressing Electronics Intermittence Across DOD's Sustainment Enterprise (*April 11, 2019).

[34]GAO has reported in the past that DOD needs access to technical data—recorded information used to produce, support, maintain, or operate a system—which can enable the government to complete maintenance work in-house, as well as to competitively award contracts for the acquisition and sustainment of a weapon system. *See* GAO, *Defense Acquisition: DOD Should Clarify Requirements for Assessing and Documenting Technical-Data Needs*, GAO-11-469 (Washington, D.C.: May 11, 2011).

To mitigate challenges related to acquisition and contracting policies, depot officials told us that military services are purchasing enough new technology for all their depots rather than have each depot purchase technology individually. For example, according to Navy officials, they purchased the equipment to implement cold spray technology across all four shipyards, which makes implementing the best practice or lesson learned more timely. Additionally, officials from one depot told us that they use public-private partnerships to bridge gaps for systems that lack access to the necessary data rights to conduct maintenance on the systems.[35] Our February 2019 report identified additional steps DOD is taking to mitigate challenges related to intellectual property, especially software sustainment.[36] First, our prior work found that DOD is in the early stages of addressing a statutory provision for DOD to (1) develop policy on the acquisition or licensing of intellectual property; and (2) establish a cadre of intellectual property experts to help support the acquisition workforce on intellectual property matters.[37] Second, in our prior work, we reported that DOD officials we spoke with emphasized that there are situations in which the data rights needed may not be known until years into sustainment and that it would be useful if data rights could have a pre-negotiated price and be an option as part of the initial contract. Such an option would give the government the right, but not the obligation, to purchase the data rights at the pre-negotiated price if needed in the future.

Conclusions

The sharing and implementation of best practices and lessons among the 17 depots is crucial to sustaining military readiness by ensuring that the military services can regularly maintain critical weapon systems and return them to the warfighter for use in training and operations. Successful collaboration of maintenance best practices and lessons learned across military services, private industry, and academia is increasingly essential as DOD operates, and thus needs to maintain,

[35]DOD defines a public-private partnership as a cooperative arrangement between a government-owned and government-operated activity and one or more private-sector entities to perform defense-related work, use DOD facilities and equipment, or both. DOD Instruction 4151.21, *Public-Private Partnerships for Product Support* (Nov. 21, 2016) (incorporating Change 4, July 31, 2019).

[36]GAO, *Weapon System Sustainment: DOD Needs to Better Capture and Report Software Sustainment Costs*, GAO-19-173 (Washington, D.C.: Feb. 25, 2019).

[37]*National Defense Authorization Act for Fiscal Year 2018*, Pub. L. No. 115-91, § 802 (Dec. 12, 2017) (*codified* at 10 U.S.C. § 2322).

weapon systems. DOD shares best practices and lessons learned among the depots through a variety of venues, including networking, working groups, and benchmarking. However, DOD has communication challenges, including a lack of awareness of many sharing venues, which may hinder the ability of the depots to share best practices and lessons learned. The Office of the Secretary of Defense has not created, shared, or maintained a comprehensive and updated list of all depot-specific DOD sharing venues (i.e., working groups) that includes points of contact. Without a centralized list and points of contact, it is unclear what groups exist and who to contact to participate, which may impede sharing of best practices and lessons learned. Further, while the Army stated it established lessons learned organizations for sharing materiel best practices and lessons learned, it did not maintain them due to organizational restructuring and resource constraints. Establishing and maintaining effective organizations dedicated to sharing materiel best practices and lessons learned would encourage knowledge sharing among the Army depots.

Recommendations

We are making two recommendations, including one to the Under Secretary of Defense for Acquisition and Sustainment and one to the Secretary of the Army. Specifically, the Secretary of Defense should direct that:

The Under Secretary of Defense for Acquisition and Sustainment should ensure that the Deputy Assistant Secretary of Defense for Materiel Readiness create, share, and maintain a comprehensive and up-to-date list of all DOD sharing venues (i.e., working groups), including points of contact, related to depot maintenance. (Recommendation 1)

The Secretary of the Army should ensure that Army Materiel Command reestablish and maintain organizations dedicated to sharing materiel best practices and lessons learned, as required by Army regulations. (Recommendation 2)

Agency Comments and Our Evaluation

We provided a draft of this report to DOD for review and comment. In written comments on a draft of this report, DOD concurred with the recommendations. DOD's comments are reprinted in their entirety in appendix III. DOD also provided technical comments, which we incorporated as appropriate.

We are sending copies of this report to the appropriate congressional committees, the Secretary of Defense, the Secretaries of the Army, Navy, and Air Force, and the Commandant of the Marine Corps. In addition, the report is available at no charge on the GAO website at http://www.gao.gov.

If you or your staff has any questions about this report, please contact Diana Maurer at (202) 512-9627 or maurerd@gao.gov. Contact points for our Office of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff that made key contributions to this report are listed in appendix IV.

Diana Maurer
Director,
Defense Capabilities and Management

List of Committees

The Honorable James M. Inhofe
Chairman
The Honorable Jack Reed
Ranking Member
Committee on Armed Services
United States Senate

The Honorable Richard C. Shelby
Chairman
The Honorable Dick Durbin
Ranking Member
Subcommittee on Defense
Committee on Appropriations
United States Senate

The Honorable Adam Smith
Chairman
The Honorable Mac Thornberry
Ranking Member
Committee on Armed Services
House of Representatives

The Honorable Pete Visclosky
Chairman
The Honorable Ken Calvert
Ranking Member
Subcommittee on Defense
Committee on Appropriations
House of Representatives

Appendix I: Scope and Methodology

To conduct the work for our reporting objectives, we reviewed relevant laws and the Department of Defense (DOD) and military service guidance that govern depot maintenance and the sharing of best practices and lessons learned. We included in our scope DOD depots performing major depot-level maintenance.[1] We conducted a survey of DOD's 17 depots performing depot-level maintenance to gain an understanding of how each depot shares with each other and implements best practices and lessons learned.[2] The response rate for the survey was 100 percent. These depots included:

- Anniston Army Depot, Anniston, Alabama
- Corpus Christi Army Depot, Corpus Christi, Texas
- Letterkenny Army Depot, Letterkenny, Pennsylvania
- Red River Army Depot, Texarkana, Texas
- Tobyhanna Army Depot, Tobyhanna, Pennsylvania
- Norfolk Naval Shipyard, Portsmouth, Virginia
- Pearl Harbor Naval Shipyard, Honolulu, Hawaii
- Portsmouth Naval Shipyard, Kittery, Maine
- Puget Sound Naval Shipyard, Bremerton, Washington
- Fleet Readiness Center East, Cherry Point, North Carolina
- Fleet Readiness Center Southeast, Jacksonville, Florida
- Fleet Readiness Center Southwest, San Diego, California
- Albany Production Plant, Albany, Georgia
- Barstow Production Plant, Barstow, California
- Ogden Air Logistics Complex, Ogden, Utah
- Oklahoma City Air Logistics Complex, Oklahoma City, Oklahoma
- Warner Robins Air Logistics Complex, Warner Robins, Georgia

[1]The term "depots" will refer to 17 installations reviewed in this report performing major depot-level maintenance, including the Army's depots, the Navy's shipyards and fleet readiness centers, the Marine Corps' production plants, and the Air Force's air logistics complexes.

[2]To capture the full range of activities surrounding best practices and lessons learned, our unit of analysis for each survey was the depot as a whole. As such, our results will be reported by number of depots, rather than depot commanders or other metrics.

We analyzed survey responses to gain an understanding, for example, of which depot officials are coordinating with others to share best practices and lessons learned, which sharing venues are attended, and the extent to which this information sharing is beneficial. To ensure that the survey questions were clear, comprehensible, and technically correct, we conducted expert reviews of our draft survey with four subject matter experts with knowledge and experience in auditing DOD depots. We also conducted two pre-tests of our draft survey with the depot commanders of Anniston Army Depot and Warner Robins Air Logistics Complex, respectively.[3] During each pre-test, conducted by teleconference, we read the instructions and each survey question aloud and asked the depot commanders to tell us how they interpreted the question. We then discussed the instructions and questions with each depot commander to identify any problems and potential solutions by determining whether (1) the instructions and questions were clear and unambiguous, (2) the terms we used were accurate, (3) the survey was unbiased, and (4) the survey did not place an undue burden on the depot officials completing it. We noted any potential problems and modified the survey based on feedback from the subject matter experts and depot commanders, as appropriate. We sent a fillable survey and a cover email to 17 depots on May 29, 2019, and asked them to complete the survey and email it back to us by June 14, 2019. We closed the survey on July 3, 2019. Data were auto-extracted from the Adobe PDF form into an Excel spreadsheet. Our examination of the survey results included both a quantitative data analyses on closed-ended questions and a review of open-ended responses to identify common themes.

Additionally, to gather detailed examples of DOD's efforts to share best practices and lessons learned, we visited a non-generalizable sample of 5 depots (Anniston Army Depot, Anniston, Alabama; Norfolk Naval Shipyard, Portsmouth, Virginia; Fleet Readiness Center Southwest, San Diego, California; Marine Corps Albany Production Plant, Albany, Georgia; and Ogden Air Logistics Complex, Ogden, Utah). To select our sample, we considered variation in geographic location, military service representation, and types of weapon systems maintained. At these sites, we conducted group discussions with individuals across the depot to gain insight into their roles in sharing best practices and lessons learned. Qualitative data analyses were conducted by our staff who have subject

[3]As the expert review and pre-test we conducted generally indicated that our questions were clear and comprehensible, and as the universe for this survey was only 17 depots, we determined that we had taken reasonable and sufficient steps to ensure the reliability of the survey instrument.

matter expertise to identify themes and select examples of best practices or lessons learned shared through collaboration with another depot. We then obtained and analyzed documentation of sharing, such as working group charters and trip reports documenting results from visiting another depot; as well as benefits experienced from implementing a best practice or lessons learned, including time and cost savings.

We interviewed officials from the Office of the Under Secretary of Defense (Acquisition and Sustainment) (Deputy Assistant Secretary of Defense for Materiel Readiness), Joint Chiefs of Staff (Joint Lessons Learned Division), and the military service headquarters (Headquarters, Department of Army G4; Deputy Assistant Secretary of the Navy for Expeditionary Programs and Logistics Management; Headquarters Marine Corps, Installations & Logistics; and Air Force Acquisition, Logistics & Product Support. We also interviewed officials from the military service logistics or materiel components (Army Materiel Command; Naval Sea Systems Command; Naval Air Systems Command (Commander, Fleet Readiness Center); Marine Corps Logistics Command; and the Air Force Materiel Command) as well as the military lessons learned centers (Center for Army Lessons Learned, Naval Warfare Development Command, Marine Corps Center for Lessons Learned, and the Air Force LeMay Center for Lessons Learned).

Finally, we reviewed our prior reports related to challenges experienced at DOD depots and DOD's report to Congress on the sharing of best practices for depot-level maintenance among the military services.[4] We assessed the documentary and testimonial evidence we collected against DOD and military service guidance on lessons learned and materiel maintenance and GAO's *Standards for Internal Control in the Federal Government*.[5] Specifically, the information and communication component of internal control—the actions management uses to internally communicate the necessary quality information to achieve the entity's objectives—was significant to this audit.

We conducted this performance audit from January 2019 through January 2020 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to

[4]DOD, *Report to Congress on Sharing of Best Practices for Depot-Level Maintenance Among the Military Services* (March 2018).

[5]GAO, *Standards for Internal Control in the Federal Government*, GAO-14-704G (Washington, D.C.: September 2014).

obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Appendix II: Depot Working Groups and Communities of Practice

During the course of our work examining the extent to which the Department of Defense (DOD) experiences benefits and has challenges with (1) sharing and (2) implementing best practices and lessons learned among the depots, we collected information from the depots on the working groups and communities of practice in which they participate. The list below is compiled from analysis of our survey data, in which we surveyed all 17 of DOD's depots, as well as the interviews we conducted during our site visits to a non-generalizable sample of five depots. Note that this is not a list of all the possible working groups and communities of practice which exist among the depots, simply those which the depots shared with us.

1. 448th Supply Chain Management Wing
2. Air Force Metrology and Calibration Working Group
3. Air Force Sustainment Center Logistics Directorate's Strategic Planning Division
4. Aircraft Cyber Threat Working Group
5. Aircraft Maintenance Group Summit
6. Aircraft Storage Strikeboard
7. AIRSpeed Office
8. Army Safety and Occupational Health Information Management System Working Group
9. Army Safety and Occupational Health Management System Working Group
10. Carrier Team One
11. Cold Spray Action Team
12. Commander, Fleet Readiness Centers Advanced Technology & Innovation Integrated Project Team
13. Commercial Technologies for Maintenance Activities Working Group – Additive Manufacturing
14. Commodities, Electronics, Missiles, & Propulsion Maintenance Groups
15. Coordinate Measuring Machine Community of Practice
16. Corporate Electrical Community of Practice
17. Corrosion Control Working Groups

18. Cyber Resiliency Office for Weapon Systems Working Groups
19. Depot Maintenance Activation Working Group
20. Depot Maintenance Enterprise Action Group
21. Diminishing Manufacturing Sources and Material Shortages Knowledge Sharing Portal
22. DOD Digital Manufacturing Users Group
23. DOD Unmanned Systems & Robotics Summit
24. DOD Voluntary Protection Programs
25. Engineeringpalooza
26. Enterprise IT Systems Strikeboard
27. F-35 Joint Risk Working Group
28. H-53 Fleet Support Team
29. Heavy Metal Working Group
30. Industrial Base Commander's Meetings
31. Integrated Quality Teams
32. Investment Working Group
33. Joint Additive Manufacturing Steering Group
34. Joint Additive Manufacturing Working Group and Community of Practice
35. Joint Intermittence Team
36. Joint Requirements Working Group
37. Joint Robotics Working Group
38. Joint Technology Exchange Group
39. Metrics Community of Practice
40. Modernization Working Group
41. National Center for Defense Manufacturing and Machining
42. Naval Surface Warfare Center, Carderock Division Human Augmentation
43. Naval Undersea Warfare Center Division, Keyport Human Performance/Augmented Reality/Virtual Reality
44. Navy Forum for Small Business Innovation Research/Small Business Technology Transfer Transition

45. Non-Destructive Inspection Forum
46. Non-Destructive Testing Working Group
47. Norfolk Naval Shipyard Technology and Innovation Community of Practice
48. Organic Industrial Base Commander’s Summit
49. Project Management Executive Steering Committee
50. Public-Private Partnership Community of Practice
51. Quality Performance System Community of Practice
52. Quality Work Environment Working Group
53. Residential Economic Development Inc.
54. RepTech Working Group
55. Shipyard departmental level Communities of Practice: C200, C1200, C1200N, C600, C400, etc.
56. Shipyard-only Community of Practice
57. Software Engineering Institute Agile Collaboration Group
58. Software Maintenance Group Summit
59. Sub Team One
60. Tri-Air Logistics Complex Summits
61. Weapon-system Specific Enterprise Cross-talks: C-130 Enterprise Crosstalk, A-10 Enterprise Crosstalk, etc.

Appendix III: Comments from the Department of Defense

OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE
3500 DEFENSE PENTAGON
WASHINGTON, DC 20301-3500

SUSTAINMENT

JAN 15 2020

Ms. Diana Maurer
Director, Defense Capabilities Management
U.S. Government Accountability Office
441 G Street, NW
Washington DC 20548

Dear Ms. Maurer,

This is the Department of Defense (DoD) response to the GAO Draft Report GAO-20-116, "MILITARY DEPOTS: DOD Can Benefit From Further Sharing of Best Practices and Lessons Learned," dated December 4, 2019 (GAO Code 103257).

Attached is DoD's proposed response to the subject report. My point of contact is Colonel Curtis Hafer, who can be reached at curtis.r.hafer.mil@mail.mil or (703) 697-3047.

Sincerely,

Steven J. Morani
Deputy Assistant Secretary of Defense
(Materiel Readiness)

GAO DRAFT REPORT DATED DECEMBER 4, 2019
GAO-20-116 (GAO CODE 103257)

"MILITARY DEPOTS: DOD Can Benefit from Further Sharing of Best Practices and Lessons Learned"

DEPARTMENT OF DEFENSE COMMENTS
TO THE GAO RECOMMENDATION

RECOMMENDATION 1: The GAO recommends that the Under Secretary of Defense for Acquisition and Sustainment should ensure that the Deputy Assistant Secretary of Defense for Materiel Readiness create, share, and maintain a comprehensive and up-to-date list of all DoD sharing venues (i.e., working groups) related to depot maintenance with their points of contact.

DoD RESPONSE: Concur. The Under Secretary of Defense for Acquisition and Sustainment should ensure that the Deputy Assistant Secretary of Defense for Materiel Readiness create, share, and maintain a comprehensive and up-to-date list of all DoD sharing venues related to depot maintenance with their points of contact.

RECOMMENDATION 2: The GAO recommends that the Secretary of the Army should ensure that Army Materiel Command re-establish and maintain organizations dedicated to sharing materiel best practices and lessons learned, as required by Army regulations.

DoD RESPONSE: Concur. The Secretary of the Army will ensure that Army Materiel Command will re-establish and maintain organizations dedicated to sharing best practices and lessons learned, as required by Army regulations.

Appendix IV: GAO Contact and Staff Acknowledgments

GAO Contact

Diana Maurer, 202-512-9627 or maurerd@gao.gov

Staff Acknowledgments

In addition to the contact listed above, Jodie Sandel (Assistant Director), Laura Czohara (Analyst-in-Charge), Clarine Allen, Felicia Lopez, Amie Lesser, Christina Murphy, Clarice Ransom, Andrew Stavisky, and Courtney Tepera made key contributions to this report.

Related GAO Products

Navy Maintenance: Persistent and Substantial Ship and Submarine Maintenance Delays Hinder Efforts to Rebuild Readiness. GAO-20-257T. Washington, D.C.: December 4, 2019.

Naval Shipyards: Key Actions Remain to Improve Infrastructure to Better Support Navy Operations. GAO-20-64. Washington, D.C.: November 25, 2019.

F-35 Aircraft Sustainment: DOD Faces Challenges in Sustaining a Growing Fleet. GAO-20-234T. Washington, D.C.: November 13, 2019.

Depot Maintenance: DOD Should Adopt a Metric That Provides Quality Information on Funded Unfinished Work. GAO-19-452. Washington, D.C.: July 26, 2019.

Military Depots: Actions Needed to Improve Poor Conditions of Facilities and Equipment That Affect Maintenance Timeliness and Efficiency. GAO-19-242. Washington, D.C.: April 29, 2019.

Weapon System Sustainment: DOD Needs to Better Capture and Report Software Sustainment Costs. GAO-19-173. Washington, D.C.: February 25, 2019.

Army Modernization: Steps Needed to Ensure Army Futures Command Fully Applies Leading Practices. GAO-19-132. Washington, D.C.: January 23, 2019.

DOD Depot Workforce: Services Need to Assess the Effectiveness of Their Initiatives to Maintain Critical Skills. GAO-19-51. Washington, D.C.: December 14, 2018.

Navy and Marine Corps: Rebuilding Ship, Submarine, and Aviation Readiness Will Require Time and Sustained Management Attention. GAO-19-225T. Washington, D.C.: December 12, 2018.

Navy Readiness: Actions Needed to Address Costly Maintenance Delays Facing the Attack Submarine Fleet. GAO-19-229. Washington, D.C.: November 19, 2018.

Depot Maintenance: DOD Has Improved the Completeness of Its Biennial Core Report. GAO-19-89. Washington, D.C.: November 14, 2018.

Air Force Readiness: Actions Needed to Rebuild Readiness and Prepare for the Future. GAO-19-120T. Washington, D.C.: October 10, 2018.

Weapon System Sustainment: Selected Air Force and Navy Aircraft Generally Have Not Met Availability Goals, and DOD and Navy Guidance Need to Be Clarified. GAO-18-678. Washington, D.C.: September 10, 2018.

Military Readiness: Analysis of Maintenance Delays Needed to Improve Availability of Patriot Equipment for Training. GAO-18-447. Washington, D.C.: June 20, 2018.

F-35 Aircraft Sustainment: DOD Needs to Address Challenges Affecting Readiness and Cost Transparency. GAO-18-75. Washington, D.C.: October 26, 2017.

Depot Maintenance: Executed Workload and Maintenance Operations at DOD Depots. GAO-17-82R. Washington, D.C.: February 3, 2017.

Depot Maintenance: Improvements to DOD's Biennial Core Report Could Better Inform Oversight and Funding Decisions. GAO-17-81. Washington, D.C.: November 28, 2016.

Naval Shipyards: Actions Needed to Improve Poor Conditions that Affect Operations. GAO-17-548. Washington, D.C.: September 12, 2017.

Army Working Capital Fund: Army Industrial Operations Could Improve Budgeting and Management of Carryover. GAO-16-543. Washington, D.C.: June 23, 2016.

Military Readiness: Progress and Challenges in Implementing the Navy's Optimized Fleet Response Plan. GAO-16-466R. Washington, D.C.: May 2, 2016.

Defense Inventory, Further Analysis and Enhanced Metrics Could Improve Service Supply and Depot Operations. GAO-16-450. Washington, D.C.: June 9, 2016.

Navy Working Capital Fund: Budgeting for Carryover at Fleet Readiness Centers Could Be Improved. GAO-15-462. Washington, D.C.: June 30, 2015.

Sequestration: Documenting and Assessing Lessons Learned Would Assist DOD in Planning for Future Budget Uncertainty. GAO-15-470. Washington, D.C.: May 27, 2015.

Operational Contract Support: Actions Needed to Enhance the Collection, Integration, and Sharing of Lessons Learned. GAO-15-243. Washington, D.C.: March 16, 2015.

F-35 LIGHTNING II JOINT PROGRAM OFFICE
200 12th Street South, Suite 600
Arlington, Virginia 22202-5402

MEMORANDUM FROM F-35 Authorizing Official (AO)

TO: F-35 Operational Sites Information System Security Managers (ISSM)
F-35 Joint Program Office (JPO) Program Management Office (PMO)

SUBJECT: (U) Information Technology (IT) Special Equipment Exemption Determination for the F-35 Portable Intermittent Fault Detector (PIFD)

Reference: (a) Department of Defense (DoD) Instruction (DoDI) 8510.01, Risk Management Framework (RMF) for DoD Information Technology (IT), 12 March 2014, incorporating change 2, 28 July 2017
(b) F-35 Program Instruction 500-02.01, IT Special Equipment Exemption Process, 11 September 2017
(c) Attachment 2: F-35 IT Special Equipment Determination Checklist for the F-35 PIFD v1.0, 19 November 2020
(d) Attachment 3: F-35 IT Special Equipment Security Concept of Operations for the F-35 PIFD v1.0, 22 September 2020

1. (U) In accordance with references (a) through (d), the F-35 PIFD has been assessed and characterized as IT Special Equipment Type 1, this determination eliminates the requirement of a full RMF assessment.

2. (U) This system is approved for use by all JPO PMOs and at any JPO sponsored facility.

3. (U) The decision to designate the F-35 PIFD as IT Special Equipment is based upon the following:

   a. F-35 JPO Security Control Assessor (SCA) has reviewed references (a) through (d) and conducted an onsite assessement of subject equipment.
   b. The SCA has determined that this equipment satisfies a Type 1 (one) definition and has a single purpose of performing advanced diagnostics for the user by detecting, isolating, and investigating faults in wiring, harnesses, looms, connections and circuit boards while being a portable package. This is accomplished by sending an electrical signal through the circuit, and returns a pass/fail if it is able to complete the circuit.
   c. As the system is currently configured, this system introduces no risk to the Air Vehicle.

4. (U) The AO has reviewed references (a) through (d) and has stipulated the following:

   a. PFID is subject to an annual onsite assessment. This assessment will verify the continued need for the system and validate the current state of compliance.

b. Any change to the system configuration or failure to adhere to sustaining the equipment as agreed in references (c) and (d) will invalidate this determination and will require a reassessment.

5. (U) Any proposed or considered deviation of this configuration status shall be brought to the attention of the SABI AO representative immediately. The point of contact for this authorization is Denise Madison. She can be reached by phone: (703) 607- 4866 or email: Denise.Madison@jsf.mil.

JARED M. FREY
Chief Information Security Officer
AO Designated Representative, SABI
F-35 Lightning II Joint Program Office

Joint Interment Testing (JIT) Intermittent Fault Activities

Gregory Kilchenstein

Director, Enterprise Maintenance Technology

ODASD – Materiel Readiness

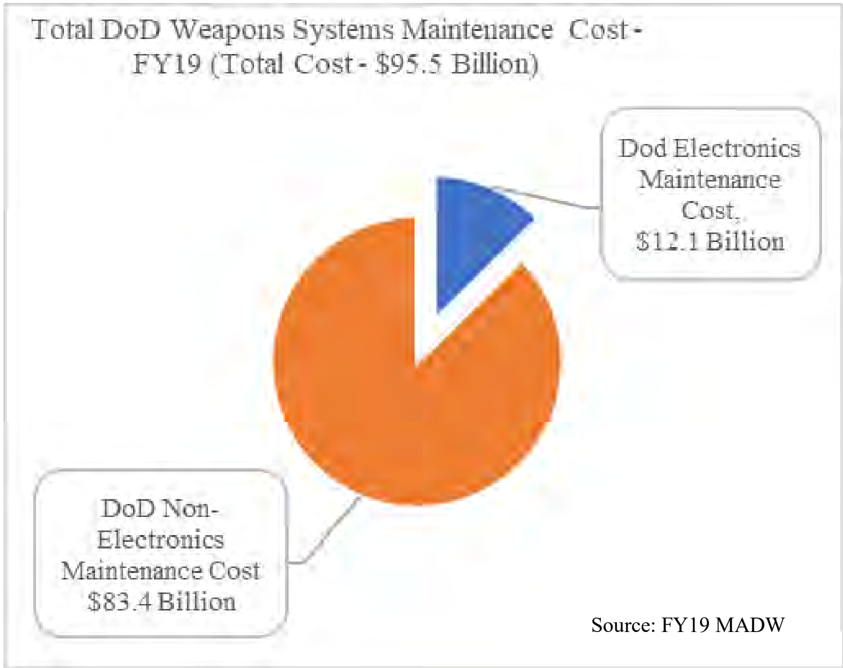
JSWAG
Spring 2021

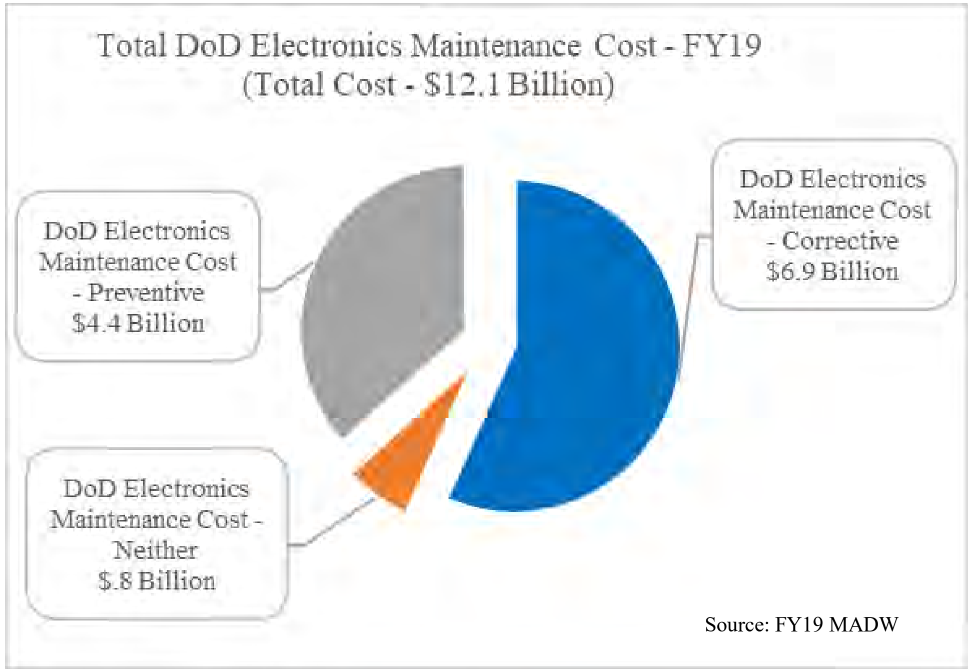
Intermittent Fault Definition

Intermittent faults are short duration impedance variations (opens/shorts) that occur in conductive paths in LRU/WRA chassis/ backplanes or weapon system electrical wiring interconnect systems (EWIS). Intermittent faults occur as a result of various operational environmental stimuli, including, but not limited to, thermal stress, vibrational stress, gravitational G-force loading, moisture and/or contaminant exposure, as well as changes in the material due to age and use, such as the growth of tin whiskers, metal migration and delamination of materials. These faults can occur individually and /or in rapid succession on any chassis or backplane circuit or weapon system EWIS. Fault durations range in time from nanoseconds to milliseconds and have variable impedances. These circuit path disruptions are frequently caused by cracked solder joints; intermittent coax lines (e.g., shield corrosion, damaged center conductor, etc.); broken, cracked or frayed wires; loose clamps; and unsoldered pins. These circuit path disruptions often cause functional failures/faults in LRU/WRA chassis and backplanes or weapon system EWIS whose root cause(s) cannot be detected and isolated using traditional automatic test equipment (ATE) and troubleshooting processes. Lacking the ability to detect and isolate intermittent failures and provide environmental stimuli during test and repair process, such assets are commonly reported as no-fault-found (NFF) or as one of the reported-NFF repair codes (e.g., cannot duplicate (CND), retest OK (RETOK), beyond capability of maintenance (BCM), disassemble-clean-reassemble (DCR), etc.).

Source
MIL-PRF-32516

Intermittent Fault Problem





Intermittent electrical failures continue to be a leading contributor to DoD's $3 billion annual No Fault Found (NFF) problem, unnecessarily consuming 25% of the electronics maintenance budget.

Chartered JIT WG Goals

- Define and validate joint performance requirements for a Joint Service intermittent fault detection system.
- Collect and analyze implementation and operational data on commercial field intermittent fault detection systems in use currently.
- Define the minimum fault detection threshold requirements for the applicable wiring systems, component types, and system architectures.
- Identify, define and validate test methods for ensuring that specified minimum performance requirements for detecting and isolating intermittence are met.
- Publish a joint performance requirements Military-Performance (Mil-PRF) document.
- Brief and publish findings in a technical report and make a recommendation to Service Components on a path forward.

JIT WG Activities

- September 2012 – JIT Chartered
  - ❖ Instrumental in shaping the strategic and tactical activities required to identify diagnostic equipment capable of detecting intermittent faults.
  - ❖ Developed minimum performance requirements for detecting and isolating intermittence:
- January 2014 - Contract Awarded: Intermittent Fault Emulator (IFE) –
  - ❖ NAWCAD, Lakehurst
  - ❖ Hill AFB
- March 2015 – Published: MIL-PRF-32516, Electronic Test Equipment, Intermittent Fault Detection and Isolation for Chassis and Backplane Conductive Path
- January 2016 – Intermittent Fault Detection and Isolation Industry Capability Assessment at NAWCAD Lakehurst
- November 2020 - Government/Industry Coordination:
  - ❖ Draft MIL-PRF-32516A, Electronic Test, Intermittent Fault Diagnostic Equipment (Electrical)
  - ❖ Draft MIL-PRF-32516/1, Intermittent Fault Diagnostic Equipment (Electrical), DEPOT Level
- April 2017 – Published: MIL-HDBK-527, Guidance for Intermittent Fault Emulator (IFE)
- May 2018 – Completed: CTMA Partner meeting to discuss the development of an implementation plan for intermittent fault diagnostic equipment (IFDE).
- August 2918 – Completed evaluation: FRC-East, LP-CRADA, PIFD Technology

JIT WG Activities - continued

- February 2019 – Published: Technical Studies, Analyses for Intermittent Fault Detection Isolation System (IFDIS) Implementation Across DoD, Final Report
- April 2019 – Signed: Office of the Assistant Secretary of Defense Memorandum
- December 2019 – Completed demonstration: Naval Air Station Lemoore Industry Week
- March 2020 - Published (Added Intermittent Fault definition): MIL-HDBK-525 with Change 1, Electrical Wiring Interconnect System (EWIS) Integrity Program
- March 2020 – In process: MIL-HDBK-454B, General Guidelines For Electronic Equipment; Drafted Intermittent Fault Guideline and forwarded to Handbook custodian.
- Monthly Teleconference – Second Tuesday, Government only
- Ongoing Efforts:
  - ❖ Draft MIL-PRF-32516/2, Intermittent Fault Diagnostic Equipment (Electrical), Field Applications
  - ❖ Draft MIL-PRF-32516/3, Electronic Test Equipment, Emulator, Intermittent Fault Detection and Isolation
  - ❖ Congressional Inquiry Response
  - ❖ Follow On - Office of the Assistant Secretary of Defense Memorandum

IFDIS Deployment

USAF IFDIS #1
F-16 Hill AFB
2008

USAF IFDIS #2
F-16 Hill AFB
2009

USAF IFDIS #3
F-16 Hill AFB
2014

Navy IFDIS #1
F/A-18 FRC-SW
2016

Navy IFDIS #2
F/A-18 FRC-W
2017

Navy IFDIS #3
F/A-18 FRC-MA
2018

Navy IFDIS #4
EA-18G NSWC Crane
2019

F-35 JPO
PFID ATO
2020

Intermittent Fault Implementation Strategy

Phase I

Scope Intermittence Problem

- Charter JITCBM+ JIT WIPT
- Specify Detection & Isolation System
- Understand Scope Across DoD
- Formalize The Failure Mode (MIL-PRF-32516)
- Develop MADW Algorithm
- Develop A Solution Set
- Develop IFE
- Conduct Industry Days
- Implementing DoD Maintenance Activities

Phase II

Expand Implementation

- DoD Depot Maintenance Activities
- Update MIL-PRF-32516
  - EWIS
  - Weapon System
  - Depot
  - Field
  - IFE
- Formalize Military Service Guidance
  - JSWAG
  - MIL-HDBK-454
  - MIL-HDBK-525
  - MIL-HDBK-527
- Establish Centers of Excellence Establishment

Phase III

Implement At Field Level

- Leverage Phase II Results
- Establish Certification Central Agency
- Expand Centers of Excellence
- Continue to Refine MADW Data
- Increase Adoption of IFD Technology
- Distribute F-35 JPO Results & Cost Savings
- Increase adoption of IFD Solution Set for EWIS

Phase IV

Normalize the Use of IFD

- Expand to All Levels of DoD Maintenance
- Expand to on Weapon System Monitoring
- Expand to Initial Manufacture of Electronic Components
- Collaborate with JSWAG
- Train Workforce

JSWAG
Proposed JIT Committee

The JSWAG JIT Committee provides a forum to advise and assist in the implementation of a DoD intermittent fault detection (IFD) solution. The committee will leverage current and emerging IFD technology for demonstration, testing, and cost-benefit analysis. Actions will include but not be limited to:

- Educate and inform electronics maintenance community on IFD.
- Define and validate joint performance requirements for a Joint Service IFD system.
- Collect and analyze implementation and operational data on IFD systems currently in use.
- Identify, define and validate test methods for ensuring that specified minimum performance requirements for detecting and isolating intermittence are met.
- Leverage DoD's Maintenance and Availability Warehouse to assist in the identification of intermittence related readiness and cost drivers, and recommend IFD opportunities. Investigate and develop plans for integrating IFD with existing EWIS maintenance and repair diagnostics and diagnostic equipment.
- Investigate intermittence-driven EWIS unscheduled maintenance. Develop recommendations and plans for decreasing intermittence-driven unscheduled maintenance and shifting to schedule-based IFD proactive maintenance.
- Collaborate with industry and academia on innovative intermittence-driven NFF solutions and methods.

Backup Slides

Intermittent Fault Emulator

MIL-HDBK-454 Proposed Intermittent Fault Guideline

GUIDELINE TBD

INTERMITTENT FAULT DIAGNOSIS

1. Purpose. This guideline establishes criteria for diagnosing intermittent faults in Electronic Equipment backplane, chassis and wire harness conductive paths.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-PRF-32516	Electronic Test Equipment, Intermittent Fault Detection and Isolation for Chassis and Backplane Conductive Paths
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests.

2.1 Definitions.

2.2 Intermittent faults. Intermittent faults are short duration discontinuities (opens/shorts) that occur in conductive paths in Electronic Equipment chassis/ backplanes and wire harnesses. Intermittent faults occur as a result of various operational environmental stimuli, including, but not limited to, thermal stress, vibrational stress, gravitational G-force loading, moisture and/or contaminant exposure, as well as changes in the material due to age and use, such as the growth of tin whiskers, metal migration and delamination of materials. These faults can occur individually and /or in rapid succession on any chassis, backplane circuit or wire harness. Fault durations range in time from nanoseconds to milliseconds and have variable random impedances. These conductive path disruptions are frequently caused by: cracked solder joints; intermittent coax lines (e.g., shield corrosion, damaged center conductor, etc.); broken, cracked or frayed wires/wire harnesses; loose clamps; improper crimp connections and unsoldered pins. These conductive path disruptions often cause functional failures/faults in Electronic Equipment chassis, backplanes and wire harnesses whose root cause(s) cannot be detected and isolated using traditional automatic test equipment (ATE) and troubleshooting processes. Lacking the ability to detect and isolate intermittent failures and provide environmental stimuli during test and repair process, such assets are commonly reported as no-fault-found (NFF) or as one of the quasi-NFF repair codes (e.g., cannot duplicate (CND), retest OK (RETOK), beyond capability of maintenance (BCM), disassemble-clean-reassemble (DCR), etc.).

MIL-HDBK-454 Proposed Intermittent Fault Guideline (continued)

3. General Guidelines.

3.1 General. Each type of Electronic Equipment is different in its function, configuration and operational environment. As a result, no single test method or procedure can adequately replicate an intermittent fault occurrence for all Electronic Equipment. A careful review of the nature of the failure and the operational conditions under which the failure occurred is required. The following steps are recommended when by careful analysis it is determined that the failures occur during ground or flight operating conditions, and the operating temperature does not appear to be contributing to the occurrence of the failures.

3.2 Intermittent faults typical resulting effects.

3.2.1 Vibration-induced. The following is a list of typical effects that may occur as a result of vibration (this list is not intended to be all-inclusive):

a. Chafed wiring.
b. Loose fasteners/components
c. Intermittent electrical contacts
d. Electrical shorts.
e. Deformed seals.
f. Failed components.
g. Optical or mechanical misalignment.
h. Cracked and/or broken structures.
i. Migration of particles and failed components.
j. Particles and failed components lodged in circuitry or mechanisms.
k. Excessive electrical noise.
l. Fretting corrosion in bearings.

3.2.2 Temperature-induced. The following is a list of typical effects as a result of temperature and temperature changes (this list is not intended to be all-inclusive):

a. Binding or slackening of moving parts.

MIL-HDBK-454 Proposed Intermittent Fault Guideline (continued)

b. Deformation or fracture of components.
c. Cracking of surface coatings.
d. Leaking of sealed compartments.
e. Failure of insulation protection.
f. Differential contraction or expansion rates or induced strain rates of dissimilar materials.
g. Intermittent electrical contacts.
h. Electrical shorts/opens.
i. Failed components.
j. Changes in electrical and electronic components.
k. Electronic or mechanical failures due to rapid water or frost formation.
l. Excessive static electricity.

3.2.3 Combined environmental-induced. Temperature, humidity, vibration, and altitude can combine synergistically to produce the following failures. Although altitude is included in the following discussion typically in regard to Electronic Equipment operating environment it mainly impacts cooling and is a function of temperature. Typically Combined Environmental Test facilities do not include altitude test capability. It should be noted that airborne Electronic Equipment may be operated in environments exceeding -55 °C to +120 °C, 40,000 foot altitude and high vibration due to take-off/landing and carrier catapult launches and arrested landings. The following examples are not intended to be comprehensive:

a. Shattering of optical material. (Temperature/Vibration/Altitude)
b. Binding or loosening of moving parts. (Temperature/Vibration)
c. Separation of constituents. (Temperature/Humidity/Vibration/Altitude)
d. Performance degradation in electronic components due to parameter shifts (Temperature/Humidity)
e. Electronic optical (fogging) or mechanical failures due to rapid water or frost formation. (Temperature/Humidity).
f. Differential contraction or expansion of dissimilar materials. (Temperature/Altitude)
g. Deformation or fracture of components. (Temperature/Vibration/Altitude)
h. Cracking of surface coatings. (Temperature/Humidity/ Vibration/Altitude)
i. Leakage of sealed compartments. (Temperature/Vibration//Altitude)
j. Failure due to inadequate heat dissipation. (Temperature/Vibration /Altitude)

MIL-HDBK-454 Proposed Intermittent Fault Guideline (continued)

3.3 Operational environment. A review should be conducted of technical manuals, operating manuals and any available operating environment information, prior to development of test procedures using the tailoring process in MIL-STD-810 to determine where forcing functions of temperature, humidity, vibration, and altitude are foreseen in the Electronic Equipment operational environment. Use this method only if the proper engineering has been performed such that the environmental stresses associated with the individual test methods are considered. If appropriate, tailor Electronic Equipment testing to include storage thermal environments and include in environmental testing or, perform them as separate tests, using the individual test methods. It is recommended that where the operational temperature and vibration test levels are not known that the qualification temperature and vibration levels during troubleshooting of the Electronic Equipment be reduced in order to not over stress the Electronic Equipment. The intent is to subject the Electronic Equipment to temperature/vibration level low/high enough to stimulate the intermittent fault, but not reduce the operational life of the Electronic Equipment.

4. Detail guidelines. Testing for intermittent faults should be conducted using diagnostic equipment meeting the performance requirements of MIL-PRF-32516. The diagnostic equipment covered by this specification is intended for use in detecting and isolating intermittent faults in Electronic Equipment, chassis, backplanes and their wire harnesses. The diagnostic equipment is intended to be used with the Electronic Equipment (with internal subassemblies removed) being stimulated by temperature, vibration or vibration/temperature to emulate the environment in which the fault originally occurred. MIL-PRF-32516, Appendices A through C, provide recommended guidelines for defining this external stimulation.

5. Integrated diagnostics. See guideline 77.

NSWC Crane Ribbon Cutting

FISCAL YEAR 2020

INDUSTRIAL CAPABILITIES

REPORT TO CONGRESS

PREPARED BY:
OSD A&S INDUSTRIAL POLICY
JANUARY 2021

The estimated cost of this report or study for the Department of Defense is approximately $159,000 in Fiscal Years 2020–2021. This includes $24,000 in expenses and $134,000 in DoD labor.Generated on 2020Dec23, RefID: C-C691E6A

TABLE OF CONTENTS

SECTION 1

FOREWORD

FOREWORD

A 21ST CENTURY DEFENSE INDUSTRIAL STRATEGY FOR AMERICA

Introduction to the Fiscal Year 2020 Industrial Capabilities Report to Congress

In many ways, Americans have every reason to be confident about our national security future.

The American military is still the most powerful in the world. Its leading defense industry companies are still global leaders in weapons innovation and production. Likewise, the Department of Defense is still the colossus of the federal system, i.e., the single biggest buyer of goods in the U.S. government. But unless the industrial and manufacturing base that develops and builds those goods modernizes and adjusts to the world's new geopolitical and economic realities, America will face a growing and likely permanent national security deficit. Our offices, the Under Secretary of Defense for Acquisition & Sustainment and the Office of Industrial Policy, have the primary responsibility for assessing this challenge, and are the authors of the 2020 Industrial Capabilities Report.

America's defense industrial base was once the wonder of the free world, constituting a so-called "military-industrial complex" that, regardless of criticism, was the model for, and envy of, every other country – and the mainstay of peace and freedom for two generations after World War II. Today, however, that base faces problems that necessitate continued and accelerated national focus over the coming decade, and that cannot be solved by assuming that advanced technologies like autonomous systems and artificial intelligence (AI) and 5G and quantum will wave those challenges away, and magically preserve American leadership.

On the contrary, those advanced technologies themselves rely on a manufacturing complex whose capability and capacity will have to be trusted and secure to protect the Pentagon's most vital supply chains. These include microelectronics, space, cyber, nuclear, and hypersonics, as well as the more conventional technologies that make up our legacy defense equipment.

What will be required is a defense industrial strategy based on a four-part program to:

1. Reshore our defense industrial base and supply chains to the United States and to allies, starting with microelectronics, and restore our shipbuilding base.

2. Build a modern manufacturing and engineering workforce and research and development (R&D) base.
3. Continue to modernize the defense acquisition process to fit 21st century realities.
4. Find new ways to partner private sector innovation with public sector resources and demand.

All these steps will be necessary to create a robust, resilient, secure, and innovative industrial base. As the National Security Strategy noted, a "healthy defense industrial base is a critical element of U.S. power."[1] The defense industrial base is the key to preserving and extending U.S. competitive military dominance in the coming century and, with it, deterrence that will keep Americans safe and keep the peace. Realizing a defense industrial strategy will require a substantial commitment of capital investment and resources, as well as continuing and extending the reforms to the Defense Department's industrial base that have been underway in the past several years.

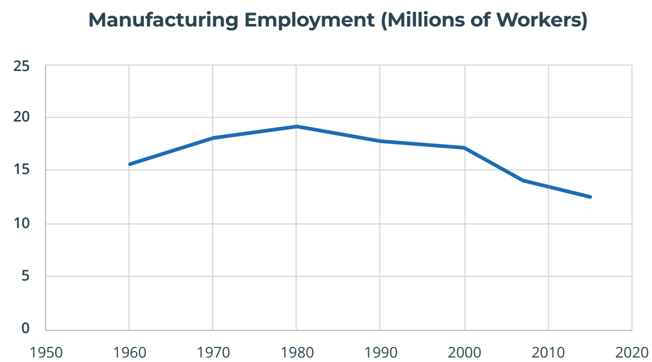
*****

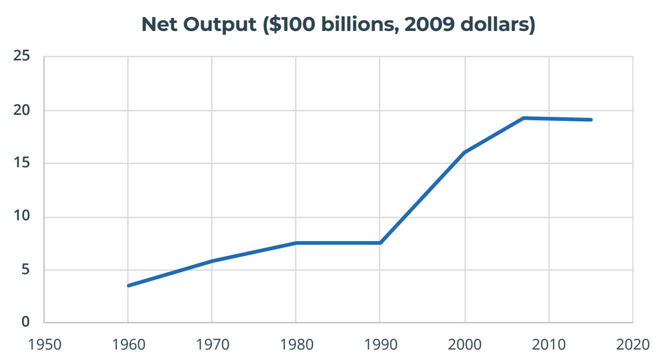
The issues confronting our defense industrial base can be viewed in the context of four major evolutions stretching over more than a half-century, each of which requires us to accelerate change and reform.

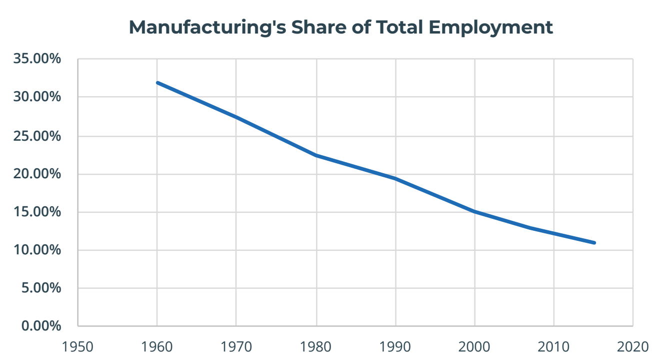
The first has been the steady deindustrialization of the United States over the past five decades, including workforce and manufacturing innovation. From 40 percent of the U.S. gross domestic product (GDP) in the 1960s, manufacturing has shrunk to less than 12 percent today, while shedding more than five million manufacturing jobs from 2000 to 2015 alone. Just fifty years ago, manufacturing industries employed 36 percent of male workers. Today, manufacturing employs fewer than 11 percent of all workers.[2]

While total manufacturing output has grown during this period, thanks in part to labor-saving technologies, the workforce on which a defense industrial renaissance would depend has become, in effect, an endangered species.

Together, a U.S. business climate that has favored short-term shareholder earnings (versus long-term capital investment), deindustrialization, and an abstract, radical vision of "free trade," without fair trade enforcement, have severely damaged America's ability to arm itself today and in the future. Our national responses – off-shoring and out-sourcing – have been inadequate and ultimately self-defeating, especially with respect to the defense industrial base.







These trends have had particular impact on the core element of a successful manufacturing economy: the machine tool industry. Of the world's top twenty-one machine-tool makers, only two today are American: Gleason and Haas Automation. By contrast, eight are based in Japan, and six in Germany. And while its domestic machine tool sector remains nascent, China has emerged as a major machine tool customer. Machine tools laid the groundwork for the mobilization miracle of World War II, a fact understood by friends and foes alike, while America has allowed its machine tool sector to turn from a national asset into a national security vulnerability.

The second development was the end of the Cold War, which was seen by many to render obsolete the assumptions and requirements that drove a legacy defense industrial base aimed at defeating a peer competitor, the Soviet Union, i.e., producing weapons that would counteract the Soviet advantage in quantity in conventional arms. This included building a massive nuclear arsenal, and later innovations such as stealth, precision guided munitions, and the multiple independent re-entry vehicle (MIRV).

The collapse of the Soviet Union and the end of Cold War tensions and priorities should have brought an intense rethinking of the Department of Defense's needs, including fundamental changes to the structure of its industrial base. One change that did take place was the drastic consolidation of the largest defense contractors from fifteen to five, which, among other things, reduced competition for contracts, formerly a key driver behind controlling costs and spurring innovation.[3]

The War on Terrorism, with its focus on disrupting terrorist cells and havens, and counterinsurgency and stability operations delayed by a crucial decade and a half the adjustment to new geopolitical and military realities, including the steady rise of an aggressive and militant China, and an unreconciled Russia.

The third evolution has been the advent of high-tech and advanced digital technology, from personal computers, cell phones, and solid-state sensors to the internet and 5G wireless technology along with AI and quantum computing. These technologies are and will continue to be the driving forces of the U.S. and global economy, and will also determine the military balance of the future – while at the same time opening up critical security threats in peacetime, through cyber and intellectual property theft and information warfare, not to mention future scenarios involving quantum computer attacks on critical civilian and defense infrastructure.

Moreover, these technologies pose new problems for defense contractors and for the Pentagon in securing a trusted supply chain for critical items such as processed rare earth elements and microelectronics, where gaps and unanticipated interruptions can be triggered by the loss of a sole supplier for purely economic reasons, or by an embargo or military action by an adversary. Events of either type can jeopardize a sustainable industrial base.

Pentagon leaders recognized that this technological revolution would require a major shift in the military's basic requirements for warfighting, but also would demand building relations with an industrial base very different from the one that had supplied its equipment needs for decades, i.e., with newer companies such as Google, Oracle, and many other Silicon Valley firms. To facilitate this shift, the Department of Defense launched the Third Offset strategy, using, in the words of one thoughtful DoD official, "combinations of technology, operational concepts, and organizational constructs—different ways of organizing our forces, to maintain our ability to project combat power into any area at the time and place of our own choosing."[4]

However, the Pentagon's Third Offset did not evolve into a robust strategic doctrine. Meanwhile, the military services took an understandable and narrower approach, generally pursuing advanced technologies to fit their individual operational needs. This meant that the opportunity for a more extensive systematic rethinking and reordering of DoD's industrial base was missed or at a minimum delayed. Today's overseers of the defense industrial base have been busy making up for lost ground, as the Industrial Capabilities Report demonstrates.

The fourth evolution has been the rise of The People's Republic of China (PRC) as a dual threat, both military (the Chinese Navy is now the largest in the world with 350 vessels) and economic, which threatens critical supply chains, and also challenges our export control, foreign investment, and technology transfer policies.

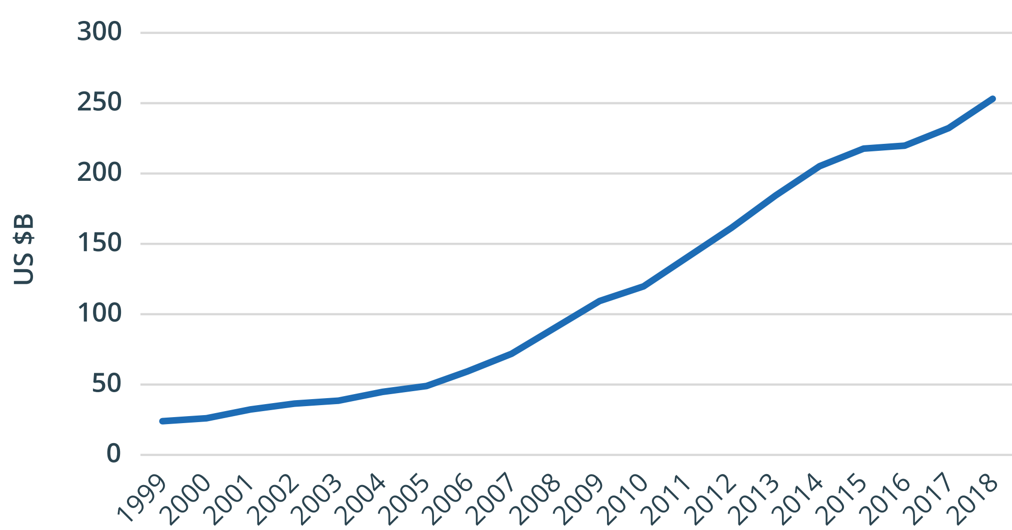
China's spectacular rise as the world's second-largest economy is well known, with GDP growing at an average annual rate of 9.45 percent since 1978, and China is now poised to become the world's biggest economy by 2040. The rise of China's military spending has also been widely reported, with a nearly twenty-five-fold increase over the past two decades, jumping from over $10 billion in 1999, to over $250 billion in 2019. China currently spends more on defense than do Japan, South Korea, the Philippines, and Vietnam combined, and is second only to the United States in its military budget. China's lower costs may mean that its defense spending has purchasing parity with ours.

China's defense spending is augmented by its policy of "military-civil fusion," which erases barriers between civilian and military sectors to ensure the latest technologies like AI and quantum computing are quickly integrated into security capabilities.

Though the exact amount of China's defense spending is opaque for the most part, the NATO definition of China's military expenditures captures the activities normally associated with defense spending and provides a reasonable benchmark. While China's defense budget is smaller than the U.S. defense budget, it is the vectors of that spending that are most alarming.

One is naval construction. The buildup of China's navy, including aircraft carriers, has been one of the most remarkable and strategically disruptive global defense spending trends in the past two

China's Defense Spending 1999-2018



Data Source: World Bank
https://www.macrotrends.net/countries/CHN/china/military-spending-defense-budget

decades. By commissioning fourteen warships a year, Beijing has made clear that it intends to be a world-class maritime power in addition to having the world's largest military on land. While China's naval buildup has been able to piggyback on its rapidly expanding commercial shipbuilding industry, U.S. shipbuilding, by contrast, has become a key vulnerability in the U.S. defense manufacturing base, as we will see.

Two other critical components in China's growing military power have been a huge expansion in its ballistic and anti-ship missile inventory and its nuclear weapons arsenal. Its missile arsenal contains advanced capabilities such as maneuverable anti-ship ballistic missiles, MIRVs, and experimental hypersonic glide vehicles, all designed to target American aircraft carriers and forward air bases – the mainstays of U.S. military power projection in the Indo-Pacific region. In addition to the obvious cost in lives, replacing carriers or other ships, or repairing damaged vessels, would severely challenge the most robust shipbuilding base. Attempting to repair or replace forward bases in mid-conflict would be an even more complex challenge.

Nor should we ignore Beijing's on-going activities as the world's most egregious cyber threat and intellectual property (IP) thief. America loses nearly $450 billion on an annual basis to cyber hacking, which originates overwhelmingly from China. This behavior already has severely damaged the Department of Defense and its prime contractors, from stolen plans for major weapons systems such as the F-35, to identity theft from America's defense and security workforce.

The Department of Defense cannot, of course, reverse these global developments by itself. However, it is devising an industrial strategy that responds to this highly disruptive and rapidly changing environment, and is leading the way to turn these changes to America's advantage.

How will the Department accomplish this? By focusing that strategy on the four key categories outlined in the Industrial Capabilities Report: assessment, investment, protection, and promotion of our defense industrial base, both today and in the future.

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Assessment. In September 2018, the Department of Defense released *Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States*, a report in fulfillment of Executive Order 13806. The "13806 report" isolated "five inter-related, but conceptually distinct, macro forces" affecting the U.S. industrial base. These included:

- The decline of the U.S. manufacturing base.
- Budget caps, sequestration, and inconsistent U.S. budgets that sharply reduced resources for the military across the board, particularly investment in the industrial base.
- "Deleterious U.S. government business and procurement practices," including contracting regulations and constant program changes that drive up cost without necessarily adding effectiveness.
- Industrial policies of nations such as China that provide an unfair comparative economic advantage and predatory trade policies that "degrade the viability, capabilities, and capacity of the U.S. national security innovation base."
- Diminishing U.S. science, technology, engineering, and mathematics (STEM) education and industrial jobs, both of which have a deleterious effect on the industrial base's ability to sustain itself and to innovate.

As a result, the study found examples by the dozens where "the vitality and resiliency of the industrial base" had been acutely affected, from aircraft design and cybersecurity to machine tools and materials.

Since then, the President and his Secretaries of Defense have taken significant steps to ameliorate vulnerabilities in the industrial base's critical sectors, as described in this report. But the number of cases, typically three to seven levels from the top of the supply chain, where there is just one – often fragile – supplier is staggering. This represents a significant deterioration from just a decade ago when three-to-five suppliers existed for the same component, let alone several decades ago, when the U.S. military generally enjoyed dozens of suppliers for each such item.

Many U.S. small and mid-size businesses exited the defense field over the last three decades not only because of reduced demand (we build a lot fewer platforms than we once did), but because doing business with the government proved too difficult, with margins too low. Rules that were designed to give good value to taxpayers did not necessarily provide good returns for these firms, often family-owned. They chose instead to employ their entrepreneurial talents and financial resources in the commercial market.

The 13806 report also identified sixteen key industrial sectors, whose risks and vulnerabilities are assessed in more detail below. The core of the department's industrial base includes government-owned government-operated (GOGO) and government-owned contractor operated (GOCO) shipyards, depots, arsenals, and ammunition plants. These have been at critical risk for many years thanks to the macro factors identified earlier: the decline of manufacturing and STEM education, the need to rely on single suppliers for many critical components, and a serious erosion of America's manufacturing workforce.

The National Security Strategy defines the National Security Innovation Base as the "American network of knowledge, capabilities, and people—including academia, National Laboratories, and the private sector—that turns ideas into innovations, transforms discoveries into successful commercial products and companies, and protects and enhances the American way of life." The strategy continues, the "genius of creative Americans, and the free system that enables them, is critical to American security and prosperity."[5] We would add, and to the future of our defense industrial resources and the ability of our military to arm itself effectively today and in the future.

Therefore, we have identified three steps to connect the defense industrial base to that U.S. national innovation base.

First is integrating new manufacturing technologies and processes, where a series of DoD programs across the military departments and Office of the Secretary of Defense are useful, indeed critical.

The second is a Department of Defense-wide focus on supporting an industrial base for peer conflict. After a decade and a half of equipping the military for operations in Iraq, Afghanistan, and elsewhere, and as directed by the National Defense Strategy, the Pentagon is recalibrating to face the challenges posed by China and Russia. While the Services never stopped planning and procuring for high-end combat, the threats posed by adversaries require increased investment and focus on the most advanced capabilities, and on the industrial base to support them.

The third and arguably most difficult is confronting difficult but necessary investment choices, including expanded funding for capital investment in facilities and training and maintaining the workforce. Without that serious and targeted investment – billions instead of millions – America's defense industrial base is simply unsustainable, let alone capable of supporting our deployed forces and legacy equipment while solving the complex warfighting challenges posed by advanced technologies in the 21st century, from AI and cyber to hypersonics and autonomous air and sea systems.

The Office of the Under Secretary for Acquisition & Sustainment works with the Military Departments to produce the analysis to drive actions to solve these problems. The Industrial Base Council (IBC) is the "executive-level forum established to ensure industrial base readiness and resilience" at the three- and four-star level. The Office of Industrial Policy and the Defense Contract Management Agency chair the IBC's Joint Industrial Base Working Group, which oversees the flow of information concerning the critical industry sectors identified under E.O. 13806 and emerging technology domains.

The Office of Industrial Policy assessed America's shipbuilding woes, both defense and commercial, which began more than five decades ago. Fourteen defense-related new ship-construction yards have shuttered, and three have exited the defense industry. Only one new-ship-construction yard has opened. Today, the Navy contracts primarily with seven private new-construction shipyards, owned by four prime contractors, to build its future Battle Force, representing significantly less capacity than the leading shipbuilding nations.

The Future Naval Force Study (FNFS), developed by the Department of Defense to ensure American naval supremacy, sets forth a multi-year program divided into five-year increments with careful attention to meeting base budgetary limitations to achieve the goal of a 355-ship navy. Yet that plan has to rely on a maritime industry, both naval and commercial, that has significantly less capacity than the world's other leading shipbuilding nations – South Korea, Japan, and, ominously, China.

So while today, the United States Navy's Battle Force consists of 297 ships, China has managed to build the world's biggest navy with 350 vessels. China's shipbuilders also enjoy the advantage of being part of the world's biggest national steel producer and user. The United States meanwhile is fourth, after China, India, and Japan.

How do we fill the shipbuilding gap? Start by building more ships. Not only will that expand the fleet, it will drive the analysis and decisions required to ensure a shipbuilding base that can produce and sustain an expanded Navy. That our shipbuilders delivered in 2020 no fewer than ten ships (two Virginia-class submarines, one America-class amphibious assault ship, three littoral combat ships, two Spearhead-class expeditionary fast transports, one Arleigh Burke-class destroyer, and one Lewis B Puller-class expeditionary sea base) is a remarkable achievement. It is a harbinger of what can be done with even a modest expansion of that capacity.

Alexis de Tocqueville noted in 1832 that Americans "are born to rule the seas…." In the final analysis, reaching our nation's minimum naval goals will demand substantial investment in refurbishing old yards and establishing new ones, and partnering more with trusted allies who want to invest in the U.S. shipbuilding base. More broadly, a renewed commitment to reinforcing America's place as the world's leading maritime nation will, as it always has, lead to jobs, workers with skills that will be useful to a variety of other domains such as electric transportation, and next-generation energy storage and batteries that loom large in America's future.

Another area of concern, but also an example of recent progress, is software engineering. Software acquisition remains one of the most expensive and most complex sectors in the DoD. For example, the F-35 Joint Strike Fighter has required more than eight million lines of code, almost all of which had to be written by its prime contractor and sub-contractors, virtually from scratch and, then again, after Chinese cyber-theft. All software "blocks" – the systems designed to take the plane from testing to full production – experienced serious production and budgetary delays. These, in turn, contributed to expanding the Lightning II's total price tag.

One could argue that today's defense systems are no more or less than physical platforms for software, yet developing and buying that software had become a major bottleneck.

Standard Pentagon programming was not designed to deal with software, so crucial to operating systems large and small, including networked warfare. The Department of Defense has traditionally acquired IT and software-based systems in the way it bought aircraft carriers – as if they were physical items to be forged or welded or mass-produced. The standard acquisition cycle has been geared around multiyear milestones and intensive evaluation reviews that can take months or years. The modern software development cycle, by contrast, moves in weeks, days, and even hours and seconds – because software is a digital item, subject to real-time improvement and innovation, whose only limits are the human imagination and the speed of an electron. To take one example, given the unique iterative dynamic of software development, the Pentagon's traditional serial approach to "the color of money" – different budget accounts for development, production, and sustainment – was a major obstacle.

The Department of Defense Innovation Board and Defense Science Board dug into this problem and other challenges with software development and acquisition. Based on their findings, we issued in October 2020 a ground-breaking new direction: the Software Acquisition Pathway. We have been working with the Congress and the Services to pilot the creation of "software colored money" as an imperative.

Fixing software acquisition was part of a larger process of changing another key vulnerability, namely, how an outdated and sclerotic acquisition system, layered since the 1960s, has hampered the industrial sector.

Ultimately, the most important asset our defense industrial base possesses isn't machines or facilities, but people. America needs an ambitious effort, like the Eisenhower National Defense Education Act, to support education and training for manufacturing skills required to meet DoD and wider U.S. requirements. As the Industrial Capabilities Report notes, while China has four times the U.S. population, it has eight times as many STEM grads, while Russia has almost four times more engineers than the United States. We have lost ground also in many equally important touch labor industrial skills sets.

A skilled workforce is especially critical in a defense-focused industrial strategy, which requires innovative and bold solutions and production and integration of extremely complex systems. Here the OSD Industrial Base Analysis & Sustainment (IBAS) capability plays a crucial role. It is finding ways to close the gap, including programs for training and incentivizing a new manufacturing workforce. It is preparing the way for new affordable manufacturing of defense systems, and reducing the risk of over-extended supply chains and chronically low inventories.

Unfortunately, the budget allotted for IBAS, which has ranged from $10-104 million, is empirically inadequate for the job to be done. A budget of $1 billion would enable the program to expand, by a vast number, employment in the U.S. production sectors. The current mismatch between mission and means hampers the ability to focus solutions on the right problems across industrial sectors, and grow large numbers of highly-skilled, well-paying American jobs.

This issue is one that should be confronted more broadly, under the headings of:

1. Investment. The mismatch between what must be spent to support key programs and initiatives and the resources available must be addressed to avoid a series of catastrophic vulnerabilities in critical sectors of the defense industrial base. Fortunately, there are new paradigms available for public-private partnering to accomplish these ends, including creating a flexible manufacturing workforce that would be available for rapid mobilization of the defense industrial base in the event of a major conflict. Many of these are outlined in this report. We will take time here to point out two of them.

The first is in the critical area of semiconductors and microelectronics. Microelectronics are critical to producing and maintaining existing military systems, for advancing emerging technologies like AI, 5G, and quantum computing, and for sustaining critical infrastructure and indeed, our entire modern economy. Microelectronics are in nearly everything, including the most complex weapons the Department of Defense buys, such as Aegis warships, the F-35 joint strike fighter, soldier systems, and our nuclear weapons and their command-and-control – which together form the backbone of our national defense.

Thirty years ago, more than one-third of all microchips produced worldwide came out of the American companies that gave Silicon Valley its name (silicon being the key ingredient in manufacturing microchips containing millions of microscopic transistors). Today that number has slipped to only 12 percent, with most production in Asia. China is projected to dominate global semiconductor production by 2030, and in the meantime, current suppliers in Taiwan, South Korea, Malaysia, and elsewhere are in easy range of Chinese missiles, subversion, or air or maritime interference.

Thus in addition to its growing dominance in the area of production, Beijing is already in a position, through its geographic and political position, to threaten virtually our entire supply chain through theft, corruption of microelectronic products, disruption of supply, coercion, and other measures even short of military action. This leaves American deterrence and critical warfighting capabilities at the mercy of our main strategic competitor.

The Boston Consulting Group and the Semiconductor Industry Association recently issued a report calling for public-private funding of up to nineteen new semiconductor manufacturing facilities (or fabs) in the continental United States over the next decade.[6] The report estimates that this will require at least a $50 billion federal investment in addition to industry's share. However, it also forecast that initiative will create more than 70,000 high-paying jobs, and would position the United States to capture a quarter of the world's growing chip production.

The cost of a new fab today is roughly $10-30 billion, which is far more capital investment than even America's biggest semiconductor companies can afford if they are to produce chips that are price-competitive – that is, that Americans and other customers will buy. Chip manufacturing equipment is hugely expensive and has to be replaced with each new wave of innovation.

Outside of the United States, foreign governments and their citizens pay the lion's share, one way or another, of the cost of building the fab. The companies do not. They take on the other massive set of costs: running the fab. The hard truth is that if the United States does not start doing the same, our nation will continue to see its historically low share of chip production continue to decline to irrelevance. We will have few new fabs. We will have fewer semiconductor production jobs. We will have frightening vulnerability to foreign cut-offs whose impact would make our COVID-related shortages look miniscule.

A recent success story is the recent ribbon-cutting for the new Skywater Technology Foundry in Bloomington, Minnesota – the first new semiconductor fab to open in the United States in a generation. A combination of Defense Department investment in facilities and research and development and private equity capital to streamline operations is producing integrated circuits for the automotive, computing and cloud, consumer, industrial, and medical sectors, and radiation-hardened microelectronics that are vital for the military's use of outer-space.

Congress's recent bipartisan passage of the landmark semiconductors legislation opens vistas for future creative pooling of federal and private capital to fund fabs in the United States. A cost-effective and hugely successful model worthy of intense American study is the Taiwanese approach, which catapulted the island in just several decades into the leading producer of microelectronics in the world.

Hypersonics development and nuclear weapons sustainment are other areas quickly approaching a tipping point in terms of investment. Facilities – including unique production equipment and in many cases the necessary workforce – require reconstitution, major modernization, and increases in capacity. Test ranges and instrumentation need significant capacity increases and modernization. Investment in both industry and Defense Department facilities is necessary to achieve the required capability and capacity.

Finally, it is also worthwhile to take a hard look at the overall research and development (R&D) picture. The United States continues to lead the world in gross domestic spending on R&D in 2019, although China is rapidly and consistently closing the gap. Nonetheless, aerospace and defense companies are among the lowest R&D spenders compared to other critical sectors. America's six biggest defense contractors have spent on average 2.5 percent of their sales on R&D each year. This compares to 10 percent of sales for "big tech" firms like Facebook, Amazon, and Google. So, while defense companies' R&D spending has increased from 2014 to 2019, and while aerospace firms in general spend more than pure defense firms, R&D spending per firm would have to increase by 50-60 percent to keep pace with other domestic technology leaders. It remains for lawmakers and the Department to find ways to incentivize internal research and development (IRAD) so that our leading defense companies expand their engines of innovation and technological breakthroughs.

The bottom line is: if we are going to secure the future versus China, then far more investment is going to be required both by Federal authorities and the private sector. That includes funding to ensure that research, development, and resulting products are safe and secure from adversary influence and manipulation.

2. Protection. One of the most important developments in the past four years has been how the White House, the Defense and other Cabinet departments, and Congress have worked together to limit adversarial foreign investment into and technology transfer out of our defense industrial base – especially from and to China.

A landmark achievement was the bipartisan passage of the Cornyn-Feinstein sponsored Foreign Investment Risk Review Modernization Act (FIRRMA), which President Trump welcomed and executed with vigor. It updated the interagency Committee on Foreign Investment in the United States (CFIUS) to further restrict investment by adversaries, including China, in U.S. companies and the economy. New rules were also put in place to limit allies' reliance on Chinese technology and industry when purchasing American defense-related goods.

The DoD Directorate for Foreign Investment Review is marshalling the information and insight of more than thirty Department of Defense components to contribute to the effort by U.S. national security and financial authorities to halt dangerous Chinese acquisition of hard-earned American economic crown jewels and the private personal data of ordinary Americans.

Foreign investment is welcome, especially from allies and friends. That is why the Pentagon has encouraged participation in the National Technology and Industrial Base (NTIB) by allies such the U.K., Australia, and Canada, and why steps should be considered to expand our base of trusted partners, when they are willing to take the steps necessary to strengthen their foreign investment screening and defense industrial security rules.

Of course, and as evidenced by extensive reporting on Chinese and Russian cyberattacks, the same protections need to be implemented within the Department of Defense and its contractor base to protect our industrial assets from foreign cyberattacks and cyber theft. Preserving the U.S. overmatch in defense technology inside cyberspace is an explicit objective of the National Cyber Strategy, including ramping up offensive, defensive, and cybersecurity capabilities. The on-going effort to protect the industrial base also meshes with the recently established DoD Cybersecurity Maturity Model Certification (CMMC) program, with its five levels of new cybersecurity standards for all DoD contractors.

But there are also important vulnerabilities concerning major defense platforms that deserve to be addressed as part of progress on industrial base reform.

3. Promotion. The hard truth is, in a globalized economy, America cannot solve its defense industrial problems (or indeed many of our other industrial challenges) solely by itself. The days when our military could arm itself effectively by relying entirely on its domestic manufacturing base, as it did during World War II and the Cold War, are long gone. Instead, a long-term strategy of reshoring defense manufacturing must balance and mitigate the risks of relying on other countries as supply chain partners, in particular, countries that are allied or friendly with the United States but also have economic and/or technological ties to China, or are simply vulnerable to Chinese coercion, disruption, pressure or military action. Another side of the reshoring imperative is crafting an effective export policy for the U.S. and its allies that protects national security while not hampering innovation or key scientific advances – while also promoting the idea that the safest course always is having American companies manufacturing defense goods, right here in America.

With both these points in mind, we have been constantly looking for ways to draw in reliable international partners to become part of a trusted industrial base and supply chain. This effort might be dubbed "strategic reshoring," which includes expanding the reach of mechanisms like the NTIB and the U.S.-India Defense Technology & Trade Initiative (DTTI), as well as the new DoD Trusted Capital Program to facilitate capital investment into the industrial base from safe foreign and domestic sources.

The promotion of partnerships is not just limited to foreign partners. For example, the OSD Office of Small Business Programs has been expanding the opportunities for small and medium-sized firms across the fifty states to participate in creating a new reshored American industrial base.

It would also be a mistake to overlook how the Department of Defense can be a leader in promoting innovation in America's industrial and manufacturing base. Here a flagship program can emerge from the Manufacturing Technology program in the Office of the Secretary of Defense, whose nine institutes showcase how the Pentagon's own manufacturing techniques and innovations can lead not just its own industrial base but American industry as a whole.

Created in 1956, Manufacturing Technology is comprised of component investment programs operated out of the Office of the Secretary of Defense, Army, Navy, Air Force, Defense Logistics Agency, and Missile Defense Agency. Its nine manufacturing innovation institutes are public-private partnerships designed to overcome the challenges faced by manufacturing innovators in various technology areas, from light manufacturing to composite materials and biotechnology. To date, the DoD has invested $1.2 billion in the Manufacturing Technology Institutes, with $1.93 billion in matching funds from industry, state governments, and academia. To become a truly global leader in manufacturing innovation, a two to three-fold increase in the innovation budget by the Congress is needed.

Finally, officials need to demonstrate how advancing and modernizing the defense industrial base is vital to keeping costs down and innovation up for present and future military readiness as the U.S. prepares its armed forces in the 21st century. This will be especially true of naval and maritime forces, where reviving U.S. shipyards and launching new initiatives for manufacturing advanced systems for sea control, such as unmanned and robotic systems, will be a hinge for strategic success. But the same applies to air and land defense assets, where making acquisition cost-effective as well as timely will depend on the strength and health of our defense industrial base.

In short, following through on promoting a strong and resilient industrial base can point the way to streamlining the Department of Defense's acquisition process and defense systems' life cycle, which not only saves money but makes our men and women in uniform safer and more effective – while securing our national security future.

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In conclusion, our defense industrial base has reached an inflection point in its history regarding the balance between its vulnerabilities and its opportunities for modernization and reform. Some might say restoring our defense industrial and manufacturing base dominance will require nothing less than a miracle. The truth is, the United States and its military organizations have performed similar "miracles" before: the resolve to see that miracle through is deeply steeped in our history as a nation. Ambitious policies like these require an ability and willingness to make strategic decisions, for example, recognizing that what may have worked in the past is no longer working and will not work in the future. The consensus is growing, across political lines, on the need to reshore critical industries, create American jobs, and counter the challenges of China.

In fact, the requirement that the federal government guide and direct the Nation's industrial future, including its defense needs, is part and parcel of the American tradition. In his ground-breaking *Report on Manufactures* published in 1791, Secretary of the Treasury Alexander Hamilton urged Congress to promote what we would call America's industrial base so that the United States could be "independent on foreign nations for military and other essential supplies." In addition to protecting national independence, support for manufacturing incentives for emerging industries would level the playing field in the global markets of the day.

Virtually every U.S. president from Hamilton's day until the dawn of the twentieth century understood that sensible and targeted trade measures – anti-dumping fees, countervailing duties, and even modest tariffs to level an unfair playing field – formed the principal tool by which America fostered its industrial base. The 1990s saw an experiment in radical trade policies – dropping reciprocity – that made earlier presidents, such as FDR, Eisenhower, and JFK, all advocates of free trade, look, with their prudent tariffs, like protectionists.

The industrial base enabled our War and Navy Departments to execute the first of these defense production miracles during World War II when our military had to move from a virtual standing start (the U.S. Army ranked nineteenth in the world in 1939) to becoming the most powerful military and industrial base in the world in less than three years.

A similar pivot took place during the Eisenhower administration in the 1950s, when the Cold War forced the Department of Defense to re-engineer its concept of how to achieve victory over a conventionally-armed Soviet Union, with a bold shift of resources from World War II-era strategic doctrines to nuclear deterrence and ballistic missiles. This strategic rebalance resulted in a corresponding shift in America's defense industrial and scientific-technological base, the First Offset.

With the Second Offset in the 1970s and 1980s, the Department of Defense learned how to incorporate new technologies including GPS, networked computers, and stealth technology into a bold strategic vision and capabilities that made our warfighters more powerful and lethal, yet also safer and more secure. That transformation also led to a corresponding shift in supply chains, especially a new reliance on emerging commercial off-the-shelf technologies and companies as well as the traditional defense contractor base.

Later came the Third Offset as a way to integrate the latest advanced technologies, including cyber and autonomous systems and artificial intelligence, into a military that would have to be ready to deal with rising Russian and Chinese challenges. What we have learned in the past four years is that such an offset will not take place without conscious, difficult decisions and investments to repair and modernize our defense industrial base, including the need for a larger reshoring of American manufacturing as a whole.

Fortunately, as noted above, a broad consensus is emerging in our political leadership and the American public as a whole on the need both to reshore our manufacturing and to deal boldly with the global threat of China.

The reshoring imperative has received an additional impetus from the coronavirus pandemic, which demonstrated the hazards of relying on other, especially adversarial nations for critical materials and medical equipment. The U.S. Government successfully ramped up production of vital medical supplies, most notably vaccines, as well as ventilators, personal protection equipment (PPE's), and other products under Title III of the Defense Production Act and the Coronavirus Aid, Relief, & Economic Security (CARES) Act. This initiative relied on the World War II industrial mobilization model described in Arthur Herman's *Freedom's Forge: How American Business Produced Victory in World War II and James Lacey's The Washington War: FDR's Inner Circle and the Politics of Power That Won World War II*. The same model in Operation Warp Speed has produced coronavirus vaccines – in what can only be described as a medical research, development, and manufacturing miracle.

All these examples prove that federal resources and direction combined with the private sector's unique manufacturing and industrial ingenuity can respond to a national crisis, especially when the objectives are well-defined and funds effectively deployed. The Department of Defense, the President, and the Congress can – and must – join to reduce America's vulnerabilities, increase its security, and provide the resources for an industrial renaissance that will lift up the economic prospects and dignity of millions of ordinary Americans.

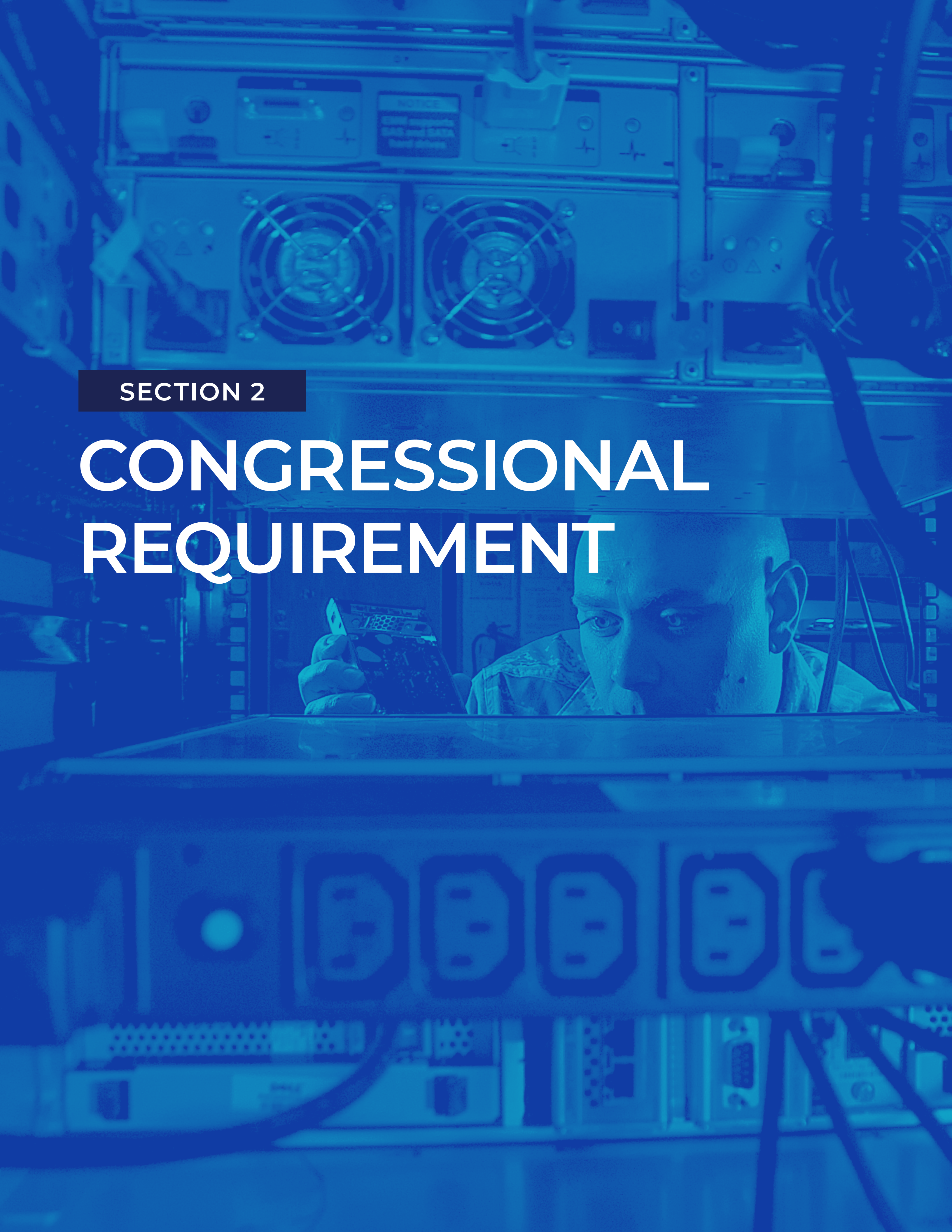
Today we see more clearly than ever what America must do to restore and sustain its vital defense industrial base. The elements for a comprehensive defense industrial strategy are all in place. Now must come the hard work of making that "robust, resilient, and innovative industrial base" a reality – for our women and men in uniform in the 21st century and for all Americans.

Ellen M. Lord, Under Secretary of Defense

Jeffrey (Jeb) Nadaner,
Deputy Assistant Secretary of Defense

SECTION 2

CONGRESSIONAL REQUIREMENT



CONGRESSIONAL REQUIREMENT

Section 2504 of title 10, U.S. Code requires the Secretary of Defense to submit an annual report to the Committee on Armed Services of the Senate and to the Committee on Armed Services of the House of Representatives by March of each year. The report is to include:

1. A description of the departmental guidance prepared pursuant to section 2506 of this title.
2. A description of the assessments prepared pursuant to section 2505 of this title and other analyses used in developing the budget submission of the Department of Defense (DoD) for the next fiscal year.
3. Based on the strategy required by section 2501 of this title and on the assessments prepared pursuant to Executive order or section 2505 of this title—

a. A map of the industrial base;

b. A prioritized list of gaps or vulnerabilities in the national technology and industrial base, including—

c. A description of mitigation strategies necessary to address such gaps or vulnerabilities;

   i. The identification of the Secretary concerned or the head of the Defense Agency responsible for addressing such gaps or vulnerabilities; and

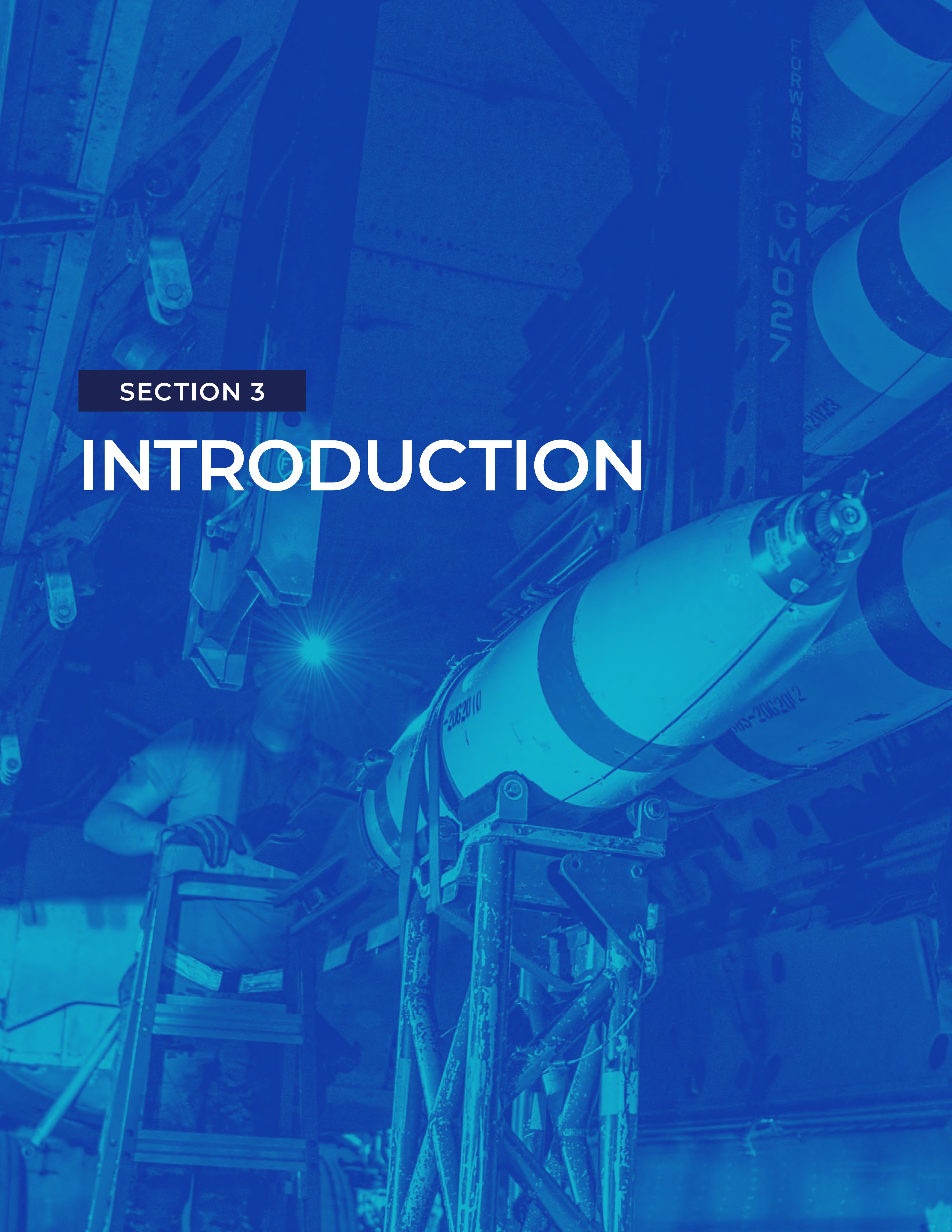
   ii. A proposed timeline for action to address such gaps or vulnerabilities; and

   iii. Any other steps necessary to foster and safeguard the national technology and industrial base.

4. Identification of each program designed to sustain specific essential technological and industrial capabilities and processes of the national technology and industrial base.

This Industrial Capabilities Report for Fiscal Year (FY) 2020 satisfies the requirements pursuant to section 2504, title 10, U.S. Code. It does not respond to section 2504a, title 10, U.S. Code, which will be delivered as a separate report.

House Report 116-442, accompanying the FY2021 National Defense Authorization Act (NDAA), directs the Secretary of Defense to include a supply chain and vulnerability assessment for rare earth elements, tungsten, neodymium-iron-boron magnets, niobium, indium, gallium, germanium, and tin in the annual Industrial Capabilities Report, along with recommendations for stockpiling actions for those materials and any other relevant materials. The Department will satisfy this reporting requirement with the submission of the *Strategic and Critical Materials 2021 Report on Stockpile Requirements,* in accordance with 50 U.S.C. 98h–5.



SECTION 3

INTRODUCTION

INTRODUCTION

By law, the Secretary of Defense must submit an annual report to the congressional armed services committees on the actions, investments, and assessments conducted in support of the U.S. defense industrial base (DIB). The FY 2020 Industrial Capabilities Report satisfies the requirements pursuant to title 10, U.S. Code., Section 2504, and provides context to the challenges facing the U.S. DIB.

This report includes the following components:

- A description of the Department's primary lines of effort (assess, invest, protect, and promote) to build resiliency in the DIB and implement the National Defense Strategy (NDS);
- A summary of the Department's response to the coronavirus pandemic and its impacts on the DIB;
- An overview of the U.S. defense industry and its outlook relative to the global defense market;
- Assessments of each of the 16 industrial base sectors, including priority gaps and vulnerabilities, and FY2020 developments;
- Assessments of emerging technology sectors;
- Overviews of the primary DIB authorities and investment mechanisms; and
- An appendix including a map of U.S. industrial base COVID-related 'hotspots' and summaries of the industrial capabilities studies and assessments completed in FY2020. This appendix contains controlled unclassified information (CUI) and will not be included in the public report.

The Office of Industrial Policy within the Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD(A&S)) is tasked with compiling this report. However, there is an extensive list of stakeholders across the Office of the Secretary of Defense (OSD), Military Departments, and other federal agencies, whose assessments and knowledge provide critical contributions to the Industrial Capabilities Report and the ongoing work of building resilience in the DIB.

The coronavirus pandemic created new risks within the industrial base, and exacerbated existing vulnerabilities. The Department's response to coronavirus pandemic drove industrial base actions and investments in FY2020. Collectively, U.S. government and industry stakeholders strove to navigate the challenges brought about by the pandemic, and continue to ensure a robust, secure, resilient, and innovative industrial base. The Office of Industrial Policy will continue to champion the DIB and implement the NDS through four primary lines of effort: assess, invest, protect, and promote.

Assess

The first step in ensuring a robust, secure, resilient, and innovative industrial base is understanding its components and current and future requirements, as well as constantly evolving threats, vulnerabilities, and opportunities. U.S. government and industry stakeholders contribute to detailed industrial sector summaries, fragility and criticality assessments, and capacity analyses, to inform the Department's budgetary, programmatic, and legislative policies in support of a strong and resilient industrial base.

Industrial Policy, Assessments
Subject matter experts within Industrial Policy's Assessments Team coordinate with program offices and other OSD and industry partners to identify, mitigate, and monitor risks, issues, and vulnerabilities across the industrial base.

Emerging Technology Assessments
The Technology, Manufacturing, and Industrial Base (TMIB) Office acts as Industrial Policy's counterpart within the Office of the Under Secretary of Defense for Research and Engineering (OUSD(R&E)). The Emerging Technology Assessments team is responsible for translating technology requirements into manufacturing and industrial base requirements. The results of these assessments are used to create technology and industrial base protection and promotion strategies.

Industrial Policy continues to identify and assess risks based on the sectors and risk frameworks developed in the Executive Order (EO) 13806 report, "Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States".

As part of the interagency response to EO 13806, the Department identified 16 industrial base sectors which continue to serve as a framework for identifying and assessing industrial base risk. Sector leads support various interagency working groups (WGs) and track specific (though frequently overlapping) gaps and vulnerabilities within the sector. These working groups are organized based on DIB sectors and emerging technologies, or are further broken down into program or issue-specific working groups and integrated product teams (IPTs).

The Joint Industrial Base Working Group (JIBWG), chaired by the OUSD (IP) and the Defense Contract Management Agency (DCMA), serves as a central hub for U.S. government stakeholders to share information, identify and prioritize risks, and accelerate the implementation of risk mitigation strategies. Dozens of offices and working groups focused on specific sectors programs, and risks, feed into the JIBWG to ensure thorough representation of DIB equities.

Invest

The *Invest* line of effort supports the Department to leverage investment opportunities to address risks, priority gaps, and vulnerabilities across the DIB. The DoD plans for sustainment activities as part of the annual budgeting process. However, business closures, changing requirements, obsolescence, and other issues can result in unforeseen funding requirements.

The following authorities and investment mechanisms enable the Department to target investments toward DIB gaps and vulnerabilities, and bring attention to funding requirements that are not addressed through traditional appropriations.

The Industrial Base Analysis & Sustainment (IBAS) Program
The IBAS Program advances and sustains traditional defense manufacturing sectors, plans for next generation and emerging manufacturing and technology sectors, and leverages global manufacturing innovation.

Defense Production Act (DPA) Title III
The Title III Program leverages authorities provided under the DPA to "create, maintain, protect, expand, or restore domestic industrial base capabilities essential to national defense."[7] The program plays a leading role in strengthening the health and resilience of domestic supply chains of strategic importance. This role includes supporting the national response to the coronavirus pandemic and addressing supply chain risks identified in the EO 13806 report, such as microelectronics and the rare earths supply chain.

To support national security requirements, DPA Title III actions stimulate private investment for critical components, technology items, materials, and industrial resources. Additionally, on May 14, 2020, EO 13922 delegated authority under section 302 of the DPA to the U.S. International Development Finance Corporation (DFC) to make loans supporting the national response and recovery from the coronavirus pandemic or the resiliency of any relevant domestic supply chains. On June 22, 2020, Under Secretary of Defense Ellen Lord and DFC Chief Executive Officer Adam S. Boehler signed a Memorandum of Agreement (MOA) to implement EO 13922.

The Manufacturing Technology (ManTech) Program
The ManTech Program and National Manufacturing Innovation Institutes (MII) are designed to help anticipate and close gaps in manufacturing capabilities for affordable, timely, and low-risk development, production, and sustainment of defense systems.

The Warstopper Program
The Defense Logistics Agency's (DLA) Warstopper Program is the Department's primary industrial readiness program for consumable items in sustainment. The program is designed to incentivize industry to meet consumable sustainment requirements for which business would otherwise not support. The program had a proactive strategy for medical Personal Protective Equipment (PPE) items prior to the coronavirus pandemic; in 2014, the Warstopper Program made a significant readiness investment in N95 respirators, coordinated for 3M to rotate six million masks for DoD after the H1N1 virus. In the midst of the coronavirus pandemic, this strategy has proven to be a successful best practice, as DLA supported the production of ventilators, and worked with other federal organizations to mirror their strategy.

Protect

The *Protect* line of effort includes actions to protect the industrial base and to mitigate risks associated with counterfeit parts, supply chain security, cybersecurity, foreign dependence, predatory investment, industry consolidation, and a number of other factors that introduce risk to the DIB.

Foreign Investment Review
Within Industrial Policy, the *Protect* function is predominately carried out by the Office's Foreign Investment Review (FIR) team. FIR leads the Committee on Foreign Investment in the United States (CFIUS) reviews for DoD and acts as the principal advisor to the USD(A&S) on foreign investment in the U.S. This involves coordination across more than 30 DoD component organizations to identify, review, investigate, mitigate, and monitor foreign direct investment in the United States. FIR relies on DoD stakeholders for the technical expertise needed to analyze the threats, vulnerabilities, and consequences associated with foreign investment.

Predatory and adversarial investments can result in diminishing U.S. sources and expertise, and increasing foreign dependence and illegitimate technology transfer, thereby threatening U.S. military superiority. To address these risks, Congress passed the Foreign Investment Risk Review Modernization Act (FIRRMA), which updated the scope of CFIUS authority. Effective February 2020, FIRRMA provides the Committee with expanded authorities to review transactions related to critical technologies and infrastructure (including the DIB), sensitive personal data, real estate transactions, and joint ventures. A "non-notify" team, also part of FIR, is responsible for identifying transactions that were not voluntarily brought before the CFIUS process.

The statute also strengthens bilateral cooperation through "excepted foreign states", including the participating nations of the multilateral National Technology and Industrial Base (NTIB). Citizens from NTIB countries (Australia, Canada and the United Kingdom) do not need to file for minority investments or real estate transactions.

The Department also conducts Mergers & Acquisitions (M&A) activities, which review consolidations in the U.S. defense industrial base to assess related risks and impacts.

Technology Industrial Base Protection, Promotion, and Monitoring
Within TMIB, the Technology Industrial Base Protection, Promotion, and Monitoring team facilitates the creation of strategies to protect and promote the industrial base by mitigating risks and exploiting opportunities identified in *emergent technology assessments.* TMIB aims to establish balance between the protection of technology and promotion of the industrial base providing it. This balance aids the Department's advancement of critical and emergent technologies, while sustaining a healthy, resilient, and competitive industrial base.

Promote

To cultivate a robust, resilient, and innovative industrial base, the Department must maintain the current DIB and identify new participants and opportunities from domestic and international partners. As the lead for industry engagement for the USD(A&S), Industrial Policy facilitates dialogue and drives collaboration and communication between the DoD and global industrial bases. OUSD(IP) encourages increased international participation in the DIB, and facilitates government-to-government discussions on industrial policy with partners and allies.

Office of Small Business Programs (OSBP)
The OSBP promotes small business involvement in the DIB by maximizing prime and subcontracting opportunities that ensure our nation's small businesses remain responsive, resilient, secure, and diversified to directly support the DIB, the NDS, and a robust economy. For more information, see the Office of Small Business Programs section of this report.

International Outreach
OUSD (IP) and the Office of International Cooperation (IC) work closely with our international allies and partners to strengthen and diversify our DIB. Outreach efforts directly support the NDS, which aims to strengthen alliances and partnerships around the globe in support of our national security. OUSD (IP) routinely coordinates government-to-government dialogue with allies and partners on joint industrial base concerns and areas for potential collaboration. Two key areas of government-to-government outreach in FY2020 focused on enhancing key partnerships, including:

- The NTIB: OUSD (IP) efforts to seamlessly integrate the United States DIB with those of Australia, Canada, and the United Kingdom are ongoing. In FY2020, NTIB initiatives focused on maintaining the continuity of medical and defense supply chains.
- The United States-India Defense Technology and Trade Initiative (DTTI): In December 2019, Under Secretary Ellen Lord and Indian Secretary for Defense Production Subhash Chandra signed the DTTI Industry Collaboration Forum agreement to provide a mechanism for developing and sustaining an Indian-United States industry dialogue on defense technological and industrial cooperation.

Trusted Capital
The Trusted Capital program is an unfunded initiative that connects companies critical to the defense industrial base with vetted trusted capital providers. The Trusted Capital Marketplace is a forum to convene trusted sources of private

capital with innovative domestic companies that have been previously down-selected by the military services and operate in emerging technology sectors critical to the U.S. defense industrial base. This serves to strengthen domestic manufacturing by increasing access to critical technology while simultaneously limiting foreign access. For more information, see the Trusted Capital Program section of this report.

SECTION 4

INDUSTRIAL BASE COUNCIL

INDUSTRIAL BASE COUNCIL

The Industrial Base Council (IBC) is an executive-level forum, composed of senior three- and four-star level leaders, established to ensure industrial base readiness and resilience across the DoD. The IBC works to assess industrial base risk, leverage DoD-wide mitigation efforts, and develop policy to address and prevent critical risks. The IBC was created with four main goals:

1. Provide an aggregated assessment to Congress on DIB risk
2. Prioritize / align industrial base (IB) efforts to DoD's Strategic priorities
3. Leverage the full authorities of the DoD to act decisively to mitigate DIB risks
4. Develop policy and inform planning, programming, budgeting, and execution (PPBE) processes to address DIB vulnerabilities

The IBC is informed by the working-level Joint Industrial Base Working Group (JIBWG), comprised of subject matter experts in each industrial base sector (Figure 4.1). Interagency working groups and task forces bring emerging industrial base

Industrial Base Council Construct

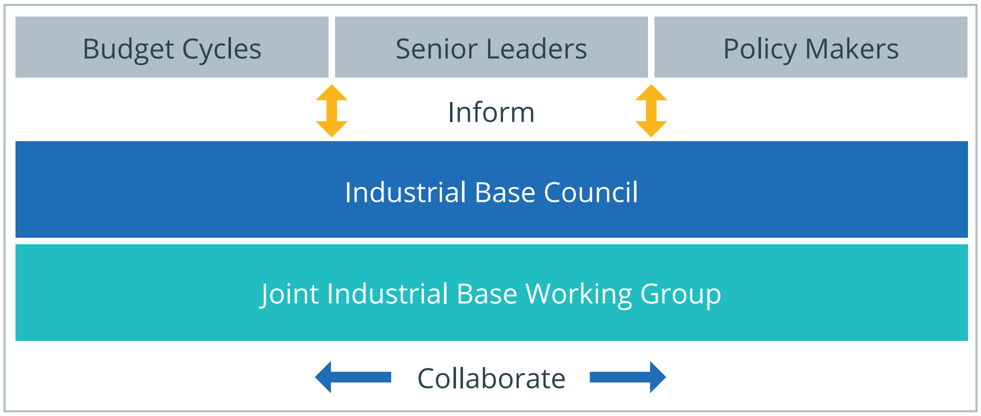


Figure 4.1

risks to the JIBWG for discussion and action. Risks and issues that require senior-level intervention are elevated to the IBC. The Council has leveraged the JIBWG's subject matter expertise and sector-based approach to mitigate and prevent systemic industrial base risk.

The IBC and COVID-19

To respond to the impact of the coronavirus pandemic on the U.S. industrial base and global defense supply chains, the IBC became a key decision-making body, working to manage DPA investments in response to the pandemic. In March 2020, the U.S. Congress passed the Coronavirus Aid, Relief, and Economic Security (CARES) Act, which appropriated $1 billion to the DPA Purchases account to prevent, prepare for, and respond to COVID-19. CARES Act funding decisions were all approved by the IBC after analysis and recommendation from the JIBWG.

SECTION 5

COVID-19 RESPONSE HIGHLIGHT

COVID-19 RESPONSE HIGHLIGHT

Introduction

The coronavirus pandemic poses a severe threat to essential industrial base capabilities, sources, and workforce skills. On March 2020, the President declared a national emergency and issued a series of Executive Orders covering nearly every DPA authority, including priority ratings and allocations (Title I), domestic production expansion and loans (Title III), and the formation of voluntary agreements among industry (Title VII).

In March 13, 2020, Congress appropriated $1 billion to the DPA Purchases account through the CARES Act; a two-fold increase from the combined total of the past decade. The program executed 46 awards in less than six months, compared to a historic program baseline of less than five new-start actions per year. The Department made a series of initial investments to improve supply chains and increase domestic production of health resources, such as N95 respirators and testing consumables.

The CARES Act also provided the Department of Health & Human Services (HHS) with authority and funding to increase domestic production of personal protective equipment (PPE) and other health resources. HHS focused its resources on healthcare investments, while the DoD allocated remaining Title III funds to mitigate COVID-19 impacts on the defense industrial base.

The DPA Title III program also provided critical support to HHS and the Department's Joint Acquisition Task Force (JATF) by right-sizing investments against COVID-19 requirements and overcoming obstacles to successful execution by the industrial base. The JATF and DLA also provided substantial assistance to HHS by increasing domestic production capacity and replenishing HHS's Strategic National Stockpile.

Spending Plans

In May 2020, the DPA Title III program submitted a spend plan for CARES Act investments to Congress and has provided subsequent weekly briefings on the plan's implementation. Of the $1 billion appropriated to the DPA Purchases account, the Department allocated approximately $676 million to defense industrial base risk mitigation, $213 million to healthcare sector investments, and $100 million to a Federal Credit Loan program in cooperation with the DFC.

The IBC reviewed subject matter input from across the Department and issued DIB investment decisions for Title III CARES Act funds. For healthcare investments, the Title III program forged partnerships with HHS and the Federal Emergency Management Agency (FEMA), quickly responding to both agencies' requests for assistance. As the Department's COVID-19 response activities became more complex, the Title III program also joined the JATF in supporting industrial base expansion and other interagency functions.

Although the Department did not issue any loans through the DFC loan program in FY2020, it expects to conclude several loan agreements in FY2021 and continue the program in FY2022.

Medical Industrial Base Case Study – Puritan Medical Product Company

Swabs are a key node in the logistics "chain" for COVID-19 testing, which stretches from swabs and PPE at the collection site to chemical reagents and test batteries at a laboratory facility.

In late April 2020, DoD entered into a $75.5 million (not-to-exceed) agreement with Puritan Medical Product Company ("Puritan") under DPA Title III. Pursuant to this agreement, Puritan will increase its aggregate production capacity for foam swabs by at least 20 million units per month, thereby doubling its production capacity.

With this award, Puritan Medical Products established a new swab manufacturing facility in Pittsfield, Maine, where it renovated 95,000 square feet of unused factory space and added more than 100 people to its workforce. Puritan realized initial production gains by June 2020, and exceeded production rate targets, established in their agreement with the Title III program, by the end of September 2020.

The U.S. government and Puritan accomplished this rapid production increase by coordinating supply chain activities on a nearly daily basis. Puritan, the Title III program, and the JATF engaged the Department of Commerce to apply priority ratings to industrial resources necessary for Puritan's production scale-up. When incumbent suppliers could not meet the need, DoD assisted Puritan with identifying alternative suppliers. The Title III program and the Department of State also assisted Puritan personnel and its subcontractors with overseas travel, so they could debug and accept automated production equipment.

Defense Industrial Base Case Study – eMagin Corporation

eMagin Corporation ("eMagin") is the leading domestic technology supplier of high brightness organic light emitting diode (OLED) microdisplays. eMagin's OLED microdisplays support DoD programs of record and ongoing requirements.

As the COVID-19 epidemic spread through the state of New York, eMagin and several of its suppliers were compelled to shut down operations for multiple weeks. The shutdown resulted in reductions in production and revenue, increases in the costs of goods sold, and cancellation of or delays in many of eMagin's customer opportunities into 2021.

DPA Title III investment at eMagin prevented the immediate loss of a critical DoD supplier, which would have been costly and difficult to reconstitute in a post-COVID-19 environment. eMagin will use DPA Title III funds to refurbish existing production equipment and purchase new equipment that will increase product yields, debottleneck production, and increase aggregate capacity.

This effort will enable the recipient to retain current staff put at risk by COVID-19 and will create 14 new jobs made up of engineers, maintenance technicians, and manufacturing personnel. It will also ensure the U.S. government maintains access to this critical domestic capability.

Defense Industrial Base Case Study – General Electric-Aviation

General Electric (GE) Aviation is one of two U.S. suppliers capable of producing large advanced combat engines. As part of the national response to the coronavirus pandemic, in support of the Propulsion defense industrial base, the DoD entered into a $20 million contract with GE Aviation to sustain critical industrial base capability for highly-specialized engineering resources.

GE Aviation will retain more than 100 highly-skilled and experienced design and mechanical engineers, preserving critical engineering skillsets and subject matter expertise. GE Aviation will accomplish this by expanding development in advanced manufacturing techniques (including additive manufacturing), promoting advanced material development, and improving digital engineering proficiencies. This will enable GE Aviation to retain critical workforce capabilities and sustain engineering positions put at risk by commercial aviation contraction during the pandemic.

SECTION 6

DEFENSE INDUSTRY OUTLOOK

DEFENSE INDUSTRY OUTLOOK

Characteristics of the Market/Overview

The Aerospace and Defense (A&D) sector declined in performance compared to the previous year. The decline in performance is due, in large part, to a downturn in the commercial aircraft sector, preceded by the following events of early 2020:

- Boeing's 737 MAX, formerly the largest commercial aircraft program in the industry by value, was decertified after two fatal crashes, which led to a production halt in January 2020. The production freeze disrupted the production and deliveries of 737 MAX parts from the suppliers, dramatically reducing revenue and production throughout the industry. These events eventually resulted in liquidity issues among suppliers due to work stoppages and restricted cash flow. Over 100 suppliers for the 737 MAX also provide parts and services for the DoD.
- The coronavirus pandemic further aggravated supply chain issues in the aircraft sector. The sector experienced significant challenges in maintaining and sustaining the health of the DIB, as a large number of defense suppliers experienced facility shutdowns, high absenteeism, furloughs, and financial instability. The decline in global air passenger traffic due to the coronavirus pandemic also threatens the viability of commercial airlines, aircraft manufacturers and their suppliers, and puts many jobs at stake.

The health of the aircraft defense industrial base will be inextricably linked to the recovery of the commercial aircraft industry, which could take three to five years to return to pre-COVID global passenger traffic. The U.S. A&D sector did not outperform the broader U.S. equity market in 2020, suggesting that investors are pessimistic about the overall health, profitability, and long-term prospects of the sector (Figure 6.1). The A&D sector averaged 2.2 percent of total Market Capitalization of the Dow Jones for the last six years.

The Big 6 Defense Suppliers

The largest six prime defense suppliers (Lockheed Martin, Boeing, Northrop Grumman, Raytheon, General Dynamics, and BAE Systems) are known collectively as the "Big Six" and represented 32 percent of all DoD prime obligations in 2019. They are also the largest companies globally by defense revenue. The Big Six thus provide a useful view with which to judge the overall health of the defense sector. The Big Six are financially healthy, continue to expand in market share, and have seen a general increase in revenue with a Market Capitalization Weighted Average Combined Annual Growth Rate (CAGR) of 5.6 percent from 2014-2019 (Figure 6.2).

Continued growth across the defense sector is further exemplified by the Market Capitalization Weighted Average of Revenue for the 25 Mid-Tier U.S. Defense Suppliers.[8] These 25 companies are a combination of U.S. and Foreign based suppliers to the DoD, based on prime obligations, as well as inclusion on the Defense News Top 100 list for 2020. These 25 companies represented nine percent of all DoD prime obligations in 2019. Average revenues for these companies reached approximately a quarter of the Big Six average revenues each year and generally increased with a Market Capitalization Weighted Average CAGR of 5.9 percent from 2014-2019 (Figure 6.2).

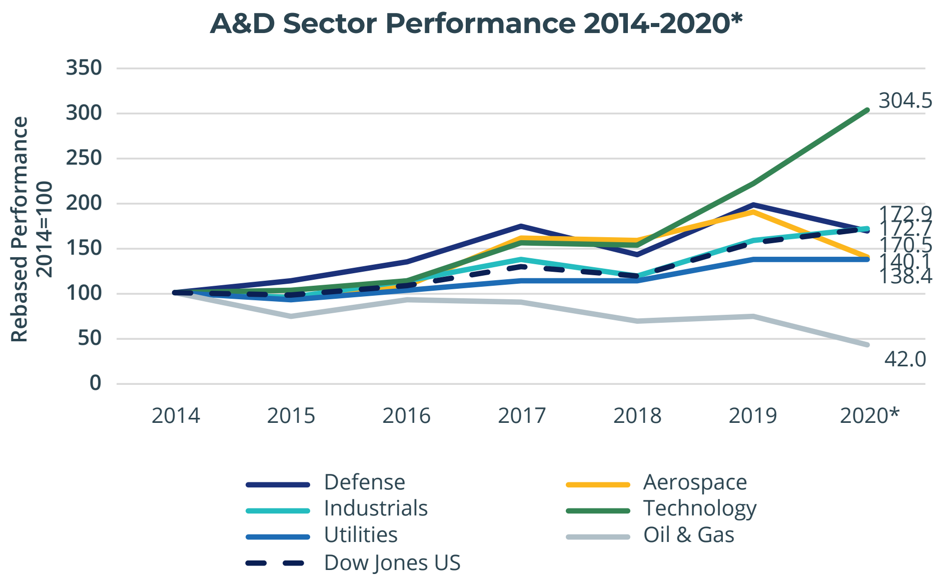


Figure 6.1: Stock Performance Trend by Market Sector [CY2014-CY2020*] (2014 Rebase) *2020 Performance as of November 16th 2020. Source: Refinitiv Eikon

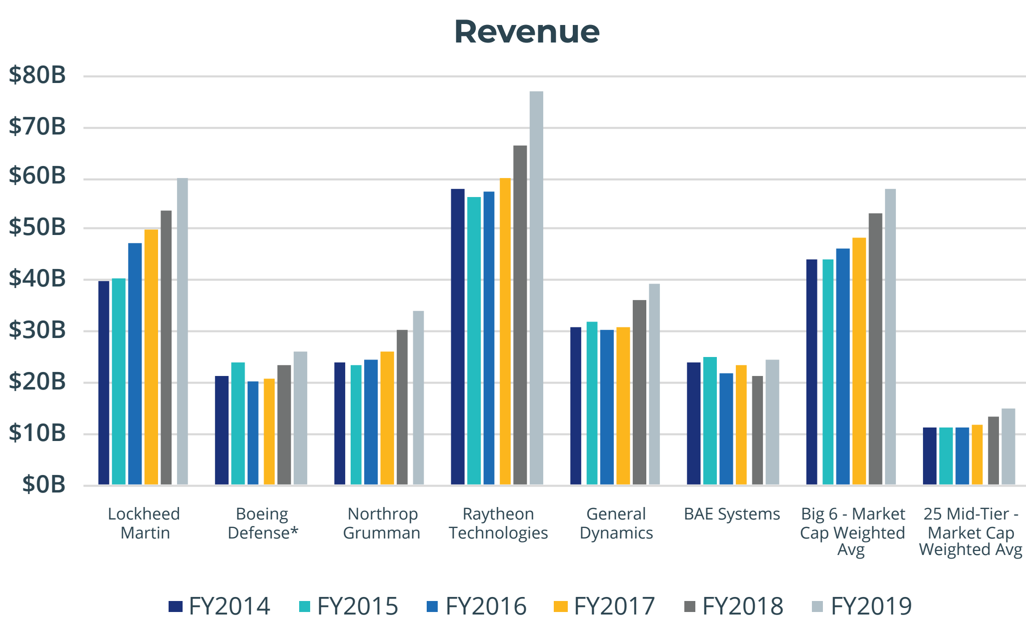


Figure 6.2: Big 6 DoD Primes Annual Revenue & 25 Mid-Tier Market Cap Weighted Avg Revenue [FY2014-FY2019] Source: Refinitiv Eikon
*Only Revenue for Boeing Defense Business Segment Displayed. The large increase in Raytheon revenues compared to prior years' reports is due to the merger between Raytheon and UTC. Historic revenues were compiled for the entities taking into account any divestitures by Refinitiv Eikon.

The Big Six are also profitable, showing positive Earnings Before Interest, Tax, Depreciation, and Amortization (EBITDA), though margins have varied by company over the last five years (Figure 6.3). Major defense suppliers saw, on average, a growing demand for their products and services within the last year, driving higher sales and greater scale and helping to reduce costs and boost competitiveness. The Boeing Defense Business Segment also helped to offset significant profit losses for the company in 2019 resulting from the Boeing 737-Max grounding. The 25 Mid-Tier Defense Suppliers also show consistent profitability, though at a lower Margin than the Big Six. The 25 Mid-Tier EBITDA Market Cap Weighted Average CAGR from 2014-2019 was 1.9 percent.

However, to maintain top line growth and mitigate the cyclicality of U.S. defense spending, some firms will continue to diversify their customer base by pursuing international and non-defense customers. Over the last several years, the Big Six maintained a relatively stable share of sales coming from outside the United States (Figure 6.4.a). Despite minimal change as a percent of total revenue, Big Six international sales increased at an annualized

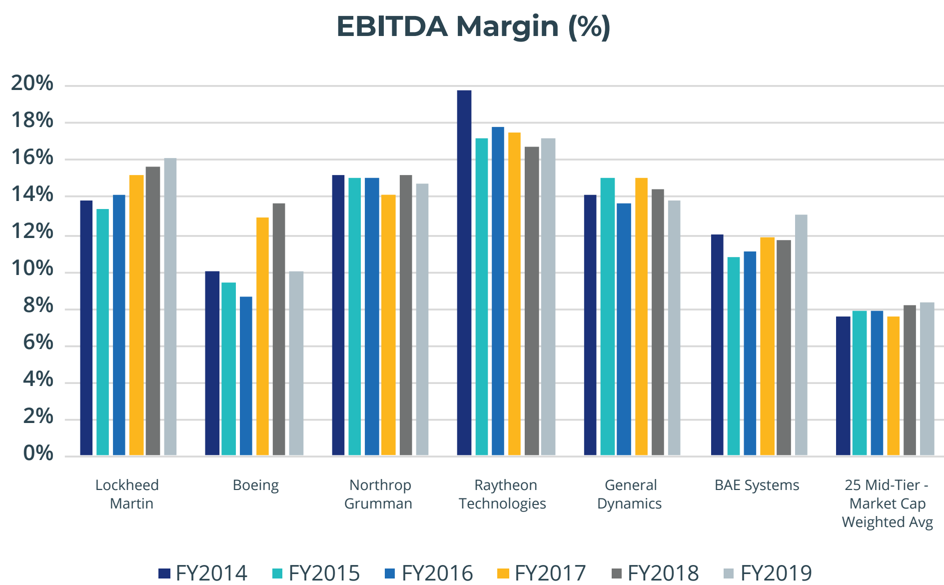


Figure 6.3: Big 6 DoD Prime & 25 Mid-Tier Market Cap Weighted Average EBITDA Margin [FY2014-FY2019] Source: Refinitiv Eikon

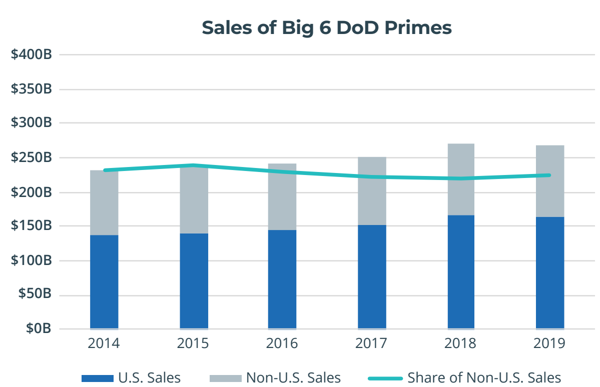


Figure 6.4.a Defense vs. Non-Defense Revenue for Big 6 Primes [FY2014-FY2019] Source: Refinitiv Eikon & Defense News Top 100

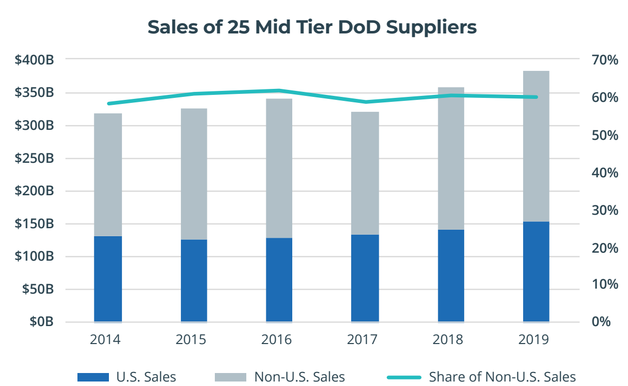


Figure 6.4.b Defense vs. Non-Defense Revenue for 25 Mid-Tier DoD Suppliers [FY2014-FY2019] Source: Refinitiv Eikon & Defense News Top 100

rate of 2.3 percent over the last six years. Non-U.S. Sales maintained a higher percentage of total sales for the 25 Mid-Tier Defense Suppliers, attributable largely to the inclusion of 12 foreign based defense suppliers in the list of 25 (Figure 6.4.b). Big Six and 25 Mid-Tier Defense Supplier sales in the U.S. increased at a similar annualized rate of approximately three percent since 2014. Non-U.S. Sales for the 25 Mid-Tier Suppliers were not as constant, but saw an annualized increase of 4.3 percent from 2014-2019.

Historically, the Big Six trended toward a rise in non-defense revenue. In 2019 the share of non-defense business revenue decreased for the Big Six, primarily due to Boeing's commercial sales losses resulting from the 737-Max grounding and historic business segment realignment following the merger of United Technologies and Raytheon (Figure 6.5).

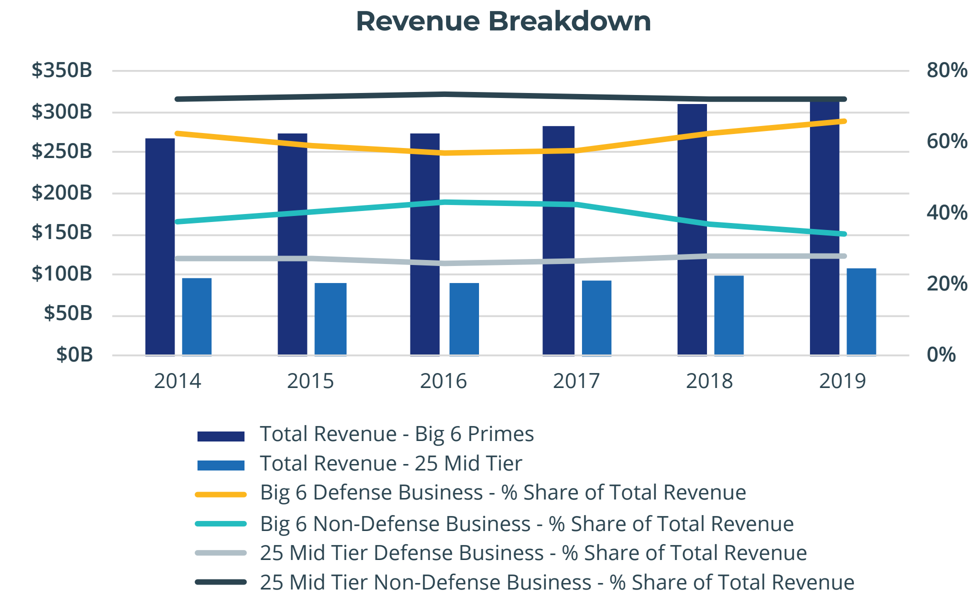


Figure 6.5: Defense vs. Non-Defense Revenue for Big 6 & 25 Mid-Tier Defense Suppliers [FY2014-FY2019] Source: Refinitiv Eikon & Defense News Top 100

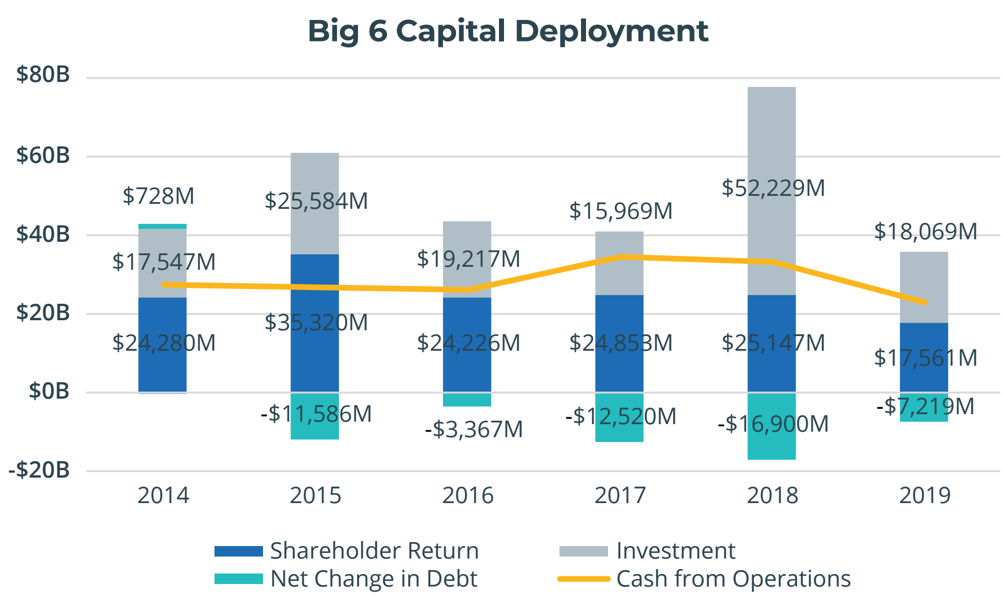


Figure 6.6: Capital Deployment of Big 6 Primes [FY2014-FY2019] Investment: Cash for Acquisition of Subsidiaries, R&D Expense, and CAPEX Shareholder Return: Dividends Paid, Decrease in Capital Stocks Net Change in Debt: Proceeds from Repayment of Borrowings Source: Bloomberg & Refinitiv Eikon

The Big Six continue to focus their capital deployment on Shareholder Return (Five Year CAGR: -6.3 percent) and Investment (Five Year CAGR: 0.6 percent). Investments hit a six year high in 2018 at $52.2 billion with firms investing largely in acquisition of subsidiaries, research and development, and capital expenditures. Investments in 2019 declined steeply to just over $18 billion following the finalization of several mergers (Figure 6.6).

Research & Development Spending

Globally, A&D companies are among the lowest R&D spenders compared to other critical sectors. The Big Six have spent on average 2.5 percent of their sales on R&D each year. The 25 Mid-Tier Defense Suppliers spent on average about half as much each year on R&D compared to the Big Six; although as a percentage of sales, they averaged slightly higher than the Big Six at around four percent of sales spent on R&D. A rebased trend plot shows that expenditures on R&D by the Big Six closely track DoD Research, Development, Testing, and Engineering (RDT&E) spending, while having little effect on the average R&D spending of the 25 Mid-Tier Defense Suppliers (Figure 6.7). This implies that the largest defense suppliers rely on the guidance provided by DoD to drive development of newer technologies and capabilities, while the Mid-Tier suppliers generally spend more of their revenues on further product development internally.

DoD RDT&E and DoD Supplier Avg Change in R&D Spend

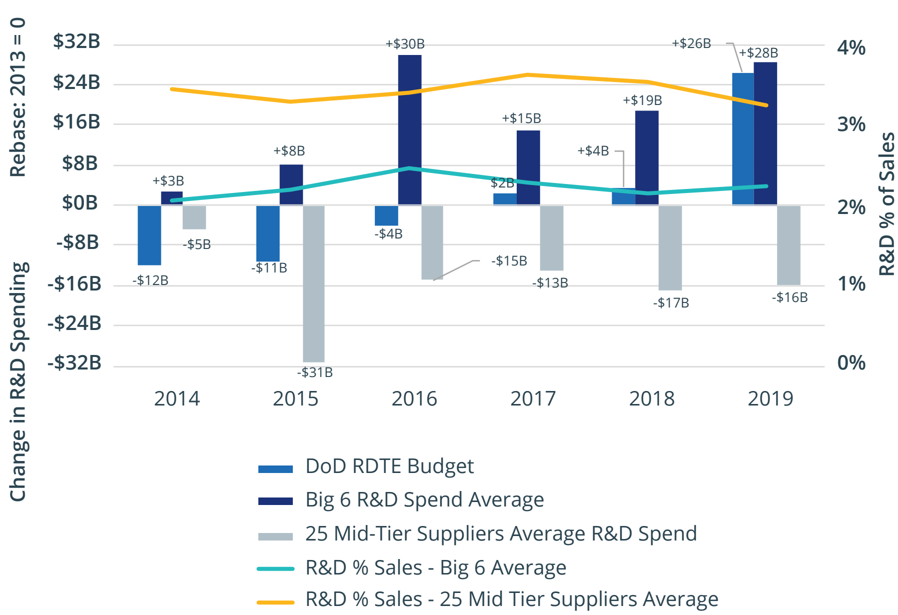


Figure 6.7: DoD RDT&E Budget Allocations; Big 6 Avg. R&D Spending; & 25 Mid-Tier Avg. R&D Spending (Rebased 2013) [FY2014-FY2019] Source: Refinitiv Eikon & DoD Budget

R&D by Country

The United States continued to lead the world in Gross Domestic Spending on R&D in 2019, although China is rapidly and consistently closing the gap with the United States. Meanwhile, the National Technology and Industrial Base, consisting of the United States, United Kingdom, Canada, and Australia, averaged just below $100 billion over the last nine years in combined GDS on R&D (Figure 6.8).

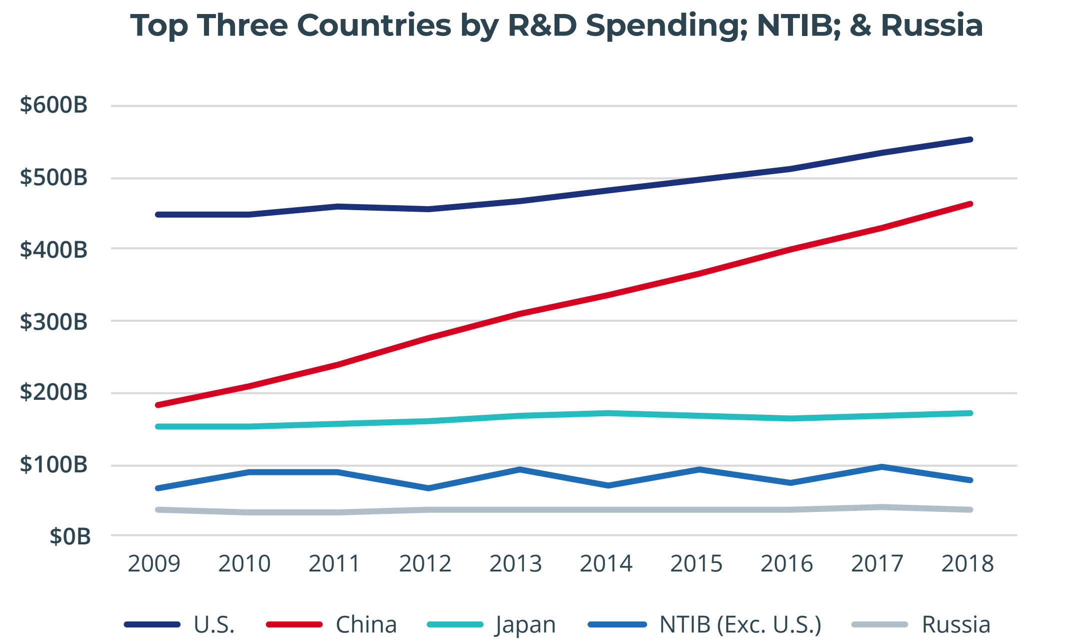


Figure 6.8: Top Three Countries, NTIB, and Russia by Gross Domestic Spending on R&D [CY2009-CY2018]
Source: OECD (R&D Data is Released on a 2-Year Lag)

R&D by Industry

The Technology sector primes known as the FAANG companies (Facebook, Amazon, Apple, Netflix, and Google) spend, on average, ten percent of their sales on R&D each year. Comparable to the characteristics of the markets (Figure 6.9), the average R&D spending by the Technology sector continues to outpace all other industries. Meanwhile the Aerospace sector decreased average R&D from 2016-2018. R&D spending appears to be trending up once again for the Aerospace sector in 2019 and consistently increased in the Defense sector from 2014-2019 (CAGR: 9.96 percent). The Dow Jones average spending on R&D continues to outperform the U.S. Aerospace and Defense sectors when compared as whole number averages.

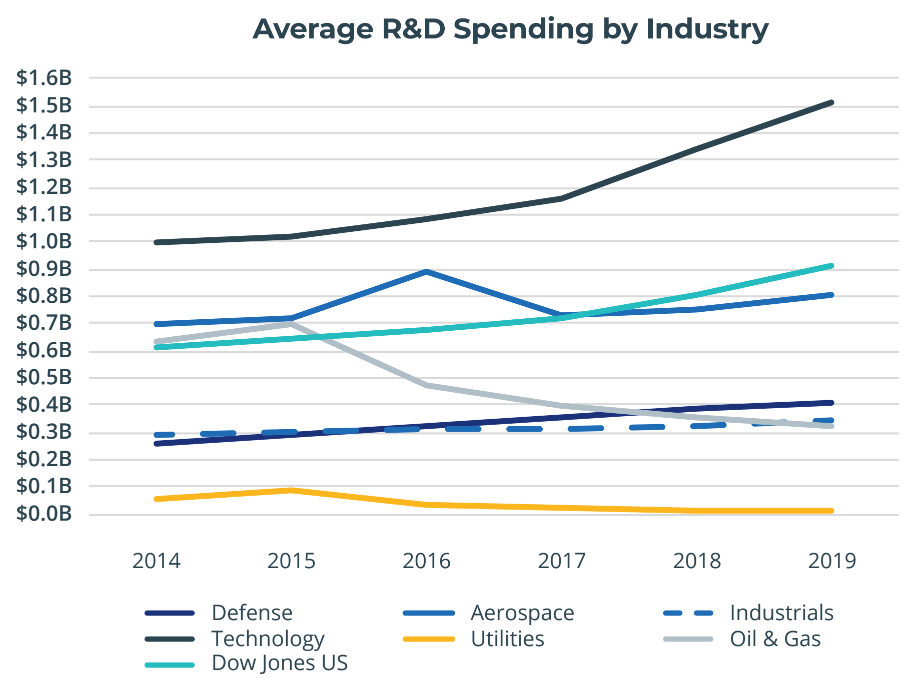


Figure 6.9: Average R&D Spending by Industry Utilizing Averages of Total Reported R&D Spending by Companies in Each Market Sector Source: Refinitiv Eikon

Global Military Spending

Global military spending continues to grow, expanding from $1.81 trillion in 2018 to $1.87 trillion in 2019 (in constant 2018 U.S. dollar value). The United States maintains its position as the largest purchaser of military goods and services in the world. Over the last decade, China established itself as the second largest purchaser of military goods and services, spending just over $266 billion in 2019. Combined, the NTIB countries, excluding the U.S., spent on average $96 billion each year from 2009-2019 on their militaries and defense related goods and services. Military spending grew in the rest of the world from $639 billion in 2008 to $793 billion in 2019, led by India, Saudi Arabia, France, Germany, Japan, and South Korea. Russia continued to maintain an average of $62 billion over the last ten years on their military spending (Figure 6.10).

U.S. Position in the Global Military Market

U.S. defense spending fluctuated over the last decade, seeing a 19.9 percent decrease from 2011-2017 and then rising 8.5 percent to its 2019 level of $718.7 billion. By contrast, China steadily increased its defense spending at an annualized rate of 14.3 percent over the past decade. The Chinese share of global military spending rose from 7.8 percent in 2009 to 14.2 percent in 2019, while the United States share of global military spending fell from 47.2 percent in 2009 to 38.4 percent in 2019 (Figure 6.11).

Global Trade in Arms

The United States and Russia remain the two largest exporters of arms in the world (Figure 6.12).
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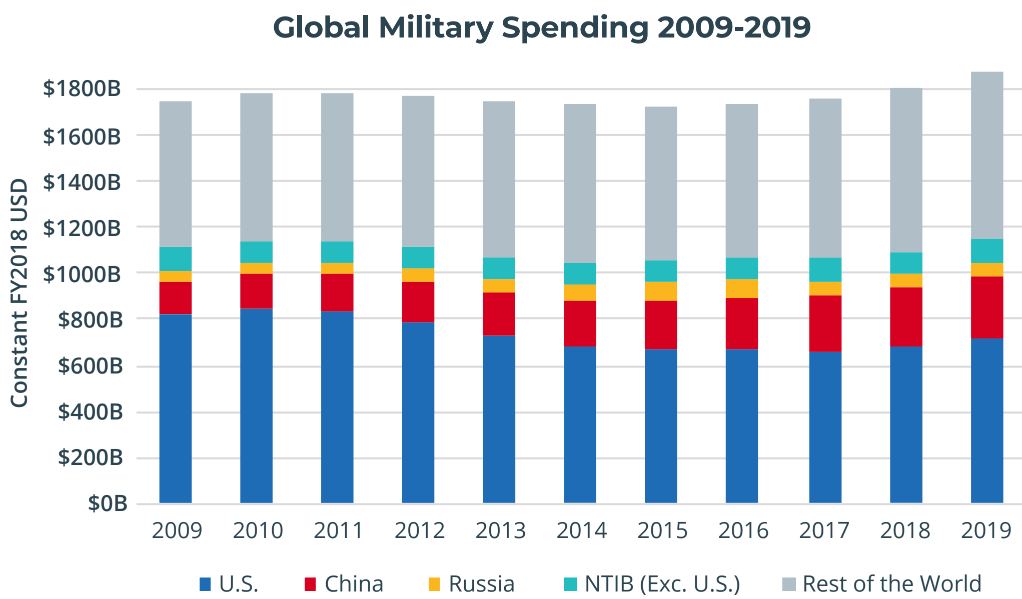


Figure 6.10: Global Military Spending (2018 Dollars) [CY2009-CY2019]
Source: SIPRI Military Expenditure Database

The United States increased its market share of Global Arms Exports from 28.3 percent in 2009 to 39.5 percent in 2019 (10 Year CAGR: 4.6 percent). Russian arms exports continue to trend downward contracting from 20.9 percent in 2009 to 17.3 percent in 2019 (ten Year CAGR: -0.7 percent). Finally, China's global arms exports market share remains relatively small despite its significant increase in defense spending, growing slightly from 4.7 percent in 2009 to 5.2 percent in 2019.

Saudi Arabia and India remain the two largest importers of arms in the world. Saudi Arabia, India, Australia, and the United Arab Emirates (U.A.E.) all increased market share of Global Arms Imported from 2009-2019, while China and Pakistan both decreased their market share for the same period (Figure 6.13).

Figure 6.11: U.S. & China Defense Spending and % of Global Defense Spending (2018 Dollars) [CY2009-CY2019] Source: SIPRI Military Expenditure Database

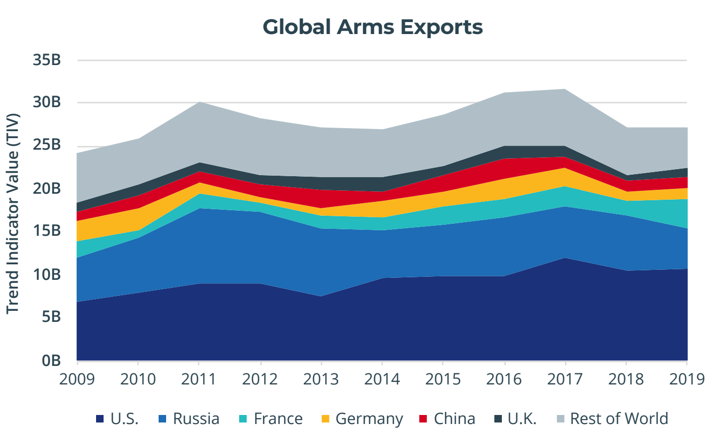


Figure 6.12: Global Arms Exports in Trend Indicator Value (Top 5 Countries) [CY2009-CY2019] Source: SIPRI Arms Transfers Database

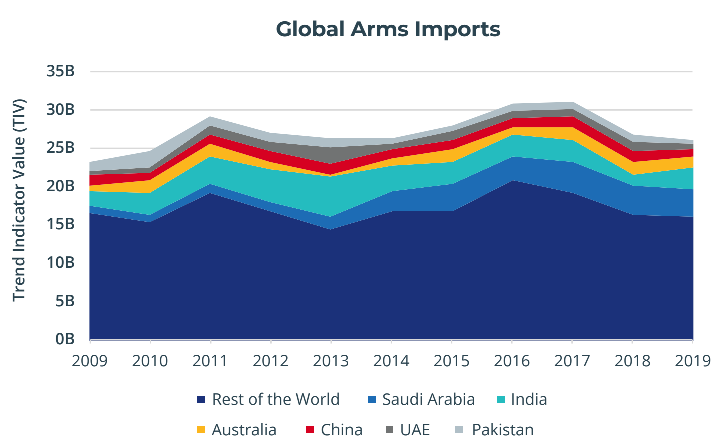


Figure 6.13: Global Arms Imports in Trend Indicator Value (Top 6 Countries) [CY2009-CY2019] Source: SIPRI Arms Transfers Database

U.S. Foreign Military Sales

U.S. Foreign Military Sales (FMS) remain inconsistent year to year, requiring the approval of military sales by Congress to foreign entities and the varying requests for military equipment from those entities. The U.A.E. and Australia purchased military equipment from the United States every year since 2011. Year to date (YTD) sales in 2020 were made to Japan, Australia, the U.A.E., Kuwait, and South Korea. Saudi Arabia in total value purchased the most military equipment from the United States over the last ten years totaling $139.1 billion (Figure 6.14).

Products from Lockheed Martin Corporation and Raytheon Technologies Corporation made up the largest share of U.S. FMS over the last several years. FMS in YTD 2020, however, saw a decrease for these two companies' products (Figure 6.15).

U.S. Foreign Military Sales (FMS) by Country

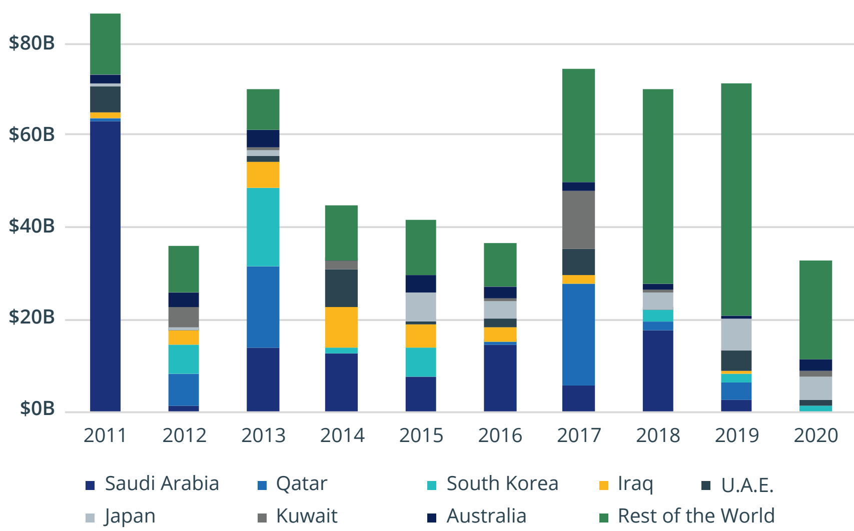


Figure 6.14: U.S. Foreign Military Sales (FMS) by Country (Top 8). [CY2011-CY2020YTD] Source: Bloomberg

U.S. Foreign Military Sales (FMS) by Company

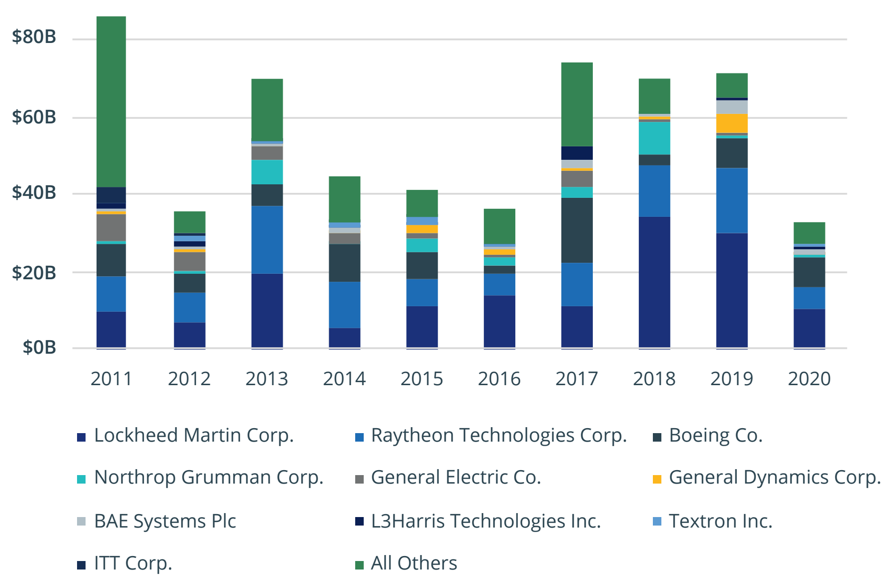


Figure 6.15: U.S. Foreign Military Sales (FMS) by Company (Top 10) [CY2011-CY2020YTD] Source: Bloomberg
* FMS sales reflect the historic combination of UTC and Raytheon for 2011-2019 and the actual reported FMS for the new entity Raytheon Technologies.

SECTION 7

SECTOR ASSESSMENTS

SECTOR ASSESSMENTS

Introduction

On July 21, 2017, President Donald J. Trump signed EO 13806 on "Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States." The EO directed the Secretary of Defense to conduct a whole-of-government effort to assess risks, identify impacts, and propose recommendations in support of a healthy manufacturing and defense industrial base. The findings were published in September 2018.

Since 2018, OUSD (IP) has continued to use the EO 13806 framework as a basis for identification and categorization of industrial base risks. However, the industrial base and supply chains are constantly evolving with new requirements, business entrants, and competitors in the defense sphere. As the DIB evolves, so do related risks.

The following section provides an assessment of industrial base gaps, vulnerabilities, and major developments within each of the traditional and cross-cutting sectors defined in the EO 13806 Report (see Table 7.1). The FY2020 DIB sector assessments identify both ongoing and short-term risks resulting from the coronavirus pandemic.

Priority gaps and vulnerabilities are also outlined in the Department's annual Unfunded Priorities List, which describes investment priorities identified across the traditional, cross-cutting, and emerging industrial base sectors, not included in the President's budget. Where the Department has identified concrete steps to address specific risks, this report provides recommended actions and investments. However, specific timelines for action depend on a variety of factors including; availability of funding, competing impacts from COVID-19 and other emerging requirements, and the extent of industry and international participation. Industrial base issues can rarely be addressed unilaterally, if ever, and must take into account both defense and economic considerations.

The sector assessments also include a sector outlook, which discusses emerging technologies and strategic competition within each sector. As OUSD (IP) and its interagency partners work to

Traditional Sectors	Cross-Cutting Sectors
• Aircraft • Chemical, Biological, Radiological, Nuclear • Ground Systems • Missiles and Munitions • Nuclear Matter Warheads • Radar and Electronic Warfare • Shipbuilding • Soldier Systems • Space	• Materials • Cybersecurity for Manufacturing • Electronics • Machine Tools • Organic Defense industrial base • Software Engineering • Workforce

Table 7.1 Traditional and Cross Cutting Industrial Base Sectors

correct existing vulnerabilities, the Department continues to identify emerging industries and technologies to provide for the needs of U.S. national defense now and in the future.

Aircraft

Sector Overview

The aircraft sector is categorized into three subsectors: fixed-wing aircraft, rotary-wing aircraft and unmanned aircraft systems (UAS) (Figure 7.2).

Fixed-Wing Aircraft	Includes fighters, bombers, cargo, transportation, and any manned aircraft that uses a set of stationary wings to generate lift and fly.
Rotary-Wing Aircraft	Includes those that use lift generated by rotor blades revolving around a mast. These aircraft are designed to operate in harsh battlefield environments, requiring robust, advanced capabilities and systems.
Unmanned Aircraft Systems (UAS)	Includes the necessary components, equipment, network, and system to control an unmanned aircraft. The unmanned aircraft systems' industry ranges from bird-size to 100+ foot wingspans. Unmanned aerial vehicles (UAVs) typically fall into one of six functional categories: target and decoy, reconnaissance, combat, logistics, R&D, and civil/commercial. The growing demand for increasingly sophisticated and versatile unmanned systems reflects the warfighter's need for intelligence, surveillance, and reconnaissance support that can reduce risk to combat forces and associated deployment costs.

Figure 7.2

Aircraft prime contractors and suppliers often rely on revenues from both defense and commercial customers. For example, Boeing's share of revenue from the U.S. government was around 24 percent between 2016 and 2018 and it sharply increased to 30.5 percent and 33.9 percent in 2019 and 2020, respectively.[9] A list of U.S. military aircraft by prime contractor (fixed-wing, rotary, and UAS) are listed in Figure 7.3.

Commercial aviation customers typically bring in large-volume orders and stable demand forecasts over longer terms than the government's future year defense program (FYDP) planning process. The suppliers often share their internal resources such as equipment, buildings, and human resources between commercial and defense work to optimize overhead cost and production efficiency. As such, demand from commercial customers is essential to support and sustain manufacturers and suppliers within the defense industrial base.

Subsector	Prime Contractor	Aircraft Type by Service		
		Army	Navy & USMC	Air Force
Fixed-Wing	Boeing		F/A-18 Hornet/Super Hornet P-8 Poseidon EA-18G Growler E-6 Mercury AV-8B Harrier II	A-10 Thunderbolt II B-52 Stratofortress B-1 Lancer C-17 Globemaster III E-3 Sentry Command Post F-15 Eagle KC-46 Pegasus VC-25 T-7A Red Hawk
	Lockheed Martin		F-35B/C Lightning II P-3 Orion/ARIES	C-130 Hercules / Compass Call F-16 Fighting Falcon F-22 Raptor U-2 Dragon Lady F-35A Lightning II C-5 Galaxy
	Northrop Grumman		E-2D Advanced Hawkeye	B-2 Spirit B-21 Raider E-8 Joint STARS
	Various	C-12 Huron		

Subsector	Prime Contractor	Aircraft Type by Service		
		Army	Navy & USMC	Air Force
Rotary-Wing	Airbus	UH-72A Lakota	UH-72A Lakota	
	Bell Boeing		CMV/MV-22B Osprey	CV-22B Osprey
	Bell Textron		AH-1Z Viper UH-1Y Venom	
	Boeing	AH-64 Apache CH-47 Chinook		MH-139 Grey Wolf
	LM-Sikorsky	UH-60 Black Hawk VH-60N White Hawk,	MH-53E, CH-53D/E/K H-60 Seahawk / Knighthawk VH-92 VH-3D Sea King	HH-60 Pave Hawk

Subsector	Prime Contractor	Aircraft Type by Service		
		Army	Navy & USMC	Air Force
UAS	Aerovironment	RQ-11 Raven	RQ-12A WASP	RQ-20 Puma
	Boeing		RQ-21 Blackjack MQ-25 Stingray	
	FLIR	Black Hornet 3		
	General Atomics	MQ-1C Gray Eagle		MQ-9 Reaper
	Lockheed Martin			RQ-170 Sentinel
	Northrop Grumman		MQ-4C Triton MQ-8B/C Fire Scout	
	Textron	RQ-7B Shadow		

Figure 7.3

Major Risks & Issues

Risk Archetypes

- Foreign Dependency
- Fragile Supplier
- Product Security

Downturn of Commercial Aviation

In FY2019, the aircraft sector was considered one of the strongest and most stable sectors; the sector exhibited growing demand in the commercial aircraft sector and stable defense demands until two significant events occurred consecutively in early 2020.

- Boeing's 737 MAX, formerly the largest commercial aircraft program in the industry by value, was decertified after two fatal crashes, which led to a production halt in January 2020. The production freeze disrupted the production and deliveries of 737 MAX parts from the suppliers, dramatically reducing revenue and production throughout the industry. These events eventually resulted in liquidity issues among suppliers due to work stoppages and restricted cash flow. Over 100 suppliers for the 737 MAX also provide parts and services for the DoD.
- The COVID-19 outbreak further aggravated supply chain issues in the aircraft sector. All three aircraft sub-sectors faced significant challenges in maintaining and sustaining the health of the DIB due to a large number of defense suppliers experiencing facility shutdowns, high absenteeism, furloughs, and financial instabilities.

Small Unmanned Aircraft Systems (sUAS)

The small UAS class applies to UAS that have maximum gross takeoff weight of less than 20lbs with normal operating altitude less than 1,200ft above ground level and airspeed less than 100 knots. As of early 2020, there were five U.S. companies in the top ten of U.S. sUAS market share holders. However, the combined market share of the five companies was only eight percent, while a single foreign company held 77 percent of the U.S. sUAS market share.[10] In recent years, many sUAS manufacturers in the U.S have either exited the consumer market or been consolidated into a fewer number of entities.

In the FY2020 DoD budget, both procurement and RDT&E budgets for UAS programs were approximately $3.2 billion in total. Approximately $153 million was allocated to sUAS programs. The DoD's annual budget for sUAS was less than four percent of the U.S. small drone market size of $4.2 billion in 2020, indicating that the U.S. small drone market is predominantly driven by commercial interests. As such, it is critical that the DoD work with the commercial sUAS industry to develop new and advanced UAS that could benefit both commercial and defense sectors and to quickly adopt commercially available systems that meet DoD requirements.

Approximately $13.4 million was awarded to sUAS suppliers under Defense Innovation Unit's (DIU's) Commercial Solutions Opening using the funds authorized and appropriated under the CARES Act. The DPA Title III efforts will allow five domestic sUAS suppliers to build sUAS components and software to keep the domestic sUAS industrial base healthy and competitive with foreign sUAS producers. The DIU specializes in accelerating adoption of leading commercial technology throughout the military and growing the national security innovation base.

The DIU has also awarded contracts totaling $11 million to six sUAS companies in 2019 and hosted an event called Blue sUAS Demonstration Day in August 2020, where five of the six companies presented cybersecure sUAS products. The Blue sUAS platforms were approved through a cyber-security vetting process and made available for purchase by any government agencies through the GSA schedule in September 2020. Although there are sUAS options that the DoD can safely procure and operate, there are still supply chain risks to be mitigated. An analysis of the bill of materials from four randomly selected U.S. sUAS platforms that meet the DoD requirements revealed that certain components rely heavily on Chinese suppliers.

Fuselage structures (e.g. carbon fiber or plastic frames), electric motors (e.g. Neodymium Iron Boron magnets) and printed circuit board (PCB) were the top three component categories that had the most reliance on parts from China (Figure 7.4). The DoD is continuously working on efforts to identify and mitigate supply chain risks within the sUAS industrial base.

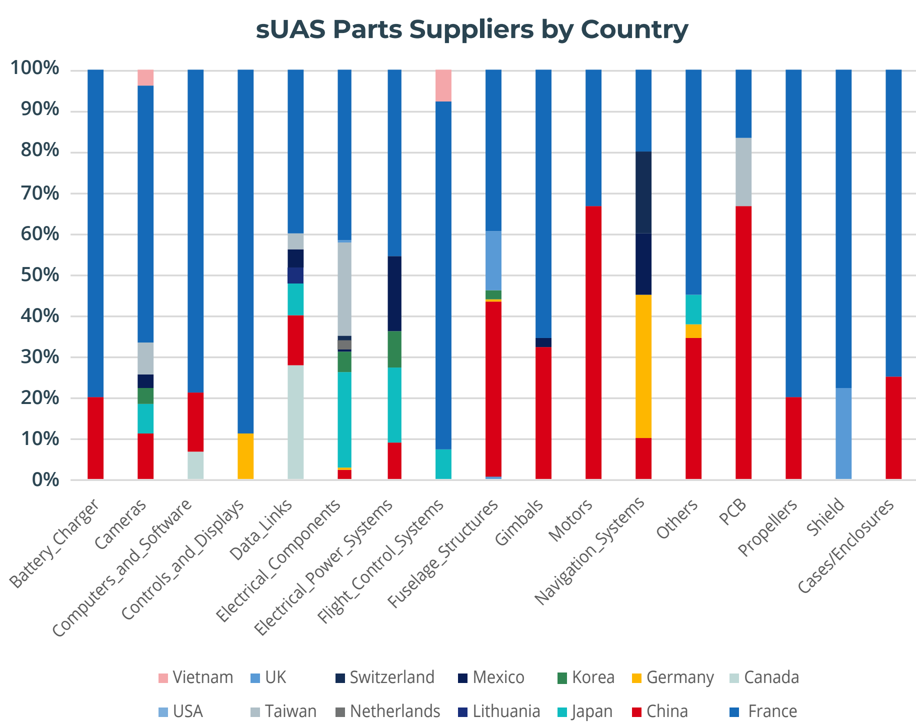


Figure 7.4: sUAS Parts Suppliers by Country

COVID-19 Impacts

Since the shutdowns in March 2020 caused by the outbreak of the coronavirus pandemic, commercial airline demand has decreased significantly. In May 2020, the airline demand declined by 91.3 percent from the previous year.[11] The downturn in the commercial aircraft market has placed numerous defense suppliers in financially difficult situations. The prime defense contractors such as Boeing (reducing by 30,000 employees by the end of 2021), Raytheon (by 20,000 employees), and GE (by 13,000 employees), have announced their plans to lay off and/or furlough their workforce. The commercial workforce is impacted the most by these actions, but there will likely be cascading impacts to the DoD, including an increase in overhead cost and loss of engineering skills and knowledge.

The DoD has made several efforts to protect the critical defense industrial base, including increasing progress payments, exercising option clauses in the current contracts, and awarding DPA Title III contracts using CARES Act funds.

FY2020 Developments

Budgetary Impacts

Overall, the DoD aircraft procurement budget for FY2020 - FY2024 is stable (Figure 7.5).

A surge of funding is anticipated in FY2025-2027 due to the likelihood of the B-21 and the Future Vertical Lift programs entering production and the F-35 and the T-7A programs in peak procurement.

A decline in procurement funding is anticipated after FY2029 due to a scheduled decline in aircraft production and likely transition to the development of 6th generation aircraft, cargo aircraft, and fighter drones.

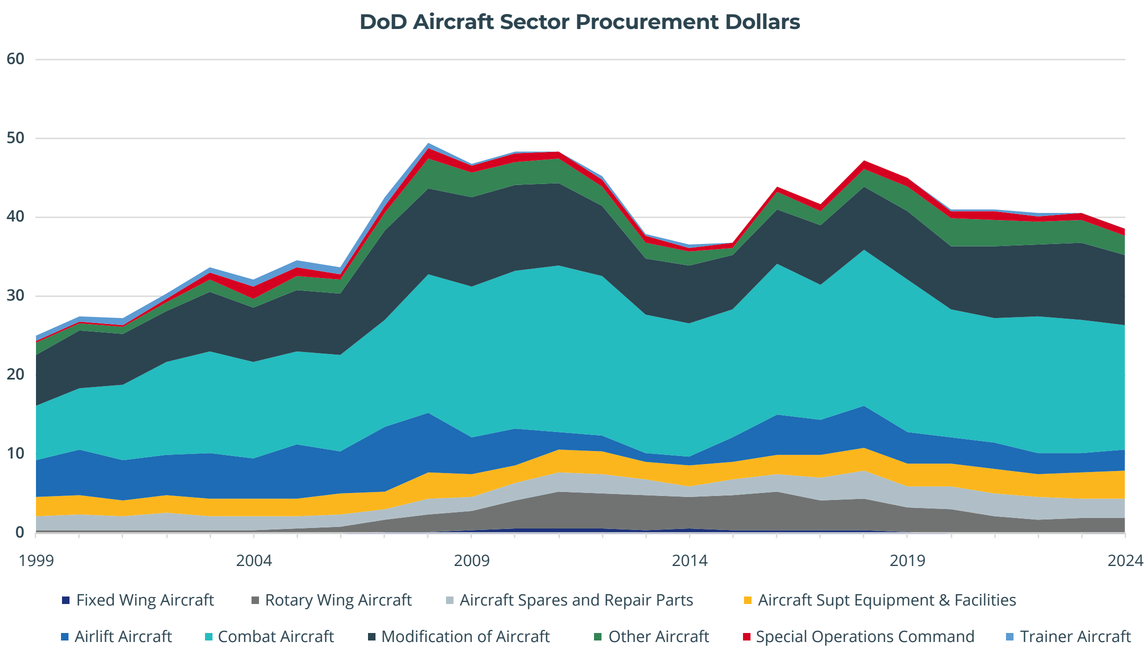


Figure 7.5: DoD Aircraft Sector Procurement Budget by Year

The RDT&E investment from FY2019 to FY2024 will decrease by approximately 45 percent due to aircraft funding moving from development to production (Figure 7.6). In FY2025, the RDT&E budget is forecasted to increase slightly above the 1999 level for programs such as 6th generation tactical aircraft, unmanned fighter, and new cargo aircraft.

The UAS sector will experience an anticipated 64 percent decrease in the RDT&E budget from FY2019 to FY2024 (Figure 7.7). However, the budgets for Counter Unmanned Aircraft Systems programs are likely to grow in the next several years.

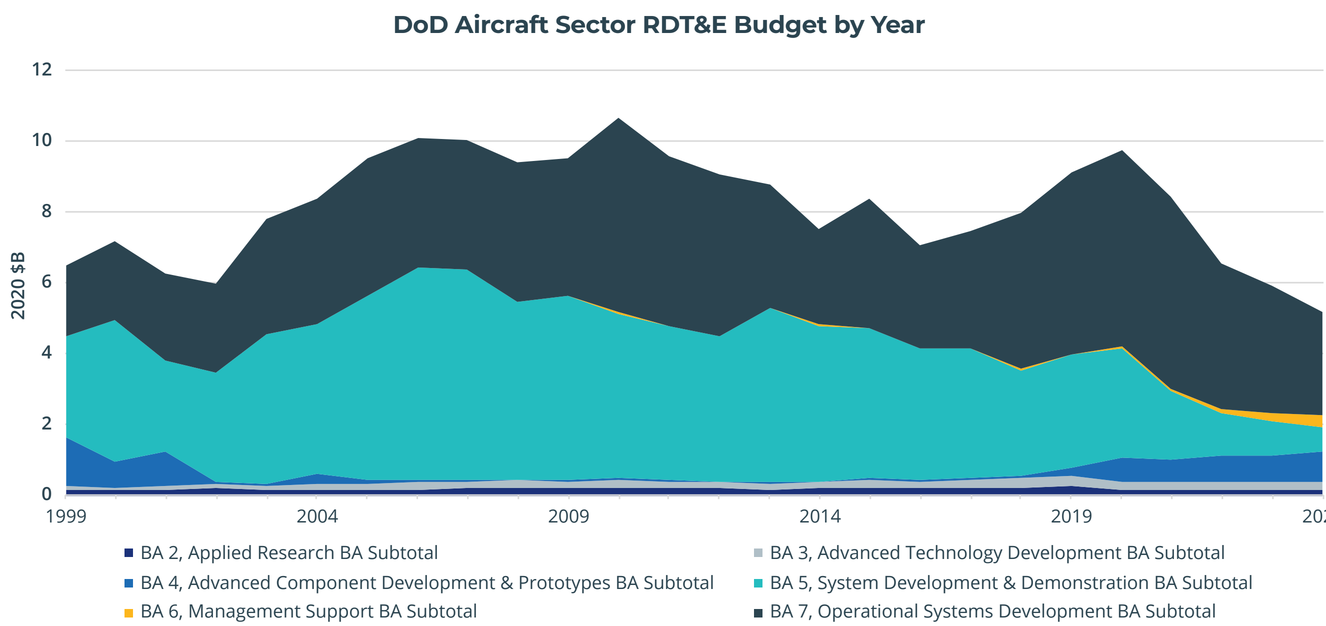


Figure 7.6: DoD Aircraft Sector RDT&E Budget by Year

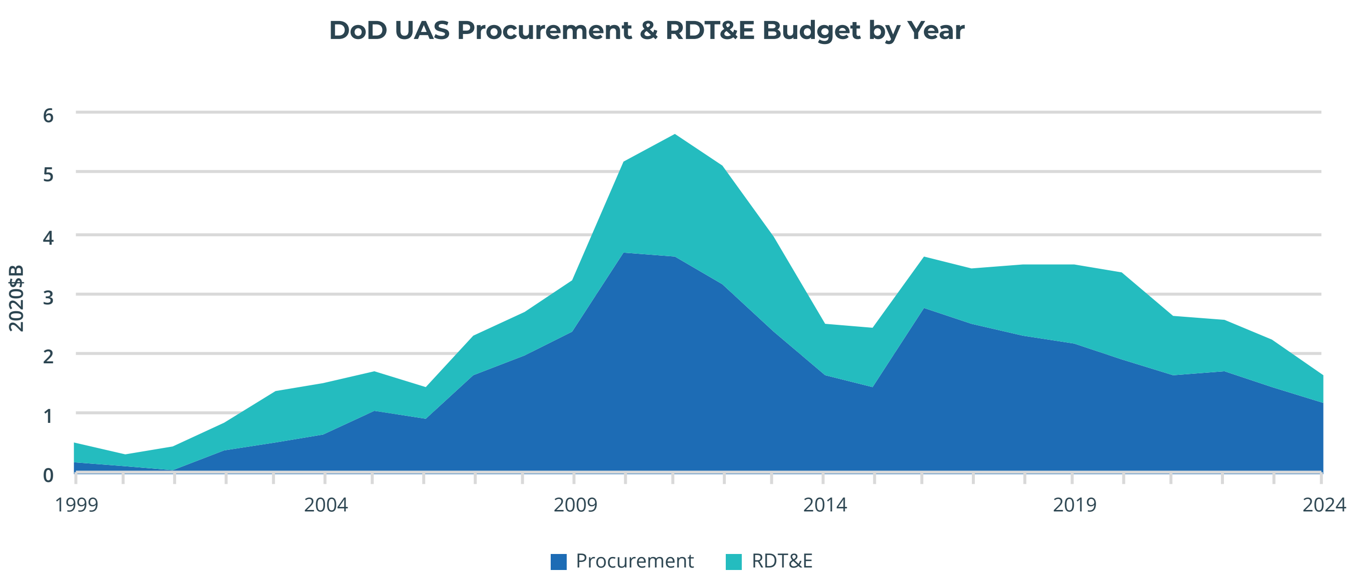


Figure 7.7: DoD UAS Procurement & RDT&E Budget by Year

Mergers and Acquisitions (M&A)

The Aerospace and Defense sector experienced a significant decline in deals, volume, and, value in FY2020. Three of the four biggest M&A transactions in FY2020 (i.e. Raytheon/United Technologies Corporation: $33.17 billion, Cobham/Advent International: $5.23 billion, and Collins/BAE: $1.9 billion) were carry-overs from FY2019, and an additional deal between Hexcel and Woodward ($7.74 billion) was mutually terminated after the COVID-19 outbreak.

Sector Outlook

Emerging Technologies

The DoD continues to track emerging threats and opportunities within the sector. Some of the fastest growing, game-changing technologies, including artificial intelligence, autonomy, additive manufacturing, and advanced robotics, could become key enablers for the sector and next generation of fighters, including both manned and unmanned systems. The U.S. Air Force has launched programs such as Skyborg, to build an artificial intelligence-enabled drone wingman, and Agility Prime, to accelerate the commercial market for advanced air mobility vehicles (i.e., flying cars). The DoD also has on-going efforts to increase its organic industrial base capabilities by integrating additive manufacturing, automation, and advanced robotics into depots.

Aviation's Recovery

The health of the aircraft defense industrial base will be inextricably linked to the recovery of the commercial aircraft industry. Many industry experts anticipate it will take at least three to five years for the airline industry to return to pre-COVID global passenger traffic.[12] Due to the downturn of the commercial aviation industry, suppliers may choose to downsize their production capacity by closing facilities or not operating equipment and machines. This in turn can potentially create supply chain bottlenecks, especially when airline passenger traffic numbers improve and the aircraft original equipment manufacturers start increasing order quantities again.

Chemical, Biological, Radiological, Nuclear Defense (CBRND)

Sector Overview

The CBRND sector of the DIB integrates science, engineering, testing, and logistics to field products that provide protection from chemical, biological, radiological, and nuclear (CBRN) threats and attacks. The 2017 NSS emphasized the importance of this sector in implementing critical capabilities to counter hostile states and terrorist groups increasingly trying to acquire CBRN weapons.

The Department of Defense Chemical and Biological Defense Program's (CBDP) mission is to enable the Warfighter and first responders to deter, prevent, protect, mitigate, respond, and recover from CBRN threats and attacks as part of a layered, integrated defense. To support this mission, the CBDP industrial base sustains the capabilities needed to support the three strategic readiness goals:

1. Equip the force to successfully conduct military operations to prevent, protect, and respond to CBRN threats.
2. Develop new capabilities to counter emerging CBRN threats.
3. Maintain industrial capabilities to achieve NSS requirements.

The sector is composed of commercial and organic industries that support a niche market heavily dependent upon DoD procurements for sustainability and new technology development. The sector is an aggregate of capabilities that are required to provide technical products in the areas of:

- Medical countermeasures to address CBRN and emerging infectious diseases,
- Protection for the Warfighter through respirators, masks, decontamination kits, etc.,
- Contamination avoidance through development and use of sensors, monitors, and detectors,
- Information systems that consist of integrated early warning, hazard prediction models, consequence management, and decision support tools,
- Rapid development and acquisition of crucial CBRND technology for the survival and unimpeded employment of special operations forces in toxic environments.

Major Risks and Issues

Risk Archetypes

- Erosion of U.S.-based infrastructure
- Capacity-constrained supply market
- Single source

The case studies below, covering a subset of CBRND products and organic industrial capabilities, illustrate how a capacity-constrained supply market and the erosion of U.S.-based infrastructure can potentially result in gaps within the sector. These gaps may lead to limited or non-existent domestic industrial capabilities necessary to protect the Warfighter and achieve NSS requirements. The case study summaries are based on analyses conducted during FY2020.

Joint General Purpose Decontaminant for Hardened Military Equipment (JGPD-HME)

JGPD-HME is an Acquisition Category III Joint Services program military decontaminant kit. JGPD-HME consists of three powdered components packaged in individual pouches. There is currently one single qualified commercial source of supply for JGPD-HME capable of producing all three components of the kit. Supply chain or manufacturing issues at the contractor level can lead to a single point of failure for JGPD-HME procurement.

The U.S. government has full technical data package rights and is standing up production capability at Pine Bluff Arsenal (PBA). First article samples for two of the three powdered components are being tested in quarter one of FY2021. PBA does not currently possess the capability to produce the third component, and has entered into a contract with the current manufacturer for a two-year supply, with the potential for additional sales beyond that timeframe. PBA is developing a pilot scale production process for the component, and anticipates their production process to be qualified within the two-year timeframe. Until PBA's production methods for all three components have been fully qualified, there will continue to be a dependency on a single source of supply for part of the kit.

Organic Industrial Base: Pine Bluff Arsenal CBRND Center of Industrial and Technical Excellence (CITE)

The PBA Arsenal directly supports numerous Joint Force readiness requirements by providing manufacturing, depot repair, and stock management of CBRND equipment and materials. Fluctuations and inconsistencies in CBRND workload and demand projections degrade the ability to sustain current capabilities and capacities, and develop capabilities for future requirements. Fluctuating demand is caused by various factors, including infrequent or inconsistent government purchases, which can cause production lines to shut down or require supplemental backing between orders. An example of this is a nerve agent antidote maintained with the DLA Warstopper program. The Department cannot afford to lose the capability, even if there are no orders at this point in time. These fluctuating demands limit the ability to surge or respond quickly to CBRND requirements. In response to these fluctuating demands, PBA is in the process of restoring metalworking and welding capabilities, as well as entering into a Public Private Partnership (PPP) with a contractor to strengthen the production of the defense industrial base.

Organic Industrial Base: DEVCOM Chemical Biological Center (CBC) Edgewood Engineering Directorate Test Laboratories

DEVCOM CBC Edgewood Engineering Directorate Test Laboratories test chemical and biological defense products against a variety of dangerous chemical and biological agents and toxic compounds. The Center performs testing on systems and products, such as individual and collective protection, contamination avoidance, decontamination materials, and component and systems testing. After an initial shutdown period in March 2020 due to COVID-19, the majority of the Engineering Directorate Laboratories developed and implemented procedures allowing a return to work with no lost test capabilities. For these capabilities, the biggest impact has been a slower turnaround time due to lower workforce numbers allowed on-site. Other factors affecting test capabilities include travel restrictions, required direct personnel contact, and concerns of health risks associated with large chamber operations. Efforts are underway to continue to analyze and determine the COVID-19 risks associated with these operations.

This niche sector is also highly dependent on single and sole source manufacturers, which is common in the smaller, highly technical industrial base sectors. In many scenarios, this constraint can be directly attributed to deleterious U.S. government procurement practices, inconsistent funding and demand signals, and eroding manufacturing capabilities and the associated workforce. However, the primary constraint rests in DoD barriers that restrict entry into the industry and present qualification challenges, limiting competition within the base. When items are needed quickly, smaller companies (or those unfamiliar with the government procurement process) will struggle to compete. Procurement lead times, which can span to 18 months, discourage many small and non-traditional DoD businesses from entering into competition for CBRND products. This is a challenge because CBRND is a niche sector that depends on small businesses as important suppliers.

FY2020 Developments

During FY2020, there have been two policy and partnership developments within the CBRND Sector. First, the coronavirus pandemic necessitated a redesign of the federal and commercial CBRN testing laboratories certification process and policy. Second, PBA, in alignment with the CBRND CITE core competency requirements, established a PPP with a contractor for onsite production of CBRN large filters.

Laboratory Certification Process Redesign

The Quality Assurance (QA) branch of DEVCOM CBC is responsible for providing laboratory certification for both government and commercial CBRN testing laboratories. The onset of the coronavirus pandemic, and associated travel and health condition restrictions, constrained the ability of the QA branch to perform onsite laboratory certification. The affected customer base encompassed the DoD Shelf Life Program, Joint Program Executive Office Enterprise, and the Tank and Automotive Command (TACOM) Chemical Biological Directorate. The pandemic restrictions required the QA branch to redesign the process and policy. The QA branch, in collaboration with the customer base, developed a virtual laboratory certification process and policy. The virtual process has enabled effective risk management to ensure Warfighters and First Responders are issued conforming products. The versatility of the process has empowered the QA branch to continue supporting the DoD's CBRN program and the security of the nation.

Pine Bluff Arsenal CBRND CITE – Public Private Partnership

The organic industrial base CBRND CITE, PBA, has increased its efforts to provide a rapid capability response to any volatile supply chain challenges. The newly established PPP between PBA and a CBRN filter contractor leverages the technical capabilities of PBA's existing large filter production line and skilled workforce. The PPP filter production will occur during the night shift using contractor supplied metal frames and parts, with normal PBA filter production workload continuing during the day shift to ensure filter availability for national defense.

Sector Outlook

The coronavirus pandemic has impacted all sectors of the defense industrial base. For the CBRND Sector, this has manifested in an increased global demand and strain on supply chains for protective equipment. CBRND manufacturers have risen to the challenge and continued production in the midst of these challenges, yet the sector continues to find itself in a precarious position with a reliance on single and sole source providers for many products. It is imperative that the DoD proactively continues to manage the critical asset of PBA in order to provide improved capabilities to counter current and emerging CBRN threats.

Cybersecurity for Manufacturing

Sector Overview

The cybersecurity for manufacturing sector includes information and operational technology within contractor factories and across defense manufacturing supply chains.

Defense manufacturing supply chain operations rely on an immeasurablenumber of touch points where information flows through a network – both within and across the many manufacturers' systems that constitute the supply chain. Every one of these supply chain touch points represents a potential vulnerability to the security of our nation's defense production.

According to data released in late 2019 by the U.S. Census Bureau, approximately 291,000 manufacturing establishments operate in the United States.[13] Nearly 99 percent of those establishments are small and medium-sized manufacturers (SMMs) with fewer than 500 employees. Multiple data sources indicate that most SMMs are unprepared to deal with a cyber-attack. This problem is acute within defense manufacturing supply chains, where SMMs—often lacking basic cyber controls— constitute the bulk of the critical lower supply chain tiers.[14]

Most information that is generated, stored, and exchanged in the DIB is not classified. The protection of such unclassified, covered defense information, or CDI (including controlled unclassified information (CUI)), presents an enormous and complex challenge. Thirty-five percent of all cyberespionage attacks in the U.S. are targeted at the manufacturing sector.[15] Most of the manufacturing data of interest to adversaries is CUI, including design information; performance specifications; shop floor execution data; factory support information (e.g., financials, system status, and personnel); and supply chain operational information (e.g., invoicing, pricing, and contract volume). As such, cybersecurity for manufacturing presents a persistent, widespread, and complex challenge to the entire DIB.

Major Risks & Issues

Risk Archetypes

- Foreign dependency
- Product security

Awareness and Wherewithal of Small Defense Contractors to Implement Cybersecurity Protections

Both the public and private sectors recognize the importance of safeguarding informational and operational assets from cyber risks. However, cybersecurity has not become an ingrained norm in manufacturing, especially in small and medium-sized manufacturers. The Defense Federal Acquisition Regulations Supplement (DFARS) clause 252.204-7012 required defense contractors and subcontractors to implement the information security protections described in the National Institute of Standards and Technology (NIST) Special Publication 800-171 Revision 1, "Protecting Unclassified Information in Nonfederal Information Systems and Organizations" by December 31, 2017. Interactions with several thousand small manufacturers by the Department of Commerce (DoC) Manufacturing Extension Partnership National Network since 2017 reveals a lack of awareness and understanding of the DFARS cybersecurity requirement, and a deficiency of financial and technical resources necessary to manage cyber security risks. Compliance with the requirements by sub-tier suppliers, while increasing, remains relatively low and is not pervasive throughout defense supply chains.

Inadequate Focus on Manufacturing-Specific Cybersecurity Needs

Manufacturing is the second most heavily attacked sector in the economy (finance is the first), and the DIB is subject to continuous, coordinated cyber-attack campaigns by nation states. Unfortunately, most cybersecurity R&D is focused on information systems, without specific emphasis on the unique needs and operational technology aspects of the manufacturing sector.

If unaddressed, the industrial base faces a high likelihood of serious and exploitable vulnerabilities, while experiencing a reduction in the number of suppliers compliant with requirements and eligible to provide products and services to the DoD. This combination of risks will impact both the resilience of existing suppliers and the integrity of the supply chain.

FY2020 Developments

DoD issued an interim rule to amend the DFARS to implement a DoD Assessment Methodology and Cybersecurity Maturity Model Certification (CMMC) framework. This framework is intended to assess contractor implementation of cybersecurity requirements and enhance the protection of unclassified information within the DoD supply chain. This interim rule is effective November 30, 2020.

Building upon the NIST SP 800-171 DoD Assessment Methodology, the CMMC framework adds a comprehensive and scalable certification element to verify the implementation of processes and practices associated with the achievement of a cybersecurity maturity level. The CMMC is designed to provide increased assurance to the Department that a DIB contractor can adequately protect sensitive unclassified information, such as CUI and Federal Contract Information, at a level commensurate with risk, accounting for information flow down to subcontractors in a multi-tier supply chain. A DIB contractor can achieve a specific CMMC level for its entire enterprise network or for particular segments, depending on where the protected information is processed, stored, or transmitted.

The CMMC model consists of maturity processes and cybersecurity best practices from multiple cybersecurity standards, frameworks, and other references, as well as inputs from the broader cybersecurity community. The CMMC levels and associated sets of processes and practices are cumulative. Furthermore, the CMMC model includes an additional five processes and 61 practices across Levels 2-5 that demonstrate a progression of cybersecurity maturity.

Level	Description
1	Consists of the 15 basic safeguarding requirements from Federal Acquisition Regulation (FAR) clause 52.204-21.
2	Consists of 65 security requirements from NIST SP 800-171 implemented via DFARS clause 252.204-7012, seven CMMC practices, and two CMMC processes. Intended as an optional intermediary step for contractors as part of their progression to Level 3.
3	Consists of all 110 security requirements from NIST SP 800-171, 20 CMMC practices, and three CMMC processes.
4	Consists of all 110 security requirements from NIST SP 800-171, 46 CMMC practices, and four CMMC processes.
5	Consists of all 110 security requirements from NIST SP 800-171, 61 CMMC practices, and five CMMC processes.

Figure 7.8

DoD is implementing a phased rollout of CMMC. Until September 30, 2025, DFARS clause 252.204-7021, Cybersecurity Maturity Model Certification Requirements, is prescribed for use in solicitations and contracts. To implement the phased rollout of CMMC, inclusion of a CMMC requirement in a solicitation during this time period must be approved by USD(A&S).

CMMC will apply to all DoD solicitations and contracts, including those for the acquisition of commercial items (except exclusively commercial off-the-shelf items) above the micro-purchase threshold, starting on or after October 1, 2025. Contracting officers will not make an award, or exercise an option on a contract, if the contractor does not have current (i.e. not older than three years) certification for the required CMMC level. Furthermore, CMMC certification requirements must be applied to subcontractors at all tiers, based on the sensitivity of the unclassified information at the subcontractor level.

Sector Outlook

Gaps in cybersecurity protections among defense manufacturers can lead to widespread and persistent vulnerabilities in the DIB, contributing to the erosion of manufacturing, economic competitiveness, and national security.

Multiple approaches exist to manage cybersecurity risks within the industrial base, but not all are appropriate or even adequate to protect all levels of controlled information, including CDI and CUI. Three key issues – lack of uniform security implementation; inconsistent implementation of adequate security by defense suppliers; and reliance on self-attestation as indicated by current DFARS requirements – expose the manufacturing sector to cybersecurity risks. Further, the implementation of emerging technological systems in the DIB will exacerbate challenges to cybersecurity, and increase the stakes of malign technology transfer in the future.

Electronics

Sector Overview

The electronics sector manufactures products for a wide variety of end user markets, including consumer electronics, computers, automotive, industrial equipment, medical equipment, telecommunications, aerospace, and defense. Electronic systems and components are ubiquitous throughout all DoD weapons systems, but global military production represents only one percent of a market dominated by commercial devices.

Major Risks & Issues

Risk Archetypes

- Foreign dependency
- DMSMS

Decline of Domestic Semiconductor Manufacturing

Currently, the United States only holds a 12 percent market share in the global semiconductor manufacturing market. The dependence on foreign sources for semiconductor products continues to represent a serious threat to the economic prosperity and national security of the U.S., as much of the critical infrastructure is dependent on microelectronic devices. This threat will become more pronounced as emergent technology sectors, such as Internet of Things (IoT) and AI, require commodity quantities of advanced semiconductor components.

In addition, the diminished focus on domestic semiconductor manufacturing has contributed to the erosion of U.S. technological supremacy in advanced semiconductor manufacturing. The current industry leaders introducing new semiconductor technology nodes are Taiwan Semiconductor Manufacturing Company (TSMC), Ltd. (Taiwan) and Samsung Group (South Korea). These companies are several technology generations ahead of Intel Inc., the United States leader in semiconductor technology.

Counterfeited Electronic Components

The U.S. Navy studied counterfeit trends based on information provided by ERAI, an electronic part reporting and dispute resolution organization; their study consisted of 9,009 part reports and 2,593 company complaints. The study confirmed that integrated circuits (ICs) continue to be the most commonly counterfeited electronic components, identified in over 60 percent of all ERAI reports from 2018 through mid-2020. Multi-layer ceramic capacitors, a relatively simple part, are the second most-counterfeited part, making up approximately 15 percent of the reported suspect parts since 2018.[16]

DoD organizations continue to develop requirements to mitigate the counterfeit microelectronics risk. For example, U.S. Naval Sea Systems Command (NAVSEA) released NAVSEAINST 4855.40, *Counterfeit Materiel Prevention* in April 2019, with compliance becoming a part of NAVSEA Inspector General audits starting in October 2020. In November 2019, the Federal Acquisition Regulatory Council also issued a new regulation, FAR 52.246-26, which requires federal contractors to report any counterfeit or suspect counterfeit parts to the Contracting Officer and the Government Industry Data Exchange Program within 60 days of the finding.[17]

Decline of U.S. Printed Circuit Board (PrCB) Manufacturing

U.S. PrCB and PrCB assembly (PrCBA) manufacturers have sufficient technical capability to meet DoD's current advanced manufacturing technology needs, excluding organic IC substrates. However, this could change with a few acquisitions or closures.

The number of small and medium PrCB manufacturers supplying the DoD continued to diminish in 2020, falling by 16.3 percent and 25.6 percent in the last five years, respectively.[18] The DoD is at risk of losing capability due to the mergers and acquisitions of small domestic PrCB manufacturing companies that are purchased by larger companies. The small companies' niche products and services necessary for national defense systems may not provide sufficient revenue or opportunity for growth for their new, larger owners. This growth will further edge out the small PrCB manufacturers who provide essential products and services for national defense systems.

Fortunately, the DoD Executive Agent for Printed Circuit Board and Interconnect Technology (PrCB EA) is developing and promoting DoD policies and regulations that encourage trusted domestic PrCB manufacturing and reshoring, which could help alleviate this concern. In addition, DoD is investing in trusted domestic PrCB manufacturing by leveraging economic stimulus funding and the DPA Title III program.

Limited Domestic Capacity for Organic IC Substrate Manufacturing

Taiwan, South Korea, Japan, and China collectively produced over 90 percent of the $8 billion organic IC substrate production in 2018; the United States produced less than 0.1 percent that year.[19] Organic IC substrates are the most advanced PrCB interconnect technology in the market today and will enable next-generation technology. Substrate-like PrCBs (SLPs), essentially equivalent to organic IC substrate constructions, are becoming more common as the feature sizes in cell phone PrCBs continue to shrink.

The U.S. PrCB industry has not developed a significant capability to deliver production capacities of organic IC substrates due to high labor costs and the hyper-competitive environment created by Asia. However, a number of U.S. companies are starting to invest in this capability.[20, 21] Domestic and future DoD investments are crucial as Japan, a previously vital source for U.S. organic IC substrate supply, has recently announced it will not support production requirements for defense-unique microelectronics.

Obsolete Technology

DoD's acquisition and sustainment systems use microelectronic technology that is generations behind commercial technology. Due to the high cost of redesign, test, and requalification, most systems do not undergo technology refreshes, which would allow the insertion of new technology parts. This leads to obsolescence issues because the microelectronics industry does not have sufficient demand to continue producing these parts. DoD alone cannot sustain production. Therefore, many parts become obsolete, and programs are forced to do costly lifetime buys, or expensive redesign/requalification efforts to utilize a different part. These are usually not budgeted for by the programs, which makes it very difficult to address these issues.

A production line utilized by many DoD programs, including anti-tamper, missiles, platforms, space systems, and potential future strategic systems recently went end-of-life, requiring just such costly efforts. Better tracking of microelectronic parts by the Department, and better planning and budgeting by programs to insert new technologies, would allow DoD to respond to these issues in a more proactive way versus the costlier reactive efforts it usually undertakes.

Congressional Action

Congress has included a number of pieces of legislation in the draft FY2021 NDAA to address some of the issues noted in this report, including on-shoring microelectronics manufacturing capability, increasing funding for research and development of new microelectronics technologies, and requiring use of domestic PCBs in DoD systems. If the final legislation is targeted to the right risk areas, and appropriations are also provided, this could start to resolve some of the major issues outlined here.

FY2020 Developments

Mergers & Acquisitions

In the aerospace and defense sector, electronic equipment contributed 23 percent of total deal value in the first half of 2020 ($15.4 billion). The most noteworthy of these mergers and acquisitions were the BAE Systems Inc. acquisition of Collins Aerospace-Military – Military Global Positioning System business, and the Teledyne Technologies Inc. acquisition of Photonics Technologies SAS.[22]

In the microelectronics sector, two substantial mergers were announced that will have significant impact in their respective market segments:

- February 2020: Dialog Semiconductor (United Kingdom) announced the acquisition of Adesto (United States), a provider of analog and mixed signal application-specific semi-conductors and embedded systems for the Industrial IoT, for $500 million. According to Dialog, the acquisition will enhance Dialog's position in the Industrial IoT. Adesto is based in Santa Clara, California, employs 270 people, made approximately $118 million in 2019, and has a portfolio of solutions for smart building automation in the industrial, con-sumer, medical and communications markets.
- September 2020: NVIDIA, Inc. announced plans to acquire ARM Holdings from Softbank (Japan) for $40 billion. ARM technology is used in approximately 90 percent of all mobile applications and in many gaming platforms. NVIDIA has announced their plan to use ARM technology to accelerate next-generation data center technology, placing them in direct competition with Intel.
- October 2020: Advanced Micro Devices (AMD) announced plans to acquire Xilinx, Inc. for $35 billion. AMD is a direct competitor of Intel, engaged in the development of Central Processor Units, the core component in modern computers. Xilinx Inc. produces a class of semiconductor devices known as Field Programmable Gate Arrays that have extensive commercial and DoD applications. This merger would give AMD a significant competitive advantage over Intel, particularly in emerging markets such as IoT and large data applications.

The most substantial bare PrCB manufacturer acquisition in 2020 was the Summit Interconnect Inc. acquisition of Integrated Technology Ltd. in Canada.[23] Summit Interconnect now has four facilities, three in the United States and one in Canada. With annual total estimated sales of over $120 million, Summit Interconnect moved into the top four U.S. bare PrCB facilities.[24]

COVID-19 Impacts

The coronavirus pandemic has significantly impacted the U.S. electronics sector's ability to provide timely support and supply for national defense systems. The U.S. electronics sector has experienced:

- Heightened awareness of the sector's foreign dependency overall, but especially China.
- Product launch delays and cancellations (53 percent) and component cost increases (37 percent); [25]
- Onboarding new suppliers without approved vendor qualification processes in order to quicken access to critical inventory (31 percent).[26]
- Extending certifications and licenses for as long as six months, and delaying new certifi-cations (e.g., International Traffic in Arms Regulations, NADCAP, AS9100); and
- Decreasing 2020 capital expenditures in facility upgrades and new technology (26 per-cent), according to an IPC survey.[27]

The microelectronics industry, however, reported a more minimal impact. During an Industrial Base Council meeting on October 2, 2020, four commercial microelectronics companies (representing small, medium, and large microelectronics producers) provided their perspectives, discussing COVID-19 impacts to the commercial industry and their companies, and initiatives the U.S. government could take to help the microelectronics industry. The overall COVID-19 impacts described by the microelectronics companies were minimal.

New Programs/Initiatives

The PrCB EA facilitates access to reliable, trusted, and affordable PrCB fabrication, assembly products and technologies that meet the DoD quality, performance, and security requirements. The PrCB EA supports collaboration within and across DoD to conduct research, development, and sustainment efforts targeting Component-unique requirements.

The PrCB EA continued research and development activities in FY2020, focusing specifically on technologies that could enhance national defense systems. This research and development includes: performance and reliability assessments of additive manufacturing based electronics; manufacturing processes, patterning techniques, material sets, and equipment requirements that support PrCBs with less than ten micrometers line and space features; solder replacement technologies; reliability assessments on enabling technologies for 2.5D and 3D packaging; direct write substrates, and printed devices, including batteries, sensors, transistors, and energetics.

DoD is also investing in heterogeneous packaging through the State-of-the-Art Heterogeneous Integration Prototype (SHIP) Program, which is driving advanced microelectronic packaging technology.[28]

There have been several new budgetary developments within DoD in the electronics sector:

- The JIBWG collected, evaluated, and vetted critical electronics sector needs resulting from the coronavirus pandemic, and made recommendations to the IBC on CARES Act funding allocations. Roughly $80 million has been allocated to the electronics sector through the CARES Act.
- In June 2020, the bipartisan Creating Helpful Incentives to Produce Semiconductors (CHIPS) for America Act was introduced in the Senate and the House. This bill will provide significant federal investments to U.S. semiconductor companies to give them a technological edge in semiconductor materials, process

technology, architectures, design, and advanced packaging to help restore U.S. leadership in semiconductor technology essential to national security.

- In October 2020, DoD awarded over $197 million to advance microelectronics technology and strengthen the U.S. microelectronics industrial base, which will underpin the development of other DoD technology priorities such as AI, 5G communications, quantum computing, and autonomous vehicles. Nearly $200 million will be issued through two DoD programs: The Rapid Assured Microelectronics Prototypes (RAMP) using the Advanced Commercial Capabilities Project Phase 1 Other Transaction Award, and the SHIP Program Phase 2 Other Transaction Award.
- The Presidential Determination authorizing the use of DPA Title III authorities to strengthen the domestic industrial base and supply chain for rare earth elements and to correct the industrial base shortfall for radiation-hardened electronics.

Sector Outlook

Trusted Certifications

To establish more comprehensive trust assurance within the U.S. PrCB industrial base, DoD in partnership with Institute for Printed Circuits (IPC) created IPC-1791 *Trusted Electronic Designer, Fabricator and Assembler Requirements.* The initiative aimed to develop a competitive network of trusted PrCB and interconnect technology providers. Efforts to keep IPC-1791 current continue: Revision A includes provisions for the certification of non-U.S. PrCB designers, fabricators, and assemblers that are sponsored by U.S. prime contractors; Revision B is currently under review and will expand requirements to include cable and wire harness assemblers, SLPs, and complementary Cybersecurity Maturity Model Certification requirements.

Additionally, section 224 of the FY2020 NDAA requires defense microelectronics products and services to meet trusted supply chain and operational security. A strategy is currently under development and will require implementation by January 2023.

Strategic Competition

"While we still design components and printed circuit cards in the U.S., the majority of fabrication, packaging, testing, etc., is done offshore," USD(A&S) Ellen M. Lord said at the Electronics Resurgence Initiative Summit. She offered some hope, adding that through public and private partnerships, the government can provide capital and a demand signal to encourage manufacturers to bring microelectronic production back to the U.S.[29]

While the global PrCB market continues to grow – from $30 billion in 2000[30] to over $65 billion in 2018,[31] the number of PrCB companies in North America has continued to decline, from over 1500 in 2000 to around 199.[32] While consolidations in the U.S. have strengthened some of the larger manufacturers, they have created a more challenging market for small PrCB manufacturers.

PrCBA manufacturing is often outsourced to electronic manufacturing service (EMS) providers. Of the top 20 EMS providers in 2019, four are based in the United States and eight in Taiwan.[33] Taiwan dominates the EMS market, leading in both revenue and number of facilities.[34] The current United States -China trade war has also prompted EMS providers to build plants outside of China, benefitting manufacturers in Vietnam and Malaysia.[35] An increase in EMS providers outside of China has provided the United States with considerable access to PrCBA manufacturing capability.[36]

The U.S. maintains a 45-50 percent combined market share in electronic design sectors such as electronic design automation and intellectual property core development. However, the U.S. market share of semiconductor manufacturing has declined from 37 percent in 1990, to 12 percent in 2020. Despite this trend, the U.S. currently maintains a combined 30 percent market share in the optoelectronic, analog, and discrete electronic component sectors. The U.S. manufacturing decline in semiconductor fabrication has benefitted large fabrication facilities in Taiwan, and more recently, China.[37] Global IC semiconductor sales in 2019 were $412.3 billion.[38]

The domestic semiconductor industry relies heavily on outsourced semiconductor assembly and test (OSAT) corporations to package and test semiconductor products. Currently, over 75 percent of electronic component packages and 98 percent of the testing performed by the OSAT sector occurs in Asian facilities.[39] This trend is expected to continue as leading edge semiconductor manufacturers, such as TSMC, are now engaged in the OSAT market.

Emerging Trends/Technologies

Finally, these emerging and foundational technologies will require the electronics sector to advance standard manufacturing processes, often necessitating investments, new processes, and new materials (Table 7.9).

Technology	Copper Interconnect/ Solder Joint Advances, Ruggedization	Thermal Management Advances	Improved Size, Weight, Power/ Finer Circuit Traces/ Smaller Vias	New Materials	Business Impacts	Advances in PrCB and PrCB Manufacturing
Hypersonics	X			X		X
Directed Energy		X		X		X
Advanced Communications			X			X
Space Offense and Defense				X		X
Unmanned Aerial Systems/ Autonomy	X		X	X		X
Advanced Robotics/AI	X		X	X	X	X

Table 7.9: Advances Required for Emerging and Foundational Technologies

Ground Systems

Sector Overview

Ground systems provide defense-unique products, integrating the functions of mobility, firepower, survivability, and communications into vehicle systems primarily for the U.S. Army and Marine Corps. These encompass tracked and wheeled vehicles for combat, combat support, and combat service support. The ground vehicle sector of the DIB has seen a drastic contraction of players in recent decades into what is now a small set of prime suppliers that design and manufacture Combat Vehicles (CV) and Tactical Wheeled Vehicles (TWV).

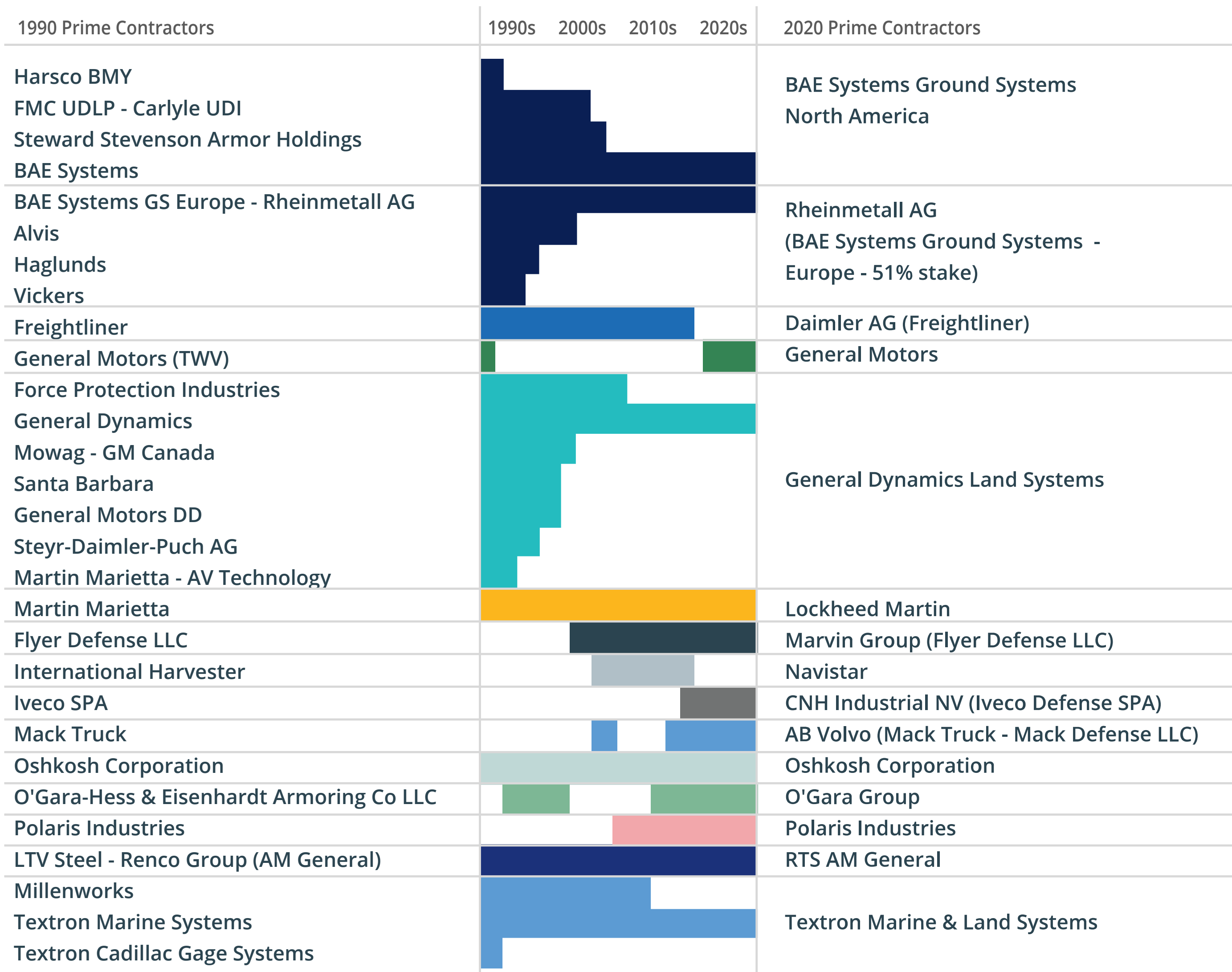


Figure 7.10 Contraction in Ground Vehicles Sector Primes
Source: DCMA IAG

**Note: companies in the matrix have had production, development, or major vehicle modification contracts in the past decade*

Combat Vehicles (CVs)

CVs are typically heavily armored and integrated with complex weapon systems, fire control, and sensors. This class of military ground vehicles tends to require defense-unique components with little commercial commonality. Although an assortment of other defense firms such as Lockheed Martin, SAIC, and Textron occasionally compete for selected CV programs as a prime or major partner, BAE Systems and GDLS largely dominate the combat vehicle subsector.

Tactical Wheeled Vehicles (TWVs)

While also designed to accommodate use in demanding military environments and missions, TWVs are usually platforms modified from commercial variants. As such, this class benefits from a shared industrial base supporting this subsector and the U.S. automotive market through complex supply chains, research and development operations, and shared assembly and production systems for component manufacturing. As a result, there is the equivalent of "warm basing" in the TWV market, where firms can maintain the expertise and product line capability to ramp up production of TWVs with minimal U.S. government or DoD involvement. Although current production of TWVs is dominated by two domestic suppliers, AM General and Oshkosh, there are multiple qualified vendors for the repair, refurbishment, and modifications business.

Major Risks and Issues

The primary risks in this sector fall into many of the risk archetypes developed in the EO 13806 report. The overall risk to this segment is moderate.

Risk Archetypes:

- Single source
- Fragile market
- Capacity-constrained supply market
- Gap in U.S.-based human capital
- Erosion of U.S.-based infrastructure

Single Source

The ground vehicles sector has evolved into a number of single source suppliers. The cyclical nature of shifting demand, declining budgets, and ever-changing requirements has driven market consolidation. As a result, DoD has only one qualified supplier for many of the platforms. Due to commonality of products across both defense and commercial product lines, the firms in the TWV market are not as segmented as those in the CV market.

Fragile Market

The ground vehicles sector is a fragile market due to the economic challenges created by the cyclic nature of demand, budgets, and requirements. Over the last few decades, budget reductions and uncertainty have resulted in delays and cancellations in new ground vehicle programs. This hinders both R&D and manufacturing technology supplier investment as well as the ability to incentivize new entrants.

Capacity Constrained Market

The segments of the ground vehicles sector remain capacity-constrained. Lack of continuous demand drives private industry to reduce excess manufacturing capacity and investments in DoD production lines. This issue is particularly acute in CV production where one U.S. manufacturer is responsible for producing approximately 80 percent of the U.S. Army's Armored Brigade Combat Team Vehicles as well as the Marine Corps' Amphibious Combat Vehicle. Rapid increases in demand for multiple new products continues to stress production capabilities at this manufacturing site, leading to program delays and quality control issues in multiple programs.

U.S.-Based Human Capital

The ground vehicles sector requires a steady flow of critical engineering and manufacturing skill sets to meet present and projected needs. Both CV and TWV markets require a new generation of skilled technicians, particularly in welding and machining, to meet future demands. These two critical skills are in short supply across all sectors of the DIB. The pipeline of trade schools and reputable technical education programs that once educated the older generations of the workforce is fragmented. If the eroding technical skill base is not addressed, the ground vehicle sector will not be able to maintain the workforce needed to keep up with demand. The CV market also requires unique engineering skills such as weapons systems engineers that are not needed in the commercial ground systems arena. These skills need to be nurtured by a suitable RDT&E base to support training the specialty engineers.

Erosion of U.S.-Based Infrastructure

Erosion of U.S. based infrastructure continues to impair the ability to maintain current capacity and prepare for future needs in the organic industrial base. By law, the DoD is required to manufacture large-caliber gun barrels at one organic arsenal. Much like the private sector, fluctuating DoD demand has resulted in higher operational costs, aging infrastructure, inability to retain human capital, and inconsistent production management. The U.S. Army recently invested in new modern equipment for the arsenal. The DoD must continue to modernize the organic industrial base to ensure its fitness to sustain current programs and meet future surge requirements.

FY2020 Developments

The coronavirus pandemic had a major impact on all DIB sectors to varying degrees. A summary of the impact on the ground sector is below:

A number of program delays resulted in production backlogs and program cost increases. Prime contractors have refined their production operations to continue to work, making up the backlogs. The two key arsenals that support this sector are in the early stages of a five-year performance improvement plan, including process improvements and equipment upgrades to better support the needs of this sector.

Ground Vehicle Sector COVID-19 Impacts	Count
Number of Affected Ground Vehicle Programs	40
Number of Reported Facility Closures for Affected Programs	31
Additional Program and Facility Impacts: • Travel restrictions delayed program reviews • Supplier disruptions impacting production schedules • Employee absenteeism limiting production • Test range non-availability • As of October 13, 2020 there have been 118 ground vehicle sector industrial facility impacts and 301 temporary DIB closures due to the coronavirus pandemic with 1 current facility closure	

Figure 7.11, Source: DCMA IAG

Sector Outlook

The U.S. Army and Marine Corps have published long-term vehicle modernization strategies to align ground vehicle priorities with ground vehicle procurement profiles. In support of these strategies, new technology development is ongoing in support of increased lethality, supportability, and mobility.

Lethality	Survivability	Mobility
• 3rd Generation Improved Forward-Looking Infrared (U.S. Industry) • 30mm cannon upgrades for the Stryker • 40mm Cased Telescoping Armament System (UK/France) • Directed energy systems	• Advanced materials/structural fiber (U.S. Industry) • Active protection systems/countermeasures (e.g., Trophy) (Raphael-Israel) • New electronic warfare (EW) systems to jam incoming missiles	• Hybrid electric and full electric propulsion (U.S. Industry) • Artificial intelligence for self-driving and situational awareness • Biofuels (DARPA) • Fuel optimization (Army Research Lab) • Ground X-Vehicle Technology (DARPA)

Figure 7.12, Source: DCMA IAG

During the upcoming FYDP period there is expected to be a decline in sector RDT&E that will require a greater focus on selective investment. Increased prototyping efforts can increase opportunities to practice critical design skills and capabilities for CVs and TWVs. The Army's Optionally Manned Fighting Vehicle program and the Marine Corps' Light Armored Vehicle replacement program will provide development opportunities for industry.

Across the FYDP, the CV production market is expected to grow as the modernization programs of the U.S. Army and U.S. Marine Corps mature and new platforms move into production.

The TWV market remains relatively stable and healthy due to its foundation in the commercial truck manufacturing sector. However, there is room for improvement to ensure the TWV industry is better able to leverage and rapidly employ innovative products and processes and critical skills between defense and commercial markets.

Machine Tools

Sector Overview

A machine tool is a power-driven machine that shapes or forms parts made of metal or other materials (e.g., plastics, composites) through processes including: turning, grinding, milling, stamping, drilling, forming, extrusion, injection molding, composite deposition, and additive manufacturing techniques. Modern machine tools leverage sophisticated industrial control systems, process parameter monitoring systems, and networked sensors. They incorporate advanced materials and precision components, as well as advanced lubricants, bearings, sensors, and coatings.

Machine tools provide the factory floor the foundation for leveraging advances in robotics, high precision automation, specialty materials, precision components, and additive, subtractive, and hybrid machining. Because machine tools support both prototyping and production operations for virtually all manufactured products, every commercial and defense manufacturer is a stakeholder in this sector.

The global machine tool sector is mature, but involves continuous innovation of new capabilities and features that drive competition. As Figures 7.13 and 7.14 show, in FY2019, China was the largest producer and consumer of machine tools. China designs, builds, and sells large volumes of relatively low-cost machine tools for consumption in the global market, and imports high-end machines from more advanced regions (notably Japan, Europe, and the United States).

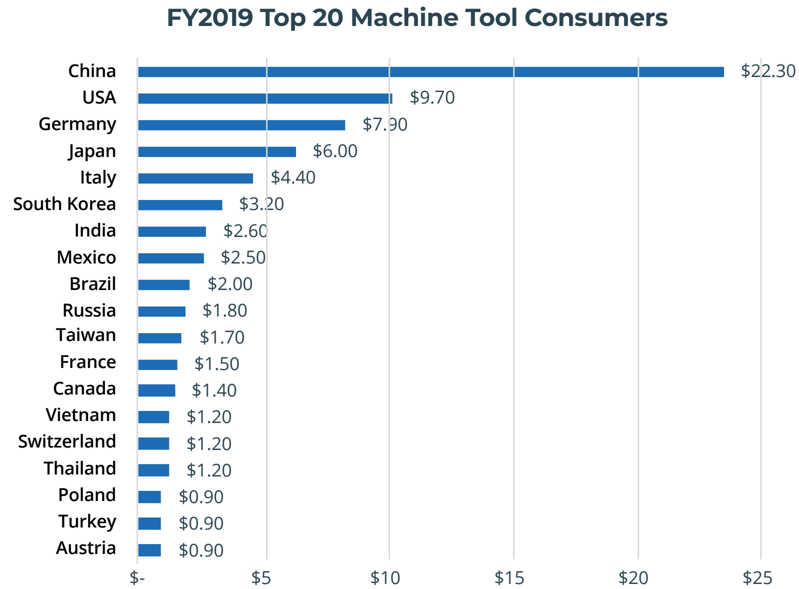


Figure 7.13: Global Machine Tool Producing Nations by Value[40]

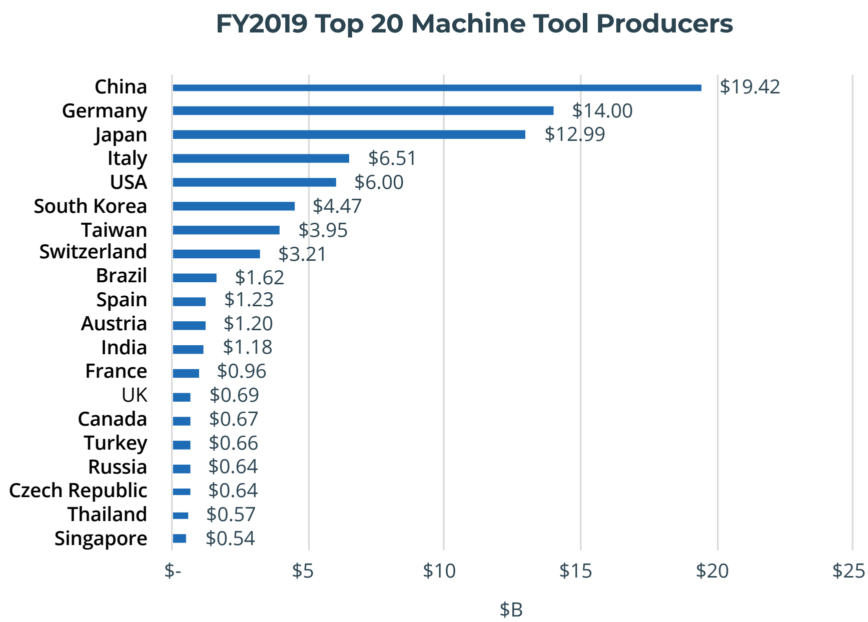


Figure 7.14: Global Machine Tool Consuming Nations by Value[41]

"Thus at the heart of the industrial health of any nation is its machine tool industry. It is no coincidence that the erosion of the machine tool industry parallels the decline of domestic manufacturing"[42]

Major Risks & Issues

Risk Archetypes:

- Foreign dependency
- DMSMS
- Gap in U.S.-based human capital

The risks detailed in the FY2019 version of this report still apply to the machine tools sector.

The playing field is still not level. In addition to widely documented and adversarial economic tradecraft, China's application of economic pressure on machine tool producing countries, especially in Asia, have steered products toward China. As Figure 7.15 shows, the U.S. has by far the worst machine tool trade balance in the list. Note that many countries with positive trade balances – such as Japan, Germany, Italy, Switzerland, South Korea, Spain, and Austria – are hardly low wage markets. However, all benefit from substantial national government support for machine tool sector R&D.

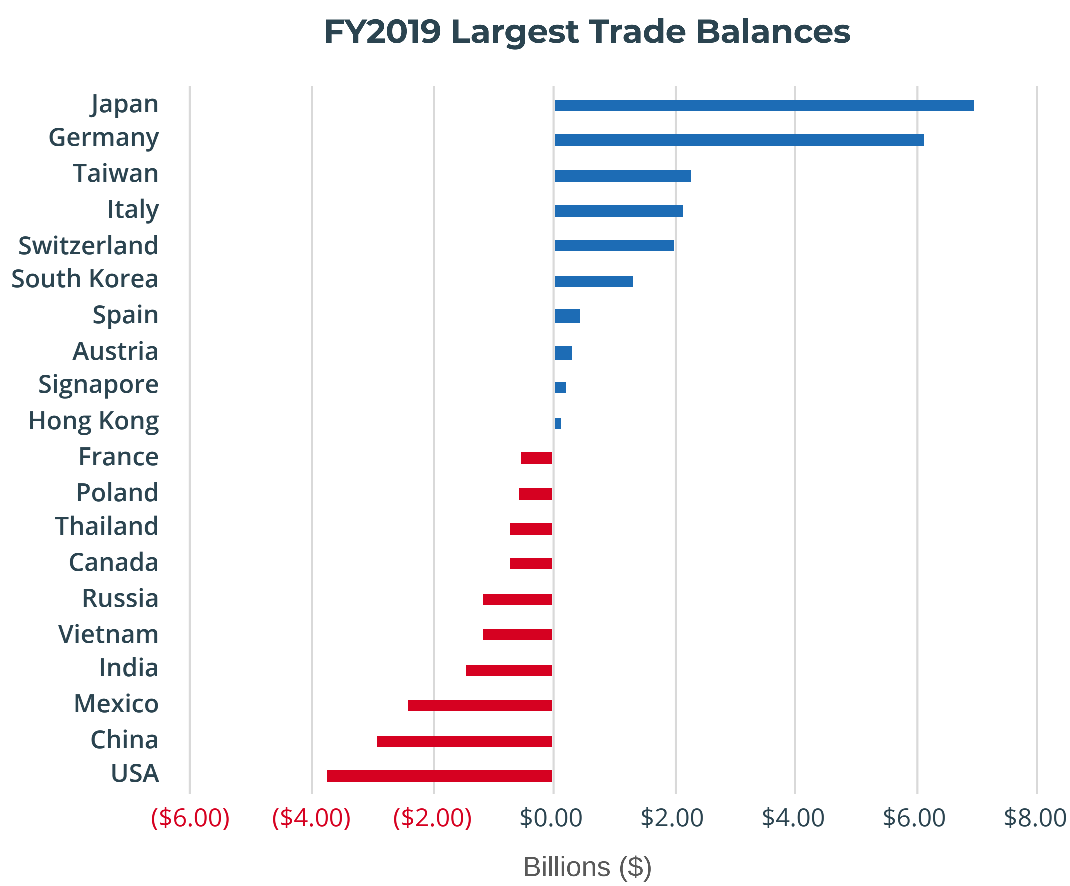


Figure 7.15: Trade Balances for Machine Tool Sector Nations[43]

The U.S. machine tool sector continues to lose diversity and capacity to international competition, industry consolidation, and business failure. The economic impacts of the coronavirus pandemic have made the situation much worse for the thousands of small "job shops" upon which the U.S. machine tool industry and the defense primes rely. Often, consolidations and failures have been the result of increased offshoring to low-cost providers to control costs and gain other tactical advantages. Offshoring can provide short-term benefits, but,

> *"in such cases, corporate strategies often diverge from national interest, where better information on the effect of such decisions on the supply chain may lead to more mutually beneficial proactive decisions. It is also prudent to develop an ability to rapidly standup manufacturing capability in sectors that have been downsized in the U.S. or to develop new flexible manufacturing capabilities so that rapid reconfigurations can be realized."*[44]

The U.S. still lacks a nationwide machine tool workforce development ecosystem operating at scale and velocity. This ecosystem is needed to replenish a shrinking, aging manufacturing workforce. Scale up of the current innovation ecosystem is required to revitalize our manufacturing base and attract talent through education programs that highlight the possibilities of machining careers. DoD and national efforts to overcome this weakness must address:

1. The cost of machine tool research in terms of equipment, space, and risk;
2. The fact that machine tool research is time-consuming but produces fewer publications—in journals with low impact factors;
3. Many university leaders view the machine tool sector as "old technology" and prefer to focus resources in "new" areas.

Supply chain impact, economic competitiveness, national security, and support and expansion of the innovation ecosystem are rarely considerations in university-sponsored research decisions.

FY2020 Developments

In March 2020, the IBAS Program and the Manufacturing Demonstration Facility at the Department of Energy's (DOE) Oak Ridge National Laboratory jointly launched "America's Cutting Edge" (ACE). ACE is the first in a nationwide network of regionally focused machine tool hubs. ACE has already made notable progress on three initial strategic research thrusts: develop technologies to increase productivity and efficiency of current machine tools; develop novel processes and control algorithms to enable hybrid manufacturing; and establish new machine tool metrology, designs, and controls for large components. In response to the coronavirus pandemic, ACE has also provided rapid tooling development for high-volume Personal Protective Equipment production, which provided key insights into control requirements for hybrid (additive plus subtractive) manufacturing.

In August 2020, the IBAS program awarded a National Imperative for Industrial Skills workforce development agreement to IACMI - The Composites Institute. This effort, which has the potential to impact all DoD manufacturing supply chains, operates in close partnership with ACE. It will implement a novel training experience that surpasses current computer-aided design/ computer-aided manufacturing capabilities at the root of manufacturing.

Sector Outlook

The coronavirus pandemic is leading to decreases in machine tools sales and production. Factory shutdowns worldwide amidst the novel coronavirus pandemic led to months of abnormality in the manufacturing technology sector. As a result, the U.S. is seeing some of the lowest machine tool order numbers in the past decade. According to the Association for Manufacturing Technology (AMT), April and May 2020 produced the lowest monthly manufacturing technology order totals since May 2010. Table 7.16 below shows the described decline in FY2020 due to the coronavirus pandemic.

U.S. Manufacturing Technology Orders						
Net New Orders for U.S. Consumption: Total National Orders ($ Thousands)						
	Total Orders		Metal Cutting Machines		Metal Forming and Fabricating Machines	
Date	Units	Value	Units	Value	Units	Value
Aug-19	2,129	$380,406	2,077	$ 375,507	52	$ 4,898
Sep-19	2,269	$385,863	2,209	$ 376,460	60	$ 9,403
Oct-19	2,073	$391,208	2,009	$ 378,423	64	$ 12,785
Nov-19	1,970	$325,363	1,913	$ 311,072	57	$ 14,291
Dec-19	2,322	$387,583	2,255	$ 381,552	67	$ 6,031
Jan-20	1,729	$289,030	1,680	$ 282,453	49	$ 6,578
Feb-20	1,617	$283,167	1,593	$ 274,865	24	$ 8,302
Mar-20	1,754	$312,367	1,725	$ 309,088	29	$ 3,280
Apr-20	1,494	$235,062	1,467	$ 228,358	27	$ 6,704
May-20	1,602	$224,671	1,570	$ 217,941	32	$ 6,730
Jun-20	2,122	$343,158	2,088	$ 338,607	34	$ 4,550
Jul-20	1,840	$336,400	1,811	$ 331,806	29	$ 4,594
Aug-20	1,698	$297,769	1,679	$ 289,417	19	$ 8,351
Average	1,894	$322,465	1,852	$ 315,042	42	$ 7,423

Table 7.16: Net Orders for U.S. Consumption of Manufacturing Technology45

Indicators show that the industry is now improving as factories reopen. In May 2020, Oxford Economics analysts had predicted that the industry would be down 50 percent for FY2020 due to the uncertainty in the return to work across the country and worldwide. Instead, the expected loss is now half of that prediction. It is reasonable to expect that China's centrally planned and controlled economy and robust government support will afford it a significant short-term advantage in this area.

Last year's report emphasized the importance of the linkage between the ability to conceive, design, develop and manufacture advanced machine tools and national self-determination. FY2020's coronavirus pandemic supported that lesson in stark terms. The inability to rapidly obtain tooling to produce the PPE and medicines required to keep American workers on the job crippled not only health care but all segments of the economy. The lack of a robust innovation ecosystem exacerbates the problem. The costs are measured not only in lost sales and production delays on major weapon systems, but also in the loss of the workers and firms that produce the products we need to prevail and thrive.

Technology Trends and Developments

For the next ten years, metal cutting tools (as opposed to metal forming or fabricating machine products), which accounted for over 97 percent of U.S. manufacturing technology orders in FY2020, are also expected to be a major product line due to the expected demand from industries such as automobiles and construction. Computerized Numerical Control tools will drive the machine tools market due to increased automation and digitalization across industries. They improve reliability and precision, and shorten production times. New COVID-19 inspired guidelines and regulations affecting worker spacing have made these capabilities even more attractive to customers and, hence, developers.

Materials

Sector Overview

The materials sector is among the most diverse sectors that the DoD assesses. It includes all elements of the periodic table in their natural and synthetic forms, as well as products throughout the materials supply chain through value-added processing, trading, and manufacturing into semi-finished products. The breadth of product coverage, global trade flows, and associated technical disciplines within the sector compels DoD to collaborate with non-defense agencies and private industry, both domestic and foreign, to ensure that the Materials Sector can support the requirements of the NDS.

The DoD largely relies on commercial markets and logistics networks to meet material demand. Since the end of the Cold War, U.S. reliance on foreign sources and globalized processing operations has accelerated. In general, this trend has decreased the cost of materials and opened new sources to U.S. manufacturers, with concomitant growth in U.S. import reliance and offshoring across the sector.

Major Risks and Issues

Risk Archetypes:

- Foreign dependency

In last year's report, the Department observed that the fundamental risk within the Materials Sector flows from the *U.S. private sector capability gap* between current, globalized supply chains and (A) current threats below the level of armed conflict and (B) serious threats in the event of armed conflict. The Department also highlighted three risk categories:

1. consolidation of supply chains in ownership, geography, and market access;
2. under-execution or lack of due diligence; and
3. lack of resilience.

These three risk factors remain in force, and the following new factors, accentuated by mobilization for COVID-19 response, have hampered the Department's ability to address them.

Acute Personnel Shortages

Upon the declaration of a National Emergency with respect to COVID-19, the Department mobilized substantial portions of its workforce to support HHS and FEMA. Within the OUSD (IP), this reorientation reflects the many additional duties performed by its personnel, particularly for DPA Title I and Title III. Similarly, the National Defense Stockpile (NDS) program repurposed its supply chain monitoring tools so the inter-agency could anticipate vulnerabilities in the Materials Sector as COVID-19 outbreaks progressed globally. Unfortunately, the NDS program was unable to make new hires or onboard newly-hired personnel in the COVID-19 telework environment, distributing current work and COVID-response tasks across a dwindling staff. As a result of these combined workforce constraints, DoD cancelled, deferred, or reduced its activities in the Materials Sector during FY2020, summarized in Figure 7.17.

Note: In House Report 116-442, the House Committee on Armed Services directed the Secretary of Defense to include a supply chain and vulnerability assessment for rare earth elements, tungsten, neodymium-iron-boron magnets, niobium, indium, gallium, germanium, and tin in this report, along with recommendations for stockpiling action for those materials and any other relevant materials. The Department has satisfied this reporting requirement with the submission of the Strategic and Critical Materials 2021 Report on Stockpile Requirements, in accordance with 50 U.S.C. 98h–5. However, the Department cautions that this report will be the last report of its type to Congress, pursuant to section 1061 of Public Law 114-328 (see Sector Outlook).

Cancelled Activities	Deferred Activities	Reduced Activities
– Meeting of the Strategic Materials Protection Board (10 U.S.C. 187)	– Time-Study for release of materials from the NDS under simulated National Emergency conditions (50 U.S.C. 98f) – Mobilization exercise for release of NDS materials under simulated National Emergency conditions (50 U.S.C. 98f) – Joint research and development activities with foreign allies under critical minerals Action Plans	– Meetings and reports for National Science & Technology Council action on critical minerals under Executive Order 13817 – Meetings and reports for the Federal Consortium for Advanced Batteries – Meetings and collaboration with foreign allies under critical minerals Action Plans – Acquisition policy and legislative proposal development

Table 7.17: Reduction in DoD Materials Sector Activities

As the Department returns to a normal work environment, many of these activities will be re-started, but the lack of workforce resilience is a significant risk in a future supply chain disruption event.

Significant Requirements Growth without Resourcing

In last year's report, the Department observed that Congress directed the NDS program to divert approximately 89.8 percent of the proceeds from its sales to other programs (see 7.18). Though Congress has halted these funding transfers, the NDS program remains undercapitalized, as described in reports under 50 U.S.C. 98h-5. The Department will deliver the final iteration of this report to Congress in early 2021 (see Sector Outlook).

Distribution Type	Total Amount (FY2003–FY2018) (Real $2018)	Average Annual Cash Flow (Real $2018)	Sample Activities / Accts.
To National Defense Stockpile Transaction Fund	$ 417.3M	$ 26.0M	– Material acquisitions – Qualification of new sources – Metallurgical R&D
To Non-Defense Accts.	($998.6M)	($62.4M)	– General Treasury Acct. – American Battle Monuments Commission (World War II Memorial) – Hospital Insurance Trust Fund – Federal Supplementary Medical Trust Fund
To Other Defense Accts.	($2,701.5M)	($168.8M)	– Foreign Military Sales Treasury Acct. – Reclamation purchases of electromagnetic spectrum – Defense Health Program – Military Service Operations & Maintenance accts.
Net Cash Flow to National Defense Stockpile Transaction Fund	**($3,282.8M)**	**($205.1M)**	

Figure 7.18: National Defense Stockpile Transaction Fund Distributions

Note: Total does not add due to rounding

Furthermore, as DoD and inter-agency supply chain assessments identify Materials Sector risk, the U.S. government routinely turns to the NDS for acquisition options. In addition to the previously-noted inadequacy of funding, the Department also observes that the NDS formerly held many of these at-risk materials.

For example, the Department of Commerce is investigating titanium sponge and vanadium under section 232 of *The Trade Expansion Act of 1962.* The NDS liquidated stocks of both materials during the post-Cold War sell-off, and to the extent possible within existing resources, the NDS program is increasing its stocks of these materials by reclaiming them from end-of-life weapon systems. Similarly, the NDS formerly contained approximately 14,000 tonnes of rare earth materials, equivalent to seven percent of today's global market. The Department submitted a legislative request to acquire rare earth materials for the NDS, but Congress has not adopted this provision for the FY2021 NDAA.

FY2020 Developments

The DPA Title III program issued multiple awards under Presidential Determinations related to neodymium-iron-boron (NdFeB) permanent magnet manufacture and strategic inventory demonstration. The DPA Title III program also issued one award using CARES Act funds to a domestic NdFeB manufacturer, whose critical manufacturing skills were at risk due to the onset of COVID-19:

- Urban Mining Company ($28.8 million), related to NdFeB magnet manufacture and maintaining critical workforce skills impacted by COVID-19
- TDA Magnetics LLC ($3.4 million) and Urban Mining Company ($1.7 million), related to the demonstration of a domestic NdFeB magnet supply chain and strategic inventory

The IBAS program also issued awards to the following vendors through its Cornerstone Other Transaction Agreement (OTA): Lynas Corporation ($0.65 million) and MP Materials ($0.66 million), for heavy rare earth separation technical development.

Sector Outlook

Funding and personnel constraints shape the Department's actions in the Materials Sector. Consequently, DoD's approach remains an exercise in economy of force, deploying against only the highest-risk materials with minimum levels of funding and time. Key activities in the Materials Sector are described below.

Defense Production Act (Title III) and the National Defense Stockpile

In the FY2021 President's Budget Request, the President recommended a significant increase to the base budget of the DPA Title III program. This funding increase aligns closely with pre-sequestration projections for the program ($185.8M forecast, versus $178.6 million requested, adjusted for inflation) (see Figure 7.19).

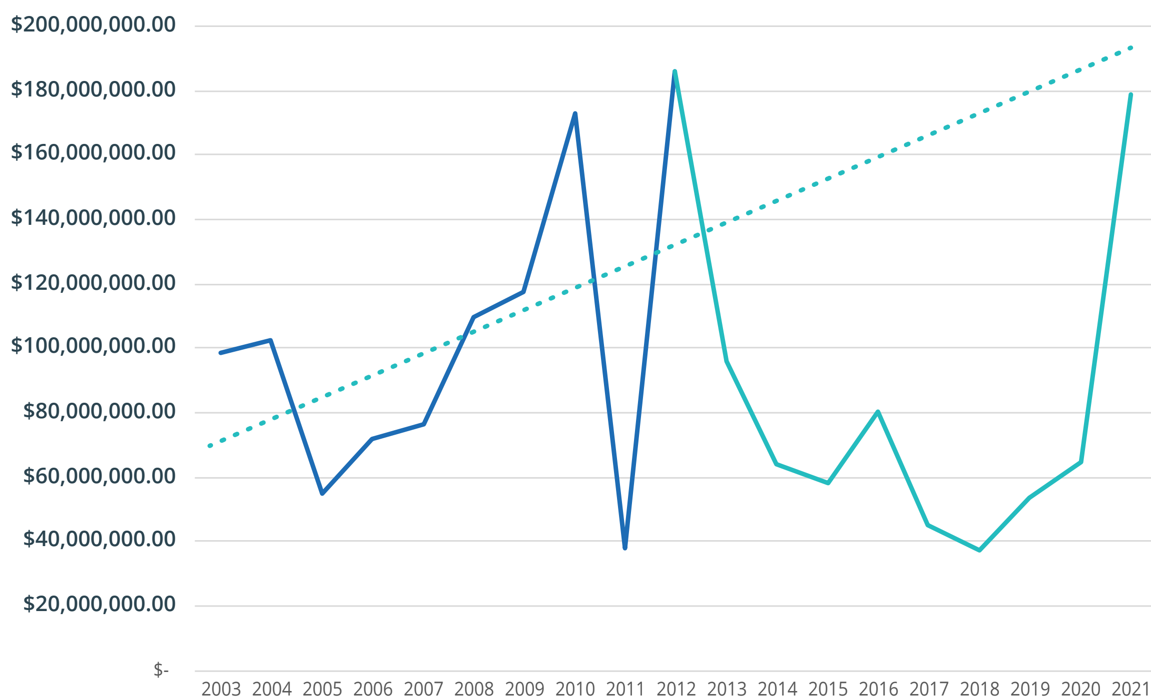


Figure 7.19: Defense Production Act Purchases Funding (Real $2019)

This resource influx will enable the DPA Title III program to execute against current Presidential Determinations far more effectively. However, the Department cautions that the FYDP for the Defense Production Act Purchases account in the FY2021 President's Budget Request returns to recent program lows, $45.9 million in FY2022 to $49.0 million in FY2025.

As noted in a prior section, the NDS program would like to re-acquire certain rare earth materials. The Department submitted a legislative proposal for the FY2021 National Defense Authorization Act to purchase (1) dysprosium, (2) neodymium-praseodymium (i.e., didymium) oxide, (3) NdFeB magnet block, (4) yttrium, and (5) samarium-cobalt alloy. Congress has not included this provision in legislation, and so, the Department is preparing follow-on legislative proposals to address this and other unmitigated Materials Sector shortfalls. Similarly, the Department notes the *Strategic and Critical Materials 2021 Report on Stockpile Requirements* (ref: 50 U.S.C. 98h-5) will be the last report of its type to Congress, pursuant to section 1061 of Public Law 114-328. This sunset provision notwithstanding, the Department will continue estimating Materials Sector shortfalls every two years, consistent with available funding and human capital.

U.S. Interagency and Allied Collaboration

The Department continues to leverage the partnerships forged in the execution of EO 13806 and E.O. 13817 to implement joint solutions, including:

- Sharing modeling best-practices, data, and data analytics approaches
- Pooling research and development funding to address common risks
- Enabling of defense and non-defense agencies in domestic and international fora

The Department maintains valuable partnerships with the Departments of State, Commerce, Interior, and Energy, as well as the U.S. Trade Representative, the DFC, and the Executive Office of the President, as well as our longstanding partnerships with NTIB members and other allies.

Modernization of Statutory Authorities for Materials Sector Mitigation

Major industrial base mitigation authorities for the DoD generally date to the Korean War-era or earlier. Some of these authorities are regularly re-authorized, but others have not undergone a meaningful reassessment since the 1970s. DoD is preparing legislative proposals for the modernization of many of these statutes, including the *Defense Production Act* and the *Strategic and Critical Materials Stock Piling Act,* and will seek appropriate stakeholder input to advance them for Congress' consideration.

Missiles and Munitions

Sector Overview

The missiles and munitions industrial base is comprised of both government-owned facilities (referred to as the 'organic' industrial base) and private sector companies engaged in the production of "smart" and "dumb" bombs.

- "Smart" bombs include tactical (cruise, air-to-air, air-to-ground, surface-to-air, torpedoes, mines, etc.) missiles, missile defense, strategic missiles, and has expanded to include hypersonic weapons.
- "Dumb" bombs include ammunition, mortars, artillery, tank rounds, naval gun/cannon rounds, etc.

However, the missiles and munitions sector definition could broaden through the 2020s due to changing technologies. Directed energy and cyber could enhance this sector by substituting non-kinetic weapons and effects for traditional missiles and munitions.

The sector is primarily defense unique and largely subject to wartime needs—meaning that procurement ramps up during wartime and declines when conflict ends. The market is defined and hampered by this conflict-reliant pattern, creating significant management and viability challenges for suppliers and their sub-tier suppliers.

Major Risks & Issues

Risk Archetypes:

- DMSMS
- Gap in U.S.-based human capital

Obsolescence & Lack of Redundant Capability

Specialty Chemicals from Foreign Sources: DoD relies on multiple non-domestic sources for many specialty chemicals, some from "non-friendly" sources. This presents a risk that supply could be disrupted during conflict, severely impacting our ability to produce munitions. OUSD (IP) is tracking development of advanced manufacturing technologies and scale-up efforts that could eliminate the need for foreign sources. Several DPA Title III efforts are scheduled for award during FY2021 to establish or evaluate domestic manufacturing capability for chemicals used in munitions. DoD investment in a series of flexible Pilot Scale Plants would also provide the capacity to address multiple critical obsolescent energetic materials within the organic industrial base, guaranteeing availability of these legacy materials as needed. These Pilot-Scale Plants would also provide a stable pipeline for rapid scale-up of next generational energetic materials for RDT&E. However, fully mitigating foreign dependency on specialty chemicals will require large investments (see Materials Sector Assessment).

Visibility into Sub-Tier Suppliers

Diminishing manufacturing sources and material suppliers (DMSMS), including obsolescence and single point failures: Due to the relatively low procurements of missiles, DoD relies on single source suppliers for many specialty materials, components, and end items, and obsolescence continues to be a major issue. These sole source components are critical pieces of the munition that are sometimes only available at government-owned facilities as manufacturers of last resort. Frequently, a component is too far down in the supply chain for DoD to have any visibility. Competitor nations are aggressively attempting to acquire critical sub-tier suppliers, either directly or through the higher-level ownership chain of the company, with limited visibility from DoD.

Loss of Design and Production; Aging Workforce

Hypersonics: Development and production of the many specialty materials and subsystems required for hypersonics is a niche area. The majority of the industrial base consists of small businesses that have focused their efforts on proving their technology and producing a handful of demonstration vehicles and glide bodies. Most of the workforce knowledge resides in these small companies. The traditional DoD industrial base is limited in production capability, resulting in large risks for cost, efficiency, and production. The industrial base is willing to self-invest in these capabilities, but a lack of definitive demand from DoD prevents them from justifying the business case necessary to do so.

Nuclear Modernization: Development and production of missiles as part of the Department's nuclear modernization efforts requires re-invigoration of certain industrial capabilities, which includes reconstituting a workforce that hasn't produced nuclear weapons in many decades.

Design and Manufacturing of Missiles and Munitions: Promising STEM and trade-skill oriented personnel are leaving the sector industry for other occupations. Individuals with these skills are becoming harder to recruit and retain due to barriers of pay, location, and cyclical sector demand. Increased engagement with the U.S, Manufacturing Institutes will support implementation of advanced manufacturing technologies, as needed, and strengthen and expand the capabilities of the US manufacturing workforce in key DoD technology areas.

Resilient Industrial Base: Surge and Gap Planning

Consistent Demand Signal: Conflict-driven procurements for missiles, munitions, and supporting energetic components make it difficult to maintain consistent and steady production demand. Steady demand enables industry to better plan for longer term stable production, negating the risk of the production line "going cold" (impacting readiness) and enabling greater surge capacity. However, U.S. government goals do not always align with industry goals.

Infrastructure: Manufacturing & Test Equipment, Test Ranges & Instrumentation

Hypersonics and Nuclear Modernization: Due to the decades-long lapse in hypersonic and nuclear weapon development and production, facilities and infrastructure (including unique production equipment) require reconstitution, major modernization, and increases in capacity. Test ranges and instrumentation also require significant capacity increases and/or modernization. Investment in both industry and organic DoD facilities is needed to achieve required capability and capacity.

FY2020 Developments

COVID-19 Impacts

COVID-19 has impacted the missiles and munitions sector less than other DIB sectors because it is nearly 100 percent DoD unique, unlike other areas which have been suffering due to the loss of commercial demand (e.g. Aircraft). There has been no decrease in the demand for missiles and munitions; this steady demand has kept the sector industrial base relatively healthy. In the spring and summer of 2020, some missile sector industrial facilities temporarily closed; however, all facilities reopened by September and remain open. Some impacts continue to be felt in program schedules and production deliveries, but the sector is better positioned should outbreaks increase again.

Ammonium Perchlorate (AP) Production

Ammonium Perchlorate is a critical energetic oxidizer with a decades-long history of use in rocket propellants, including space launch. Former suppliers have left the industry due to limited and inconsistent demand, which significantly reduced when the Space Shuttle program ended.

To address the AP supply issue, OUSD (IP) issued a Request for Information in 2017 seeking information about domestic AP sourcing. A business analysis was conducted for AP production on a GOCO plant and found not cost effective. One industry partner is developing a capability (online in late 2020) to produce AP from domestic materials, which will provide competition, supply stability, and reduce cost.

Energetic Materials

In addition to AP, the Department must address other critical energetic materials, such as Butarez, Potassium Nitrate, Zirconium, and Aluminum. A third of DoD's energetic material is produced overseas, and many materials have direct dependencies on China. Industry often chooses not to use domestic or allied sources of these chemicals even when available due to pricing.

The Critical Energetic Materials Working Group (CEMWG) executes a coordinated Department-wide approach to identify energetic materials and their ingredients that are at risk of becoming unavailable to the DoD. In 2019, CEMWG released a survey to government and industry to identify at-risk chemicals. The CEMWG found that the industrial base for chemicals was fragile, vulnerable to supply chain disruptions, dependent on foreign nations for a significant number of sole-source chemicals used in the majority of the DoD's munitions, reliant on obsolete specifications, and impacted by increasing environmental regulatory pressure within the U.S. and abroad. In January 2019, the President signed four Presidential Determinations to allow the use of DPA Title III funding to mitigate risk for critical chemicals for munitions.

Large Solid-Rocket Motors (LSRM)

To address the LSRM risk, Aerojet Rocketdyne (AR) is reconstituting LSRM manufacturing capability at its Camden, Arkansas facility. Northrop Grumman has announced its intent to include AR as part of its national team for ground-based strategic deterrent (GBSD), which should continue to provide DoD with two suppliers.

Production Capacity

DoD has conducted munitions war rooms to identify opportunities to accelerate munitions deliveries by either increasing production capacity or shortening lead times. These deep dives into each munition's industrial suppliers have been critical to identify and address capacity constraints and/or production bottlenecks. These efforts are labor and data intensive, which limits the Department's ability to execute war rooms to the highest risk items.

Sector Outlook

Missile budgets are expected to decline over the next few years, and then remain relatively stable through the next decade. The market for missiles and munitions has recovered from a decline in the early 2010s (in the wake of the 2008 recession) and the precision guided munitions market expanded by over 50 percent from 2014-2020.

Planned efforts in hypersonics and nuclear modernization will tap into new areas of the industrial base, but will also tax some of the existing base, particularly elements that support conventional missile production within the sub-tier supplier base. U.S. industry is willing to invest in production capacity and capability for hypersonics, but many suppliers are waiting on clear U.S. government plans and forecasts to justify the business case for these investments. A more detailed overview of the hypersonics industrial base is addressed in the Emerging and Critical Technologies section of this report.

The E.O. 13806 report, the CEMWG, and the war room process have improved visibility into the health of the missiles and munitions sector, and directed mitigation actions in several high-risk areas. The Department will continue to assess and mitigate higher-risk areas to improve the health of the industrial base, and continue to advocate for the strategic assessment, modernization, and expansion of U.S. and allied production capacity.

Nuclear Matter Warheads

Sector Overview

The Nuclear Matter Warheads Sector consists of U.S. government-owned, contractor-operated (GOCO) sites, and U.S. government furnished equipment used in the design, building, and testing of our nation's nuclear warheads. The U.S. nuclear deterrent is a lynchpin in defense planning and that of U.S. allies and adversaries. Nuclear weapons are designed and produced to meet an "Always/Never" standard:

1. They must always work when authorized by proper authority, and
2. They must never work in any situation or environment (normal, abnormal, or adversarial) without authorization by proper authority.

Supply chain availability and integrity are crucial to achieving the "Always/Never" standard, but an increasing set of risks threaten the integrity of the enterprise. Some of the associated research, development, production equipment, and software are designed and produced in-house by the DoD's organic industrial base. However, the majority is procured from outside vendors.

Major Risks & Issues

Risk Archetypes:

- DMSMS
- Product security

Macro forces driving risk to the Nuclear Matter Warheads Sector are a reflection of the same forces driving risks to other sectors upon which the nuclear matter warheads sector is dependent (e.g. machine tools, electronics, and materials). Chief among those macro forces is the globalization of supply chains for software, materials, and equipment.

Clearable Workforce

The U.S. faces a diminishing supply of clearable labor with the advanced education and training necessary for designing, producing, and stewarding nuclear weapons. The primary source of that labor, U.S. colleges and universities, generate insufficient U.S. citizen graduates in STEM areas relevant to the nuclear enterprise. The U.S. also lacks labor with important trade skills, including welders. Additional challenges due to clearance requirements greatly reduce the available pool of labor.

Microelectronics/Electronic Components

Nuclear warheads depend on trusted sources of microelectronics and electronics. However, due to diminishing U.S.-based microelectronic and electronic manufacturing capability, it is challenging to ensure that finished assemblies, systems, and subsystems exclusively leverage trusted, discrete components.

Critical Materials

Various sole source materials, addressed through the Nuclear Posture Review, are unavailable through trusted sources in sufficient quantities to ensure a robust and independent nuclear capability throughout a weapon's lifecycle. The problem is exacerbated by policies and requirements that limit or place restrictions on procurement options (e.g. life of program buys).

Software Systems/Applications

Lack of trusted sources of software design tools, data management systems, manufacturing execution, and facility controls introduces risk to the nuclear weapons engineering environment. This problem is exacerbated by poor cybersecurity practices of many key software vendors.

Analytical and Test Equipment

Given current nuclear weapons test restrictions, specialized analytical and test equipment is essential to ensure the "Always/Never" standard. Components, subsystems, and systems must be tested to unique qualification standards, but the test equipment supplier base is increasingly globalized and not trusted, leading to uncertainty in testing.

FY2020 Developments

The Department of Energy (DoE)/National Nuclear Security Administration (NNSA) has several warhead modernization efforts underway and managing the supply availability and integrity is key for the successful completion of these efforts.

The B61-12 Life Extension Program (LEP) will integrate DOE efforts to extend the service life of the warhead with DoD efforts to develop a guided Tail Kit Assembly (TKA) required to maintain current B61 mission characteristics. Programmatic integration of the Air Force-led, joint DoD-DOE program is accomplished through the B61 LEP Project Officers Group and its subgroups. The U.S. Air Force is responsible for development, acquisition, and delivery of a guided TKA and for All Up Round technical integration, system qualification and fielding of the B61-12 variant on multiple platforms. The production effort for the B61 TKA includes the production and delivery of TKAs, accessories, spares, ancillary equipment, trainers, lot acceptance test assets, and support. The program received the signed Acquisition Decision Memorandum authorizing the B61 Mod 12 LEP TKA program to enter into the Production and Deployment phase on October 26, 2018.

The NNSA, in coordination with the DoD, is also extending the life of the W80-1 warhead as part of the W80-4 Life Extension Program. The W80-4 will be used on the Long-Range Standoff weapon which is expected to replace the legacy Air Launched Cruise Missile in mid-2020.

COVID-19

In 2020, the COVID-19 crisis presented a series of truly unprecedented challenges for the nuclear security enterprise and its workforce. The health and safety of our employees is and will continue to be the Department's main focus. Due to our critical national security missions, the NNSA could not and cannot temporarily cease operations until the crisis is over.

NNSA adopted a policy of maximum telework and social distancing to safeguard the health and welfare of the workforce, while also identifying a number of mission-critical activities that could not be performed remotely and needed to continue on-site. NNSA worked with its sites to set priorities and relied on them to make decisions based on the local situation and regulations to protect the workforce.

At the outset of the pandemic, NNSA directed the management and operating teams to continue production of the essential components and assemblies required to maintain critical missions. NNSA leadership is currently evaluating options to manage future impacts based on additional periods of COVID-19 limitations.

Sector Outlook

The Nuclear Matter Warheads Sector is increasingly challenged by reliance on foreign vendors for the supply and maintenance of advanced machine tools, and dependent on globalized complex supply chains for materials and components. Recent and ongoing life extension programs provide opportunities to address some of these vulnerabilities as new contracts and supply chains are developed.

Organic Defense Industrial Base

Sector Overview

The Organic Industrial Base (OIB) includes government-owned government-operated (GOGO) and government-owned contractor operated (GOCO) facilities that provide specific goods and services for the Department of Defense.

The OIB is comprised of resource providers, acquisition and sustainment planners, and manufacturing and maintenance performers in depots, shipyards, manufacturing arsenals, and ammunition plants. Collectively, the OIB provides maintenance and manufacturing services to sustain approximately 339,290 vehicles, 280 combatant ships and submarines, and over 15,340 aircraft and supporting critical safety items. Roughly $92 billion of DoD's total FY2019 $687.8 billion expenditure was applied to maintenance

Organic Manufacturing Arsenals, Major Depot Maintenance Facilities, and Ammunition Plants	
Army – Anniston Army Depot, Anniston, AL – Corpus Christi Army Depot, Corpus Christi, TX – Letterkenny Army Depot, Chambersburg, PA – Red River Army Depot, Texarkana, TX – Tobyhanna Army Depot, Tobyhanna, PA – Rock Island Arsenal, Joint Manufacturing and – Technology Center, Rock Island, IL – Watervliet Arsenal, Watervliet, NY – Pine Bluff Arsenal, Pine Bluff, AR – Crane Army Ammunition Activity, Crane, IN – Holston Army Ammunition Plant, Kingsport, TN – Iowa Army Ammunition Plant, Middletown, IA – Lake City Army Ammunition Plant, Independence, MO – McAlester Army Ammunition Plant, McAlester, OK – Milan Army Ammunition Plant, Milan, TN – Radford Army Ammunition Plant, Radford, VA – Scranton Army Ammunition Plant, Scranton, PN – Quad Cities Cartridge Case Facility, Rock Island, IL	Navy – Fleet Readiness Center East, MCAS Cherry Point, NC – Fleet Readiness Center Southeast, NAS Jacksonville, FL – Fleet Readiness Center Southwest, NAS North Island, CA – Portsmouth Naval Shipyard, Portsmouth, ME – Norfolk Naval Shipyard, Portsmouth, VA – Puget Sound Naval Shipyard and Intermediate Maintenance Facility, Bremerton, WA – Naval Surface Warfare Center Indian Head Division, Indian Head, MD – Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility, Pearl Harbor, HI
Air Force – Ogden Air Logistics Complex, Hill AFB, UT – Oklahoma City Air Logistics Complex, Tinker AFB, OK – Warner Robins Air Logistics Complex, Robbins AFB, GA	Marine Corps – Marine Depot Maintenance Command, Albany Production Plant, MCLB Albany, GA – Marine Depot Maintenance Command, Barstow Production Plant, MCLB Barstow, CA

Figure 7.20

activities and services. DoD currently operates 17 major organic depot maintenance facilities and three manufacturing arsenals. Services provided within the OIB range in intricacy from daily system inspection and maintenance to Pilot Plant Scale-up, comprehensive depot-level overhaul, or rebuilding of engines and major weapon systems.

From a broader national security perspective, the OIB acts as an insurance policy to ensure a ready and controlled source of technical competence and resources. In doing so, the OIB executes sizeable legislatively and administratively directed production and maintenance workloads. Congress has developed an extensive framework of statutes that govern the establishment and workloading of core organic industrial capabilities, maximum yearly private sector industrial workload allocation, initial depot source of repair assignments, and subsequent movement of critical weapon system, engine, and component workloads. The OIB is positioned to provide the capacity and capability to support the readiness and materiel availability goals of current and future DoD weapon systems. However, FY2020 presented the OIB with both unforeseen and overarching, endemic risks and issues.

Major Risks and Issues

Risk Archetypes

- Erosion of U.S.-based infrastructure
- Sole source
- Gaps in U.S.-based human capital.

Three primary macro forces and three key "risk archetypes," as categorized by the EO 13806 report, face the OIB. The macro forces include sequestration and uncertainty of U.S. government spending, the decline of U.S. manufacturing base capabilities and capacity, and diminishing U.S. STEM and trade skills. Three corresponding major risk types confront the OIB: 1) erosion of U.S.-based infrastructure; 2) reliance on sole source providers; and 3) gaps in U.S.-based human capital.

Erosion of U.S.-Based Infrastructure: The condition of the OIB continues to be encumbered by dated infrastructure, driven by longstanding investment trade-offs resulting in resourcing shortfalls. DoD is working to address both near and long-term OIB capability gaps through initiatives expected to improve strategy, policy, performance, resource advocacy, and outcomes. However, given the resources committed to infrastructure investment in DoD's OIB, operational drivers have strained the OIB more than the budget allows. The erosion of organic infrastructure continues to impact turnaround time and repair costs of both legacy and new weapon systems, decreasing operational readiness and impacting future deployment schedules. To address this risk, DoD is developing a congressionally mandated comprehensive OIB infrastructure improvement strategy that will drive increases in Joint Force readiness and materiel availability.[46] By introducing innovative process improvement and organizational solutions to be overseen by DoD-level governance, OIB infrastructure needs will receive greater visibility, increasing the likelihood of attaining required resourcing. Additionally, the introduction of a series of new state-of-the-Art Pilot-Scale Plants with flexible products & capacities would be an infrastructure solution to provide right-sized production capability for multiple legacy & emerging energetic materials with minimum facility investment by DoD.

Reliance on Sole Source Providers: The OIB supports the nation's defense industrial base manufacturing capability to provide operationally available scenario-tasked weapon systems. It is therefore imperative to ensure continuity of operational readiness of these facilities in order to meet both peacetime and surge requirements. OIB installations have been challenged in FY2020 and have experienced significant cost and schedule disruptions, resulting in both near and long term materiel readiness impacts for weapon systems across the Military Services. Due primarily to operational impacts of COVID-19, the viability of significant portions of sole source OIB capability has been threatened. To address this risk, the OIB must recover financial losses and pre-COVID military readiness rates.

Gaps in U.S. - Based Human Capital: The OIB confronts workforce skill gap risk throughout the sector. The emergence of new weapons system technologies, coupled with legacy system retirements, has driven a substantial disparity between skill requirements and workforce capabilities. Recruitment and retention of critical skill sets is also a primary OIB concern, mainly because of strong competition for skilled labor from the private sector and a lack of defense-specific skills. To mitigate this risk, several ongoing and interrelated mitigation strategies and initiatives are underway. For example, each of the Military Departments has implemented the direct hire authority provided by Congress to hire required OIB personnel. Innovative training approaches have been introduced to improve the OIB's recruitment of trained artisans that can provide significant and immediate impacts on productivity and readiness.

FY2020 Developments

Sector Outlook

The OIB, like most sectors of DoD's industrial base, faces considerable challenges. The OIB outlook, however, is that sound progress is possible and underway, driven by an unyielding focus upon National Defense Strategy imperatives. This section highlights three elements central to the way forward for the OIB.

First, new technologies and processes continually impact the strength and resilience of the OIB. Therefore, the OIB must continually refresh and modernize tools and processes used to retain materiel readiness. Within OSD, the Office of the Deputy Assistant Secretary of Defense for Materiel Readiness leads a broad set of maintenance technology and innovation initiatives in partnership with OUSD(R&E), the Military Departments, and industry partners. These initiatives focus on cross-cutting industrial base capabilities that enable the OIB to generate materiel availability at lowest cost, enable reduced repair cycle times, and provide higher reliability more safely. Examples of OIB innovations and technology development and insertion that will impact the future viability and effectiveness of the OIB include additive manufacturing, predictive maintenance, big data analytics, robotics and automation, non-destructive inspection, and advanced electronics diagnostics. A specific example of innovative OIB technology insertion is Intermittent Fault Detection Technology. Additionally, to address OIB obsolescence issues, the Department has developed a series of Pilot-Scaled energetic material facilities that could offer flexibility in the production of multiple products at varied scales.

COVID-19 Impacts

COVID-19 had major operational and budgetary impact on the OIB in FY2020. Reduced operational exercises, force training cancellations, and mission adjustments resulted in reduced production output throughout the OIB. COVID-19 workforce non-availability also decreased operations, both internal to the OIB and throughout its supply chains. Reduced demands/sales impacted the OIB's financing mechanism, the Working Capital Fund, by diminishing the fund's corpus and thereby increasing the cost of goods sold, while concurrently hampering annual throughput. Most installations have returned to pre-COVID production levels, and each Military Service war fighting domain, except for Navy (Air), expects to "carryover" some portion of their workload into FY2021. With delays in depot repair schedules, waivers may be required due to the carryover limits in the Financial Management Regulation. U.S. Navy ship maintenance is especially affected and may be unable to fully recover its schedule due primarily to physical shipyard constraints. To ensure the OIB returns to pre-COVID production rates, it is estimated that a fiscal solution that addresses approximately ten percent of the FY2019 total spend on DoD depot maintenance is required.

The second key emerging trend related to the OIB's outlook is that near-peer focused warfighting activities, particularly those related to posture, is becoming gradually more interlinked with OIB capability and capacity. In this contested logistics environment, weapon systems sustainment, and maintaining and building contingency bases and connected infrastructure is increasingly important. While progress is being made to improve OIB resilience in a near-peer contested logistics environment, the OIB must be postured with a new and constantly evolving set of decision support systems, supply chains, resourcing, and capability provision tools.

Finally, the OIB will be significantly shaped by investment choices, particularly in key elements of OIB infrastructure. This issue has been called into sharp focus with concern about possible shorting amounts of funding required for capital equipment purchases and the requirement of "heel-toe-funding," with many projects precisely timed. These require projects and regular maintenance to be executed and funded on schedule throughout the OIB.

Radar and Electronic Warfare

Sector Overview

Military radars and electronic warfare systems play a significant role in meeting our national security objectives. Radar is essential to detecting the presence, direction, distance, and speed of targets such as aircraft, ships, and weapons, and for controlling flight and weaponry. Radar achieves detection by transmitting electromagnetic waves that reflect off objects and return to the receiver to enable detection. Required to operate in the harshest environments to support combat operations, military radar system requirements are often more stringent than those imposed on commercial systems. Radar systems have many applications and can be used to detect slight changes to surfaces over time—allowing, for example, the detection of footprints of shallow depth.

Electronic warfare (EW) systems continue to become a more integral element of military weapon systems. EW refers to military action involving the use of electromagnetic energy and directed energy to control the electromagnetic spectrum or to attack the enemy. The purpose is to deny the opponent the advantage of, and ensure friendly unimpeded access to, the electromagnetic spectrum. This includes capabilities for electronic attack, electronic support, and electronic protection. EW systems are dependent upon technologies similar to those found in radar systems, including receivers and transmitters. They include countermeasure technologies such as chaff and flares, which can target humans, communications, radar, or other assets.

DoD has roughly 100 radar systems in development, production, or sustainment with a similar portfolio of electronic warfare systems. These systems provide critical mission capabilities and perform functions in four operational domains; land, air, space, and sea. There are a total of 23 firms that produce or have produced radars for the DoD. Three domestic suppliers dominate the domestic radar market and four domestic suppliers dominate electronic warfare systems. An emerging area of investment and interest is directed energy capability. Both laser and high power microwave systems are in the research and development phase, and these technologies and industrial base areas often align with the radar and electronic warfare industrial base risks.

Major Risks & Issues

Risk Archetypes

- Single source
- DMSMS
- Foreign dependency

The Radar and Electronic Warfare Working Group, which contributed to the September 2018 Interagency Task Force response to Presidential Executive Order E.O. 13806, identified several forces driving risk to DoD.[47] The working group identified five prioritized risks that drove mitigation efforts moving forward. In FY2020, three risks were paramount.

Availability of Electronic Components

This risk is driven by aging DoD systems which lead to obsolescence of available components, the fluidity of commercial technology, and decreasing U.S. industrial and manufacturing infrastructure.

Availability of Vacuum Electronic Device Materials, Components, and Manufacturing Sources

This risk is driven by requirements to leverage multiple sole and single source material suppliers both internal and external to the U.S., market fragility with the growth of the Gallium Nitride (GaN) Solid State based systems, and decreasing industrial and manufacturing infrastructure. Two high visibility material issues include: rare earth magnets that rely on raw material and metal oxides provided from China; and the lack of U.S. sources for high quality tungsten rhenium and thoriated tungsten wire.

Reduced Competition and Innovation for Tactical Radar and EW Systems

One example of this risk is the F/A-18 Actively Electronically Scanned Array (AESA). Similar AESA radars are being produced for other applications, but once the F/A-18 production ends, only a single qualified source remains.

FY2020 Developments

The onset of the coronavirus pandemic has negatively impacted the radar and EW sector, as well as the entire commercial and military industrial base; however, considerable work has been accomplished this fiscal year. Multiple programs across DoD have supported risk mitigation activities in the Radar and EW sector in FY2020.

Two programs of note that are focusing heavily on Gallium Nitride (GaN) technology (a significant enabler for AESA-based radar and EW systems) are the ManTech and Microelectronics Innovation for National Security and Economic Competitiveness (MINSEC) programs. Both of these programs are funding efforts related to GaN manufacturing. In one ManTech project, BAE Systems is partnering with the Air Force Research Laboratory (AFRL) to develop and mature an open-foundry 140 nm GaN Monolithic Microwave Integrated Circuits (MMIC) technology, with a focus on efficient power amplification at frequencies ranging from DC to 50 GHz, and a 90 nm technology targeted towards higher frequency applications.

The radio frequency and optoelectronic (RF/OE) technical execution area (TEA) of the MINSEC program develops and demonstrates secure access to SOTA foundries, designs, and intellectual property (IP). RF/OE investments enable next generation DoD programs with advanced sensors and communications, and bolster the underlying DIB. The RF/OE Community of Interest guiding these investments comprises over 60 subject matter experts, who gather at semi-annual TEA workshops to ensure alignment across services and industry.

To mitigate risk areas impacting the vacuum electron tube industry, multiple efforts were undertaken in FY2020. Perhaps the widest reaching effort was President Trump's July 2019 use of DPA projects to mitigate the reliance on foreign sources for rare earth elements. Presidential Determination letters were signed to enable risk mitigation in five focus areas:

1. Light Rare Earth Element Separation and Processing,
2. Heavy Rare Earth Element Separation and Processing,
3. Rare Earth Metals and Alloys,
4. Samarium Cobalt Magnets, and
5. Neodymium Iron Boron Magnets.

A DoD-wide technical working group led by the DPA Title III office is currently developing the required technical data packages to allow solicitation of these projects. In FY2020, two of the five topic areas were released for bids and have closed. Efforts are currently underway to finalize and announce the awards. Rare earth magnets and materials are required not only to support the vacuum electronics industrial base and the radar and EW community, but are required to support precision guided munitions, laser systems, sensors and actuators on airborne platforms, and future electronic propulsion systems.

Additional projects are currently being worked in FY20 to develop new sources and materials to mitigate the use of foreign-sourced thoriated tungsten and tungsten rhenium wire that is required for use in the vacuum electronics industry. The DLA and the DPA Title III program are supporting those respective efforts, which are scheduled to continue into FY2021.

Sector Outlook

The NSS and NDS emphasize the need for a strong, resilient defense industrial base and the E.O. 13806 report identified macro forces that have disrupted and deteriorated the U.S. radar and EW industrial base. In FY2020, the IBAS Program developed a Radar Supplier Resiliency Plan (RSRP), which was signed by USD(A&S) Ellen Lord, and delivered to the House and Senate Armed Services Committees.

The IBAS program formed a Joint Radar Industrial Base Working Group (JRIBWG) to support the development of the RSRP by researching core issues and identifying key leveraging opportunities. The RSRP identifies five radar sector challenges and five strategies to offset those challenges. It also identifies proposed projects to bolster the radar and EW industrial base and address risk areas identified in the Interagency Task Force response to EO 13806. As discussed in the RSRP, successful execution of the plan is dependent upon long-term fiscal comments required for the JRIBWG to strengthen and sustain the U.S. radar DIB.

Shipbuilding

Sector Overview

The shipbuilding industrial base is responsible for every aspect of shipbuilding, from design to decommissioning of aircraft carriers, submarines, surface ships, and their weapons and command and control (C2) systems. Over the past five decades, the industrial base has experienced significant consolidation. Fourteen defense-related new-construction shipyards have closed, three have left the defense industry, and one new shipyard has opened.

The sector includes shipyards – fixed facilities with dry docks and fabrication equipment – as well as manufacturing and other facilities that provide parts and services for shipbuilding activities. Today, the U.S. Navy contracts primarily with seven private new-construction shipyards, owned by four prime contractors, to build its future Battle Force, representing significantly less capacity than the leading shipbuilding nations.

There are also a number of smaller private-sector shipyards and facilities building non-battle force and unmanned vessels. Repair and maintenance is conducted at large and small private yards in addition to four public naval shipyards.

The shipbuilding industrial base can be further segmented by ship type: aircraft carriers, submarines, surface combatants, amphibious warfare, combat logistics force, and command and support vessels.

Major Risks & Issues

Risk Archetypes:

- Capacity constrained supply market
- Sole source
- Fragile market
- Gap in U.S.-based human capital

The major risks in the shipbuilding industrial base remained constant in FY2020. The diminishing domestic commercial shipbuilding sector continues to magnify these risks.

Capacity Constrained Supply Market

The increase in ship construction to reach a U.S. Navy fleet of 355 ships by 2035, and even greater growth beyond that, will strain the current U.S. shipbuilding sector. The resulting additional workload is a significant increase from current production levels and will challenge shipyards and their suppliers as they expand and adjust to meet larger production volumes. A new mix of vessels in the fleet will likely force incumbent shipyards to modify their business plans and facilities to meet these new demands. Shipyards and suppliers that don't currently participate in U.S. Navy shipbuilding will see new opportunities, particularly in small and unmanned vessels.

Sole Source Suppliers

The number of domestic suppliers at the lower tiers of the supply chain continues to decline. Due to macroeconomic forces, the Navy expects this trend to continue. The limited availability of suppliers requires the U.S. Navy to consider the workload and financial health of the supply chain when making procurement decisions. Low demand volumes in certain market spaces result in the selection of single or sole sources of supply for critical products, either out of necessity, or sometimes to promote resiliency during low production periods.

Fragile Markets

There are currently four prime contractors producing nearly all of the U.S. Navy's ships, and two that comprise the vast majority of shipbuilding sales. A limited number of yards, and the size and complexity of operations, makes it difficult for new businesses to enter the market. Only one shipbuilder is currently producing aircraft carriers, and only two are producing submarines, after a decision by the Navy to divide new work between Electric Boat and Newport News.

Unstable Demand

Fluctuation in planned modernization and procurement is also a long-term challenge, as changes in ship procurement plans impact the shipyards and lower-tier suppliers' workload. Battle Force 2045, discussed below, is an example of the Navy's changing requirements. This instability is necessary for the Navy to respond to emerging threats, but it results in financial risk to the industrial base as companies struggle to align their business decisions. The timing of ship procurements is also critical to achieve the stable workload required to support the viability of the shipbuilding industrial base and to sustaining a skilled workforce. Advanced procurement for long lead time material and economic order quantities, as well as multi-program material purchases, continue to be used to ensure stability in the industrial base.

Gaps in U.S.-based Human Capital

In addition to the challenges found in other manufacturing sectors throughout the U.S., shipbuilding has unique challenges, such as too few replacements for retiring workers, insufficient labor mobility, the perception of unattractive physical working conditions, and the cyclical nature of shipbuilding.

Shipbuilders and suppliers are stepping up recruiting efforts in response to these market realities. They are supported in many different ways by a multitude of entities including the OSD, the U.S. Navy, other federal agencies, state and local governments, and local and regional economic development initiatives. U.S. government support efforts typically include funding for capital investments to improve working conditions, training grants, and tax relief in exchange for meeting employment targets.

FY2020 Developments

New Programs or Initiatives

The Navy awarded the detail design and construction of the first Constellation Class guided missile frigate with options for up to nine more ships to the Marinette Marine Corporation. Another contract contains options for the design and construction of the first two Columbia Class ballistic missile submarines. Lead ship construction awards will occur in FY2021.

In October 2020, the Secretary of Defense unveiled Battle Force 2045. Derived from the Future Naval Force Study, which is still in process, it calls for a more balanced Navy of over 500 manned and unmanned ships. It retains the goal of reaching 355 traditional Battle Force ships by 2035. Highlights regarding shipbuilding include:

- A larger and more capable attack submarine force
- A potential reduction of nuclear powered aircraft carriers with an increased role for light carriers
- The addition of 140 to 240 unmanned and optionally manned vessels to perform a wide range of missions
- An increased number of small surface combatants
- Enhanced sealift capacity

In his remarks, the Secretary of Defense committed to increasing funding to shipbuilding accounts by harvesting reform efforts throughout the rest of the DoD. The end result will be a larger, more lethal, survivable, adaptable, sustainable, and modern force than we have seen in many years.

COVID-19

All U.S. Navy shipbuilders and most suppliers have continued operations since the beginning of the coronavirus pandemic. There have been challenges in staffing to optimal levels throughout the sector, which resulted in delays and supply disruptions. The Navy is working with shipbuilders and their suppliers to minimize these disruptions. Companies are focused on maintaining strong cash balances and liquidity through a variety of strategies as a buffer to continuing fiscal challenges. The Navy has accelerated payments on its contracts, and in many cases the prime contractors have flowed these funds into their supply chains. The Navy is monitoring COVID-19 impacts to over 600 suppliers, and has provided additional funds to some of the most critical suppliers experiencing financial distress. While staffing levels and efficiencies have improved since the beginning of the outbreak, it is expected that the sector will remain staffed at approximately 80 percent of pre-COVID-19 levels for the foreseeable future. This is primarily due to enhanced safety programs, quarantine requirements, school closures, and employees with high risk health factors. The Navy expects these challenges to result in schedule delays and cost increases on many programs, but the magnitude of these is unknown.

Industry Changes

The U.S. Navy continually monitors its industrial base, focusing on critical suppliers to ensure the supply of material and components for shipbuilding programs. There are constant changes in an industrial base with thousands of suppliers, but the health of the industrial base remained steady in 2020. The Navy is closely monitoring the purchase of AK Steel Corporation and ArcelorMittal USA by Cleveland-Cliffs Inc., which has traditionally been a mining company; and the purchase of Fairbanks Morse Engines, a critical supplier of medium speed diesel engines for the Navy, by Arcline Investments, a private equity firm.

Ship Awards and Deliveries

Despite the COVID-19 disruptions, the shipbuilding sector continued to deliver ships. Ten ships were delivered in 2020: two Virginia Class submarines (SSN 791 and 792), one America Class amphibious assault ship (LHA 7), one Arleigh Burke Class destroyer (DDG 119), three littoral combat ships (LCS 19, 22, and 24), one Lewis B Puller Class expeditionary sea base (T-ESB 5) and two Spearhead Class expeditionary fast transports (T-EPF 11 and 12).

In FY2020, the Navy awarded a multi-year contract for nine Virginia Class submarines (SSN 802-810) through FY2023 with an option for an additional ship. All but one of these ships will have the Virginia Payload Module. The Navy awarded the first of its new Constellation Class guided missile frigates (FFG 62) with options for nine additional ships. One San Antonio Class amphibious transport dock (LPD 31) along with two Navajo Class towing, salvage, and rescue ships (T-ATS 9 and 10) were also awarded in FY2020. Contract options were exercised for one John Lewis Class fleet replenishment oiler (T-AO 210) and one Arleigh Burke Class destroyer (DDG 135).

Sector Outlook

Strategic Competition

China has the largest navy in the world with a battle force of approximately 350 vessels, including major surface combatants, submarines, ocean-going amphibious ships, mine warfare ships, aircraft carriers, and fleet auxiliaries. China's 2019 defense white paper described the People's Liberation Army Navy (PLAN) as speeding up the transition of its tasks from "defense on the near seas" to "protection missions on the far seas." The PLAN is an increasingly modern and flexible force that has focused on replacing its previous generations of platforms in favor of larger, modern multi-role combatants. This modernization aligns with China's growing emphasis on the maritime domain and increasing demands for the PLAN to operate at greater distances from mainland China.[48]

The shipbuilding sector of the DIB is perhaps unique in that the U.S. is not a major contributor to the global commercial market. The U.S. accounts for less than one percent of commercial shipbuilding by tonnage. China is the world's leader with South Korea and Japan rounding out the top three shipbuilding countries. Major changes to the current relative production levels of today's major shipbuilding countries is unlikely.

The largest contributing factor of declining U.S. competitiveness in global shipbuilding has been state intervention from competitor countries. China's shipbuilding industry benefits from a robust domestic industrial economy that provides raw material and components to shipbuilders. It is China's long-term goal to have an entirely self-reliant defense industrial sector, and they have established market leading positions in many heavy industries that support shipbuilding. As an example, China is the world's largest steel producer and user by a large margin.

Given current macroeconomic conditions, China is expected to continue to out-build the United States in terms of ship quantities. The U.S. Navy will continue to use its technological advantages to maintain superiority in the maritime domain.

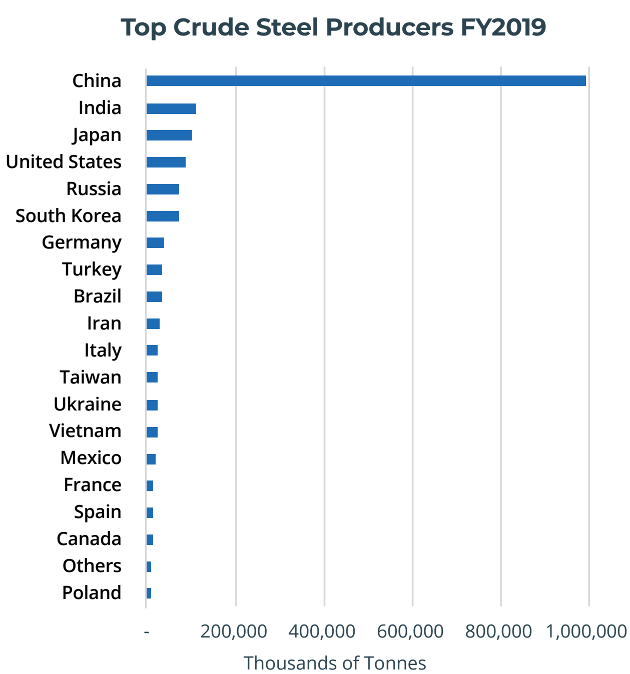


Figure 7.21: FY2019 Top Crude Steel Producers[49]

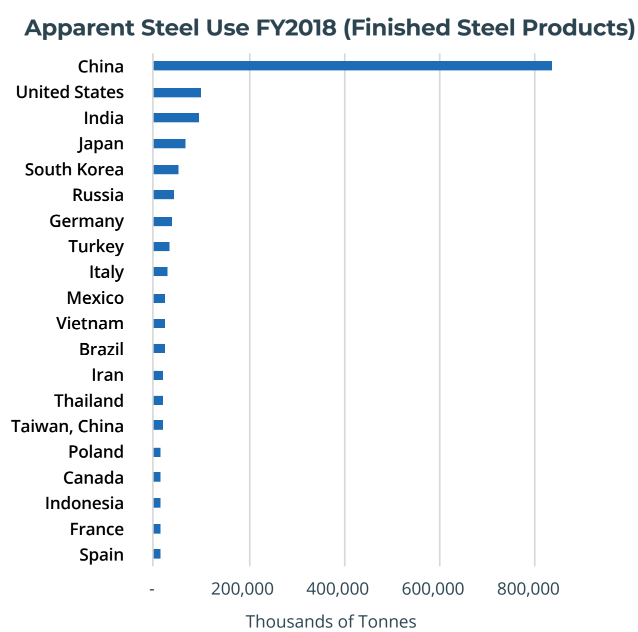


Figure 7.22: FY2018 Top Steel Users (Finished Products)[50]

Software Engineering

Sector Overview

Software engineering is the application of a systematic, disciplined, quantifiable approach to the development, operation, and maintenance of software. Software engineering capability includes the processes, resources, infrastructure, and workforce competencies to enable systems to meet operational mission requirements and evolving threats. Challenges within this sector have evolved significantly over the last several decades as the demand for engineering professionals and the DoD policy and processes for software failed to keep pace with the current and future digital transformation of the modern battlefield.

Software is in virtually every piece of electronics in the form of firmware, operating systems, and applications. This includes DoD weapon systems, mission support systems, maintenance systems, and business systems. Today's modern weapon systems rely heavily on software to provide functionality. For example, the F-35 is estimated to rely on software for 90 percent of its avionics specification requirements. This has grown significantly over the last four decades when the F-15A had just 35 percent software reliance in 1975.

Unlike physical hardware, software can be delivered and modified remotely, facilitating rapid adaptation to changes in threats, technology, mission priorities, and other aspects of the operating environment.

Software for many weapon systems is being sustained with processes developed decades ago for hardware-centric systems.

Unfortunately, software for many weapon systems is being sustained with processes developed decades ago. In addition, much of DoD policy remains hardware-centric, despite software providing an increasingly larger percentage of system functionality. In today's fast-paced, changing environments with mounting cyber threats, software engineering for software-intensive systems should utilize agile software development methodologies and development, security and operations (DevSecOps) processes, and apply contracting practices capable of rapidly delivering incremental and iterative changes to the end-user. Efficiencies gained with the widespread adoption of these processes will help to alleviate the shortfall of qualified software professionals within the DIB as addressed in the following section.

Major Risks & Issues

Risk Archetypes:

- Gap in U.S.-based human capital
- Foreign Dependency

Since software is pervasive throughout military systems and technologies, the impacts within the software engineering industrial base manifest themselves across the traditional sectors. The Software Engineering Working Group, which contributed to the September 2018 Interagency Task Force response to EO 13806, assessed impacts across sectors; as such, software risks are included in each of the sectors' inputs.[51,52]

Diminishing U.S. STEM skills, and U.S. government business practices and policies are both driving risk within the software engineering industrial base.

Government Practices & Policies

Policy, roles, and responsibilities for software engineering at the DoD level are not clearly established to effectively represent software equities at the acquisition policy and program levels. The DoD lacks a unified software engineering policy, which has produced inconsistency in practices and policy implementation across the services. Despite its prevalence, engineering sustainability of software-intensive systems during the requirements, design, and development processes has also received limited focus and priority. Collectively, these factors have negatively impacted the successful development and sustainment of software across the Department.

The DoD has also struggled to track and manage its inventory of software, which is immense and continually growing. There is limited visibility and understanding at the enterprise level of the total size, complexity, and characteristics of the inventory, which may exceed one billion lines of custom developed software code. A unified source of clear software engineering policy would aid in a unilateral implementation of appropriate practices across the industrial base.

STEM Workforce

Exacerbating the need to strengthen organic software expertise is the national STEM shortage. Today's education pipeline is not providing the necessary software engineering resources to fully meet the demand from commercial and defense sectors, and resources required to meet future demands continue to grow.

STEM covers a diverse array of professions, from electrical engineers to researchers within the medical field, and includes a range of degree levels from bachelor's to PhD. Seven out of ten STEM occupations were related to computers and information systems, with nearly 750,000 of them being software developers. Demand across all STEM sectors is not consistent; there is a surplus of PhDs seeking positions as professors in academia, while there is a shortage of individuals with electrical engineering PhDs who are U.S. citizens.[53]

The development and sustainment of increasingly complex software-intensive weapon systems requires skills from both the engineering and computer science fields. The STEM shortage cannot be addressed solely by hiring more computer programmers. Modern software-intensive systems rely a great deal on skilled software system engineers with in-depth knowledge of the systems and environments in which the software operates (e.g., avionics systems, electronic warfare, weapons, and space systems). The intersection of these disciplines creates a specialization that results in a limited resource pool when compared to the requirements of commercial software application developers. Between 2014 and 2024, job openings are projected to exceed one million for computer occupations and half-a-million for engineers.[54]

The STEM shortage is even more challenging for the DIB, which requires most employees to obtain security clearances, necessitating U.S. citizenship. Students on temporary visas in the U.S. have consistently earned 4-5 percent of bachelor's level STEM degrees awarded in U.S. colleges and universities. In 2015, these students earned a substantially larger share (11-13 percent) of bachelor's degrees in industrial, electrical, and chemical engineering. The number of STEM bachelor's degrees awarded to students on temporary visas increased from about 15,000 in 2000 to almost 33,000 by 2015.[55]

The U.S. is also graduating fewer students with STEM degrees as a percentage of population compared to China, and the trend continues to worsen. The population of China is four times that of the U.S., but is producing eight times the number of STEM graduates. The U.S. no longer has the most STEM graduates worldwide and is being rapidly outpaced by China. In 2016, the U.S. had the third most STEM graduates worldwide with 67.4 million graduates compared to China with 78.0 million.

The software engineering crisis in the DIB will not be corrected until significant effort is placed on updating software policy and processes, and more importantly, placing significant investment in software engineering education and retention initiatives. Greater attention must be paid to workforce concerns in the Software Engineering sector to maintain and develop the intellectual capital necessary to create and sustain war-winning weapon systems for the modern battlefield.

FY2020 Developments

In May 2019, the Defense Innovation Board released a report, "Software is Never Done: Refactoring the Acquisition Code for Competitive Advantage," resulting from the Software Acquisition and Practices (SWAP) study.[56] The congressionally mandated study (Section 872 of the FY2018 NDAA) outlines the importance and pervasiveness of software in modern DoD systems and emphasizes the need to decrease cycle time and develop digital talent and the enduring qualities of software that differentiate it from the hardware paradigm. Implementation of the lines of effort recommended by this study is currently underway.

In a memorandum released in October 2019, USD(A&S) Ellen Lord, released interim policy and guidance on establishing direction, responsibilities, and procedures for the management of the Software Acquisition Pathway (Recommendation A1 from the SWAP study).[57] As actions are undertaken to implement the recommendations from this study, such as the issuance of DoD Instruction (DoDI) 5000.87, "Operation of the Software Acquisition Pathway," in October 2020, the implications cast a wide net over the policy status quo. The impacts on software engineering in the DoD promulgated by these actions reflect a growing acknowledgment of the significance and prominence of software throughout the Department.

The coronavirus pandemic exposed the importance of a robust infrastructure to enable remote work. At the onset of the crisis, tremendous efforts were made to shore up the gap in capability to effectively support the mission. The software sector quickly adapted to the sudden shift in culture and applied significant resources toward improving the resilience of the new normal. While challenges remain, the urgent requirements driven by the pandemic acted as a forcing function to address a necessary shortfall in capability.

The DoD Enterprise DevSecOps Initiative, a joint program with the OUSD (A&S), DoD's Chief Information Officer (CIO), Defense Information Systems Agency (DISA), and the Military Services established teams (i.e., CloudOne, PlatformOne by LevelUp) focused on deploying hardened software factories for both existing and new environments within days instead of years (see Figure 7.23). These initiatives pulled together top talent from across the DoD, tasked with enabling the infrastructure and associated tools needed by modern software engineers to rapidly deliver software capability for the warfighter.

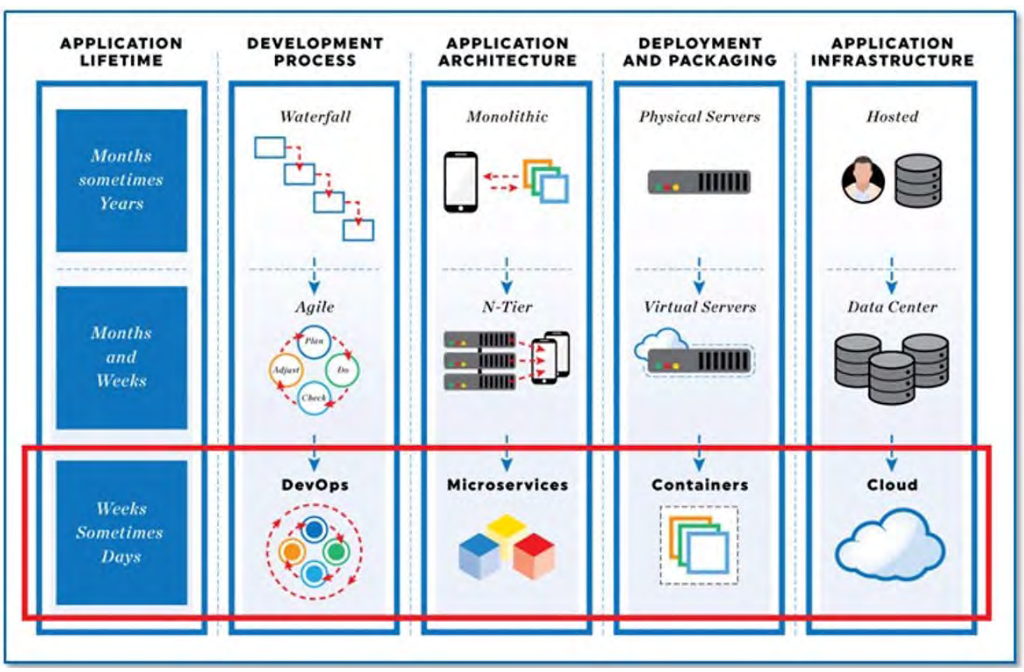


Figure 7.23, Source: DoD Enterprise DevSecOps Initiative (DSOP)[58]

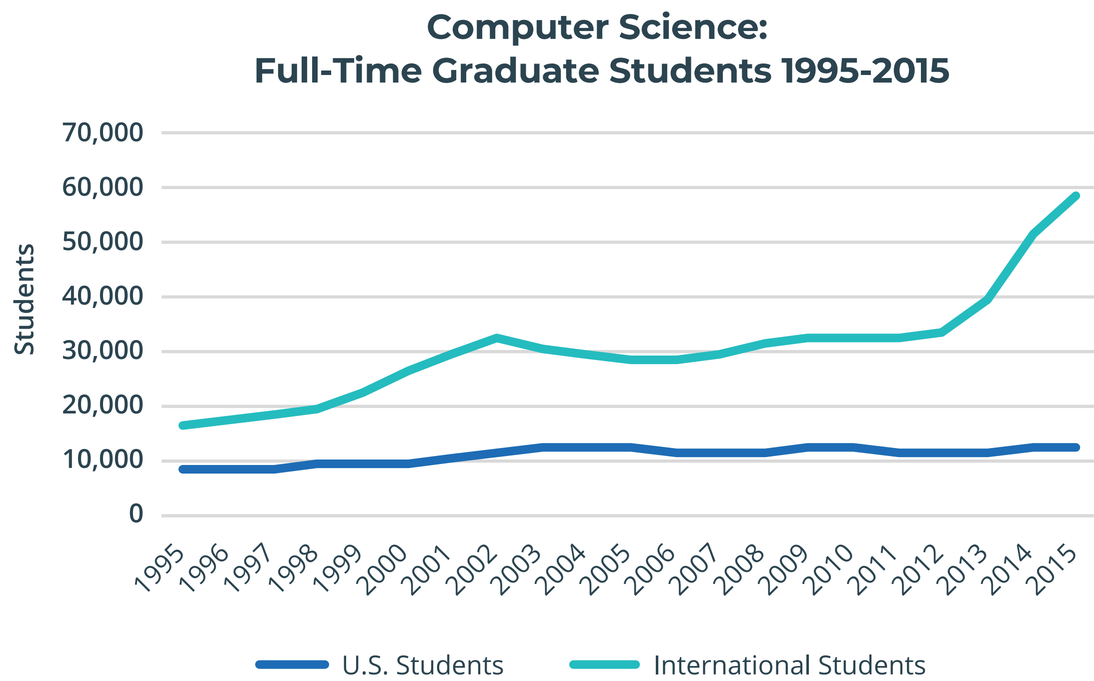
Software Engineering organizations across the services continue to focus on growing the workforce. Notably, the Software Engineering Groups of the Air Force Sustainment Center grew the organic workforce by eight percent in 2019, to a total workforce of 4500+ software engineers and computer scientists supporting over 250 distinct software projects.

Sector Outlook

From the perspective of the warfighter, adaptation at the speed of relevance is a matter of necessity to stay ahead of the ever-increasing pace of deployment practiced by our near-peer adversaries while maintaining compliance with applicable statutes. As the software engineering profession embraces cloud-based development environments with increasingly automated pipelines (enabling vastly shorter delivery cycles), policies must be updated to reflect this paradigm shift.

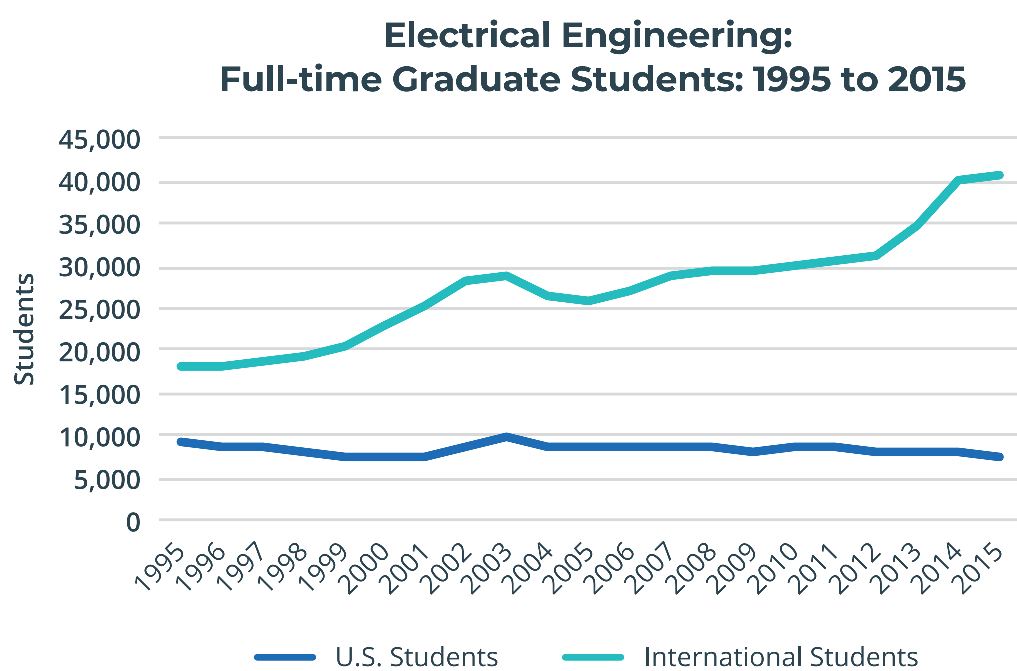
Along with the change in technologies and methods that the software engineering community is adapting by, comes a requirement for a workforce with the necessary talents to effectively employ these enablers. The production of engineers and scientists with U.S. citizenship, and the skills necessary to successfully develop and sustain the software required by the DoD in modern environments, is not keeping up with demand. As of 2017, American students make up barely 21 percent of the computer science student body and 19 percent of electrical engineering majors among our nation's universities (see Figures 7.24 and 7.25).[59] Emphasis must be directed toward inspiring the next generation to pursue STEM careers, especially in software engineering.

This issue directly threatens U.S. national self-determination in commerce and geopolitics. The STEM shortage in the DIB is quickly approaching crisis status. As stated by Arthur Herman, "We are fast approaching another Sputnik moment, we can't afford to ignore."[60] The U.S. must create a state-of-the-art STEM education strategy to cope with this reality.



Source: National Science Foundation, Survey of Graduate Students and Postdoctorates, NFAP calculations. U.S. students include lawful permanent residents

Figure 7.24, Source: National Science Foundation, Survey of Graduate Students and Postdoctorates, NFAP calculation. U.S. students include lawful permanent residents.



Source: National Science Foundation, Survey of Graduate Students and Postdoctorates, NFAP calculations. U.S. students include lawful permanent residents.

Figure 7.25, Source: National Science Foundation, Survey of Graduate Students and Postdoctorates, NFAP calculation.[61] U.S. students include lawful permanent residents.

Soldier Systems

Sector Overview

Soldier systems are the diverse products necessary to maximize the warfighter's survivability, lethality, sustainability, mobility, combat effectiveness, and field quality of life by considering the warfighter as a system. This sector includes the weapons, body armor, clothing, footwear, radios, sensors, power supply, shelters, food, and other items essential to executing U.S. military missions—from snipers to tankers to airmen to divers.

Most soldier systems have significant commercial overlap. The commercial market provides stabilizing revenue for existing defense contractors and opportunities for new players to modify commercial gear for the defense market. Companies in the sector navigate a variety of challenges, including:

- technical advancement at funding levels typically well below major defense programs;
- stringent quality control and affordability challenges in high volume production;
- legislation and regulation promoting domestic sourcing and restricting technology proliferation;
- unique defense requirements that can rapidly evolve with a wartime threat; and
- defense demand volatility that varies proportionally with operational tempo.

The advanced designs and novel industrial capabilities needed to preserve U.S. warfighter tactical advantage require a skilled workforce and modernized factories.

Major Risks & Issues

Risk Archetypes:

- DMSMS
- Single source
- Sole source
- Foreign Dependency

Industrial capability gaps in the Soldier Systems sector reduce assurance that the warfighter is prepared to successfully execute defense missions in any operating environment. Risks include single sources of supply, capacity constraints, foreign dependency, market fragility, and diminishing manufacturing sources and material suppliers. The case studies below illustrate risks that may warrant government action.

Erosion of the U.S. Textile Industry

Textiles are an integral component of many defense systems. In addition to uniforms, tents, parachutes, and backpacks, textile applications also include composite and non-woven structures such as Kevlar body armor, fiberglass in drones, and carbon fiber in advanced aircraft. Between 1995 and 2009, the U.S. textile industry suffered a historic contraction, and Asian markets now dominate global textile supply.

DoD is reliant on single and foreign sources of supply, and competes with global commercial demand for adequate production capacity. However, U.S. manufacturers face a competitive disadvantage in workforce and raw material costs and availability. DoD has relied on a sole source for Service Dress Uniform fabrics for a number of years, as well as sources of fibers that protect against flame and ballistic threats, and many other essential components. As a result of DMSMS from domestic suppliers, DLA has considered seeking a Domestic Non-Availability Determination for Service Dress Uniforms.

Erosion of U.S. Rechargeable and Non-Rechargeable Battery Industry

Military-unique battery requirements can differ from commercial demands in size, quality, safety, power density, weight, and environmental ruggedness. Lack of stable production orders, inadequate research and development investment, and disjointed acquisition strategies have resulted in lost capability and capacity, increased surge lead times, workforce erosion, and inhibited private investment.

Surge capacity-limiting constraints occur at several points along the value chain, from raw material to final battery assembly. Most battery configurations are produced by single sources of supply. The rechargeable battery market is dominated by commercial demand and primarily foreign sourced. Domestic rechargeable battery producers cannot compete in production volume, labor availability, or cost.[62]

Most domestic lithium ion cell packagers rely on foreign suppliers. Rapid expansion of the electronic vehicle market is likely to exacerbate these risks, especially if designs deviate significantly from military requirements, foreign markets drive adoption, or foreign competitors lead the way in manufacturing infrastructure investment.

Erosion of U.S. Photonics and Optics Industries

Photonics and optics are technology drivers for warfighter sensing and laser systems. Sensing technologies and applications have expanded exponentially over the last few decades and are increasingly integrated into every facet of warfighting. Unfortunately, U.S. value-added manufacturing has eroded over the last 20 years, threatening assured access to new optics and photonics.

Competitor nations are investing in key manufacturing infrastructure and have lower-cost human capital, which provides a competitive advantage. Human capital gaps in skilled blue-collar workers, and clearable U.S. nationals with advanced degrees in optics and photonics, constrain the domestic defense industry. Additionally, rapid technology proliferation brings a risk of parity with competitor nations in the market. The result is U.S. reliance on foreign sources for key technologies for defense systems like night vision.

Future advancements in flexible displays, OLEDs, and quantum mechanics offer opportunities to regain international competitive leadership in both technical innovation and manufacturing. While display alternatives may exist, there is only one known domestic source of OLED microdisplays. The DoD has made investments to manage the risk, is actively engaged with suppliers, and is monitoring the niche industry closely.

Government Business Practices

Commercial items modified to meet military specifications may still require unique-enough industrial capabilities to oppose market dynamics and fuel industrial base risk. The military specifications qualification processes can cause barriers to entry and source of production technical risks. Where significant differences exist between commercial solutions and defense products, the government is left to sustain the capability and capacity needed for production. While this is necessary in some cases, it is costly and impractical across the broad soldier systems portfolio.

In a few cases of high-volume soldier systems (e.g. body armor, uniforms, batteries, etc.), a small industrial base is further divided by contract awards to produce Service-specific variants of comparable products. Disjointed acquisition strategies can unknowingly create single sources, decrease demand signal strength and visibility, increase logistics burden, and create industrial base risk. As part of the planned risk management actions in the sector, DoD will evaluate joint requirements and acquisition strategies with an objective to create a more cohesive demand signal to industry and to adjust requirements to better align with market-stable solutions as appropriate.

FY2020 Developments

Operational Transition

The soldier systems sector is emerging from a long-term sustainment effort focused on immediate warfighter needs. Many programs have met or are approaching their acquisition objectives, which triggers a natural peacetime cycle of decreased defense spending/demand. In the past, periods of decreased defense spending have led to industry consolidation, reduction in capacity, loss of capability, reduced capital investment, and a transition toward commercial investments in order for industry to remain viable.

Peacetime industrial readiness losses have historically been recovered or replaced by alternatives as the U.S. enters other large-scale military engagements. Future soldier systems objectives include lightening the soldiers' load, developing modular/flexible/agile materiel solutions, and taking advantage of advancements in sensor technology and materials engineering.

Sector Outlook

Strategic Competition

U.S. competitors continue to modernize their capabilities to challenge U.S. technological leadership and interests across a broad industrial spectrum. Russia has been modernizing its soldier systems ensemble in a coordinated, modular, and evolutionary program called "Ratnik" - or "Warrior" - reported over the last five years. The program integrates and upgrades all aspects of soldier systems. The latest generation integrates exoskeletons, advanced sensing, and unmanned systems, paralleling the U.S. Special Operations Command's Tactical Assault Light Operator Suit.[63,64] Since 2010, Russia has significantly modernized its ground forces and ground troop tactics.[65]

China's PLA Army (PLAA) is the world's largest standing ground force, with approximately 915,000 active-duty personnel in combat units. Recent structural changes to PLAA organization and tactics aim to develop more mobile and modular units. To assist in the transformation, the PLAA is also modernizing command, control, communications, computers, and intelligence systems to enhance its forces' interoperability. PLAA forces stress the importance of ISR and leveraging information to enable future combat.[66]

China's industrial policies and national priorities are focused on advancement in areas that will enhance its soldier systems capabilities; quantum communications and computing; innovative electronics and software; automation and robotics; specialty materials; nanotechnology; batteries, power, and alternative energy; and neuroscience, neural research, and artificial intelligence.[67]

Commercial Demand Dominance

DoD competition with commercial demand continues to impact textiles, batteries, and night vision technologies, and other industry subsectors. Although commercial demand can provide stabilizing revenue to industry during periods of reduced DoD demand, it also reduces the DoD's influence on the market and ability to drive investment in the development of next generation technology.

When military and commercial requirements differ substantially, or if shared resources are scarce, commercial market dominance can directly impact lead time, surge capacity, and the sustainment or development of defense-unique industrial capabilities. Often DoD is left to adapt to commercial market-driven changes, and only when unacceptable levels of industrial base risk arise may DoD intervene to sustain critical industrial capabilities.

Space

Sector Overview

The space industrial base includes the satellites, launch services, ground systems, satellite components and subsystems, networks, engineering services, payloads, propulsion, and electronics that support National Security Space (NSS) missions and operations. These systems provide an emergent capability and strategic advantage to U.S. forces.

Demand for space capabilities and services—and resulting capability development— is increasingly driven by foreign and domestic commercial markets.

> *"Rapid increases in commercial and international space activities worldwide add to the complexity of the space environment. Commercial space activities provide national and homeland security benefits with new technologies and services and create new economic opportunities in established and emerging markets. The same activities, however, also create challenges in protecting critical technology, ensuring operational security, and maintaining strategic advantages."*
>
> – 2020 Defense Space Strategy

Certain NSS performance requirements and capabilities are also particularly stringent or unique, and require support outside of the growing commercial/civilian space ecosystem. The DoD space industrial base remains a niche market with very specialized and capital-intensive requirements that are not efficiently managed through individual program investments. Many current and planned systems also rely on dated technology and practices, as well as fragile or foreign sources.

Reliance on foreign sources for critical technologies, competition from subsidized lower-cost imports, and erratic demand from the NSS enterprise will erode essential space capabilities and critical skills, and threaten future access to space qualified domestic industrial sources. However, due to capital intensive requirements, individual programs are reluctant to invest in, and qualify, new technology and sources. This creates a need to sustain fragile domestic sources and to qualify new technologies and sources for next-generation systems.

Major Risks & Issues

Risk Archetypes

- Foreign dependency
- Erosion of U.S.-based infrastructure
- Product security
- Fragile suppliers
- Gaps in U.S.-based human capital

The Space Industrial Base Working Group (SIBWG) assesses risks within the space industrial base, develops mitigation plans, and promotes management and procurement practices across the DoD and the intelligence community (IC) to ensure access to technologies critical to the NSS community. SIBWG members—government and industry stakeholders— identify and pursue risk mitigation efforts to protect the U.S. space industrial base through cost-sharing contracts between the government and private industry.

The SIBWG currently tracks 119 essential space capabilities with identified supply chain risks. The following technologies exhibit specific risks impacting the space industrial base:

Precision Gyroscopes

Precision Gyroscopes are a critical component of the attitude determination, stabilization, and inertial navigation system on spacecraft, launch vehicles, and missiles. Three types of gyroscopes (ring laser, hemispherical resonating, and fiber optic) are commonly employed in space systems.

- Hemispherical resonating gyroscopes are an older technology mainly used on non-agile satellites and only one domestic provider remains— with limited production capacity.
- Fiber optic gyroscopes are employed in high performance agile spacecraft and missile applications. Although there are three domestic suppliers of fiber optic gyroscopes, they rely on key components (integrated optics chips and laser diodes) experiencing supply issues that threaten the viability of domestic product lines.

Space Qualified Solar Cells

Space qualified solar cells are optimized for specific environments required for NSS and National Aeronautics and Space Administration (NASA) missions, which hinders the transfer of technology to terrestrial applications and often prevents providers from diversifying to reduce risk and burden. The space industrial base is developing advanced cells to provide weight savings, decrease stowage footprint, and enable higher-power missions. However, foreign suppliers are also developing high efficiency cells, while marketing internationally at lower costs.

U.S. providers are dependent on NSS procurement funding, whose batched orders are generally low volume, low margin, and with inconsistent demand. As a result, they have struggled to remain competitive. During the coronavirus pandemic, the DPA Title III team made critical investments in the domestic space qualified solar cell market to maintain production capacity.

Traveling Wave Tube Amplifiers

Traveling Wave Tube Amplifiers (TWTAs) improve radio frequency spectrum access and increase bandwidth in military satellites. Recent commercial market downturns have resulted in layoffs and skills gaps in the space TWTA workforce. A sole domestic supplier competes with a single foreign source for production of all space qualified TWTAs. Although some U.S. programs are required to use a domestic source, the foreign source offers more competitive products and pricing. Having a strong domestic source would reduce dependence on the foreign source and ensure availability of NSS specific TWTAs.

FY2020 Developments

COVID-19 Impacts

The long-term impacts of the coronavirus pandemic are still unclear, but the DoD will monitor the sector closely. Potential areas of concern include a slowdown in capital expenditures and more rapid industry consolidation than originally anticipated. For example, the Organization for Economic Co-operation and Development (OECD) has expressed concern that COVID-19 could disproportionally affect space start-ups. The uncertainty associated with COVID-19 could cause constraints in the ability of start-ups to raise the capital required to bring innovation to the market. This could open a window of opportunity for the rapidly growing Chinese commercial sector to weaken the U.S.'s position as a commercial space leader.

Sector Outlook

Defense Space Strategy

The June 2020 Defense Space Strategy identifies four lines of effort (LOE) for the development of a "secure, stable, and accessible space domain":

1. Build a comprehensive military advantage in space;
2. Integrate space into national, joint, and combined operations;
3. Shape the strategic environment; and
4. Cooperate with allies, partners, industry, and other U.S. Government departments and agencies.[68]

The December 2019 establishment of the U.S. Space Force as a separate Service branch may bring attention to the risks facing the space industrial base and establish a more strategic investment and development approach. The SIBWG will continue to play a critical role in the Space Strategy and the fourth LOE in particular. Whereas investment by individual programs tends to result in program specific architectures, cooperation across government and industry is necessary to:

- Identify and support cross-cutting technologies and priorities;
- Invest in areas and technologies where commercial demand is insufficient, or DoD-unique components exist;
- Maintain or improve hard-to-reconstitute manufacturing processes to avoid schedule and cost impacts associated with re-establishment; and
- Anticipate technology requirements to maximize investment across space programs.

A clear strategy will help inform investment and policy priorities across the NSS enterprise and guide the actions of the SIBWG in support of a stronger space industrial base.

Commercial Space

The commercial space sector will continue to play an increasing and critical role in NSS, including space launch. The United States is an overall world leader in commercial space, but near peer competitors such as China are rapidly expanding their commercial space industrial bases.[69] The DoD, in coordination with other Federal Agencies such as the DoC and NASA will continue to leverage, support, and promote the commercial space industry, where appropriate. There are potential areas of support where the DoD and partner agencies can positively help the U.S. commercial space industry. For example, recent economic analysis by the U.S. Air Force Office of Commercial and Economic Analysis and the MITRE Corporation highlight that government support of the launch industry, coupled with commercial efforts to reduce space launch costs and increase reliability, is effective in helping U.S. commercial launch service providers gain additional global market share. However, the U.S. government should simultaneously be aware of the likely oversaturation of launch service providers, especially small launch providers, when considering the foreseeable Total Addressable Market for space launch.[70]

Workforce

Sector Overview

The DIB relies on a force of skilled workers to provide and support the products and services required to meet the U.S. government's national security needs. This shrinking workforce comprises 1.1 million designers, engineers, manufacturing and production workers and maintainers, information technology developers, and members of DoD's organic industrial base. It is a key element of the nation's critical infrastructure.

In the last several years, changing economic and national security policies have sharpened executive and legislative branch focus on the state of the DIB workforce. The combination of Presidential Executive Orders seeking to re-shore manufacturing and of ambitious production goals such as the Navy's 530-ship fleet initiative have given industry reasons to consider sizable new investments in manufacturing operations, shorter and more reliable supply chains, and advanced production technologies.

Such efforts require marked increases in the DIB's capacity and resilience. In turn, those objectives require producing more workers trained in the skilled trades or in STEM. Unfortunately, many young Americans have developed unfavorable impressions of careers in manufacturing and the trades. These impressions have been reinforced by educational policies that steer students toward four-year college programs. Meanwhile, STEM-focused programs at American universities, "are confronting a dearth in American talent generation and retention, and much of that shortfall is filled with foreign students, a large share of them from China."[71]

Major Risks & Issues

Risk Archetypes:

- Gap in U.S.-based human capital
- Foreign dependency
- DMSMS

Domestic manufacturing output grew in 2019 and early 2020, but the DIB's overall capacity to prevail against strategic competitors was still uncertain even before the coronavirus pandemic. The pandemic highlighted long standing critical risks and issues related to the supply chain for workers and materials. Many of these issues are the result of economic realities that favored off-shoring over the use of domestic supply chains for materials and workers, and investments in services rather than manufacturing; despite some marginal changes, policy incentives largely failed to overcome these issues.

The DIB workforce still suffers from the persistent issues highlighted in the 2019 version of this report. Candidate pools of potential workers are shrinking due to adverse demographics and persistent biases against industrial trades careers among parents and educators. Meanwhile, the mismatch between 1) technological knowledge and skills required by evolving manufacturing sectors and 2) suitable training programs is growing. Decades of neglect have left the robust system of technical schools the nation once relied upon for industrial training badly weakened. Finally, the existing workforce is rapidly aging out, taking irreplaceable tacit knowledge with them. Programmatic responses to education and training needs still largely focus on four-year STEM-based programs rather than digital industrial skills on the factory floor.

FY2020 Developments

In the short run, DoD's COVID-driven reinforcement of the DIB's critical infrastructure status helped limit, but could not eliminate, production losses and schedule delays in major defense programs. The coronavirus pandemic caused "demand crash," affecting commercial manufacturers and their suppliers, had pronounced adverse effects on the small, medium, and large defense suppliers that rely on commercial work to maintain economic viability over time. The coronavirus pandemic also highlighted the adverse impacts of dependence upon foreign sources of low cost labor and materials, especially China. Defense executives recognized the long-term threat of adversary influence on critical supply lines.

The COVID-19 effects notwithstanding, the USD(A&S)'s Office of Economic Adjustment (OEA) and IBAS programs executed key efforts to mitigate DIB workforce risks.

Service-Level Efforts

In keeping with priorities articulated by executives, workforce-related efforts undertaken by the U.S. Services due to the coronavirus pandemic focused on *retaining* rather than growing or enhancing the industrial workforce. In a few cases, these efforts supported the movement of workers from crippled commercial-side efforts to explicit defense work. Most other Service-level investments tied to DIB workforce development requirements are in individual weapon system acquisition and sustainment programs versus broad, defense-wide strategic workforce development efforts.

A&S Initiatives

As previewed in the FY2019 Industrial Capabilities Report, the IBAS program formally launched its 'National Imperative for Industrial Skills' initiative in FY 2020, making ten awards for prototyping agreements across the nation (approximately $30 million in total federal funding), testing various segments of the Industrial Skills Workforce Development Ecosystem Model (see Figure 7.26). Several of these awards are the result of direct partnerships with the military departments. The initiative is the Department's effort to reawaken the nation's commitment to the manufacturing and industrial skills needed to build next-generation weapons and platforms. The effort aims to promote the prestige of manufacturing and associated careers, accelerate the delivery of workers into and through training and education pipelines, and elevate U.S. manufacturing to a world-leading status. Through it, the Department consciously recognizes the nation's workforce development pipelines as vital supply chains.

The National Imperative is a logical outgrowth of 'ProjectMFG,' a highly successful and continuing series of competitive events intended to generate interest in manufacturing and industrial skills and associated careers (described in last year's report). In FY2020, the IBAS program conducted ProjectMFG events in Alabama, New York, California, Tennessee, and Virginia. Additional planned events in Texas, Ohio, and the National Finals in Illinois were cancelled due to COVID-19. ProjectMFG has been refined to support competition using virtual arenas.

OSD's OEA is designed to support long-term community investments that strengthen national security innovation and expand the capabilities of the defense industrial ecosystem. The OEA awarded six Defense Manufacturing Communities Support Program grants (totaling $25 million in federal funding) to entities in Pennsylvania, West Virginia, Ohio, Utah, California, Alabama, and Connecticut, each of which helps to advance that community's local and regional defense industrial workforce development ecosystem in unique ways.[72] Each awardee was required to provide substantial cost share.

Sector Outlook

The Department will continue to assess the immediate and long-term DIB workforce impacts from the coronavirus pandemic, while also addressing more long-term and systemic shortfalls in the workforce development pipelines that supply and sustain these vital resources. Shortages of skilled labor and its impact to the production schedule and cost of major weapons and platforms will continue to be a source of concern to both the DIB and the Department. Dependent upon access to sufficient financial resources, in FY2021, the IBAS program office will expand the National Imperative for Industrial Skills initiative by making additional awards and funding optional tasks on already-awarded agreements. IBAS will continue to seek and leverage partnerships across the Services through the 'Cornerstone' OTA membership consortium.

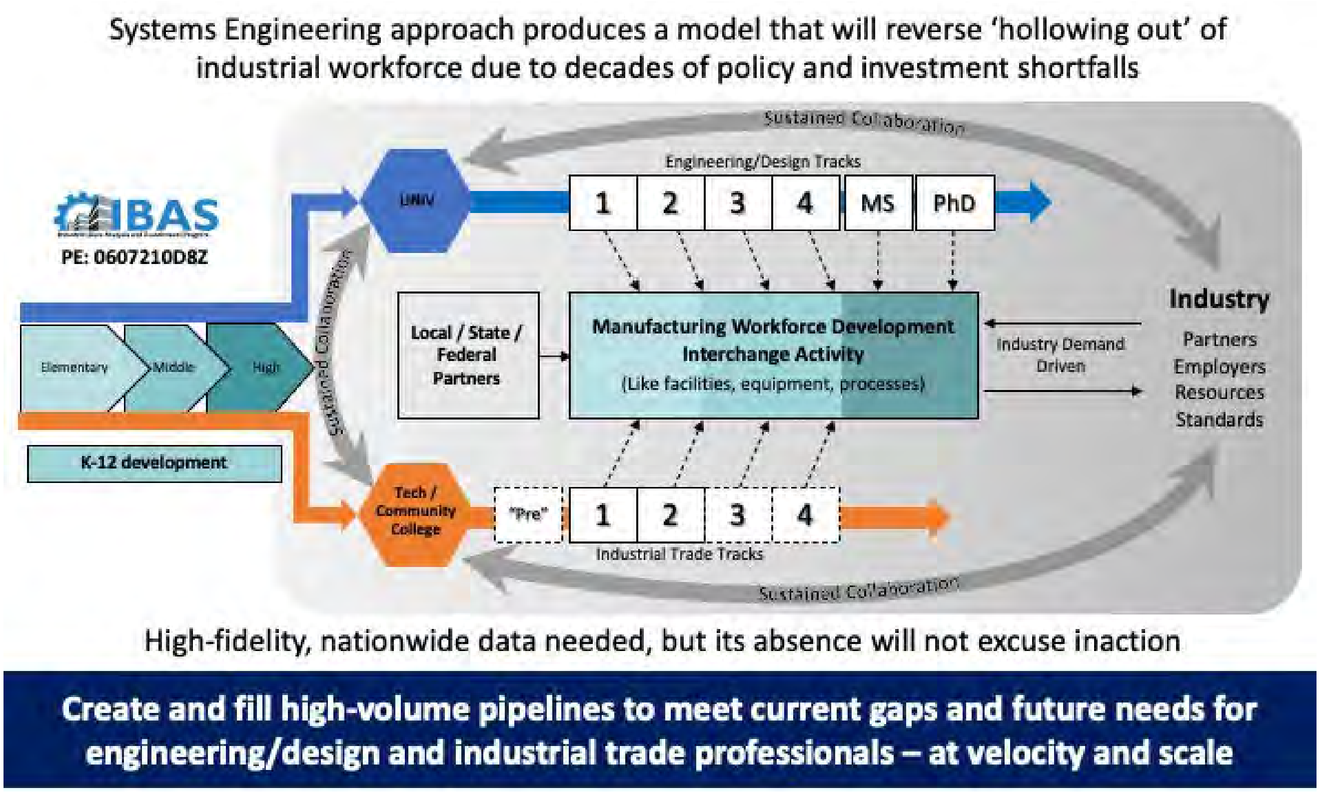
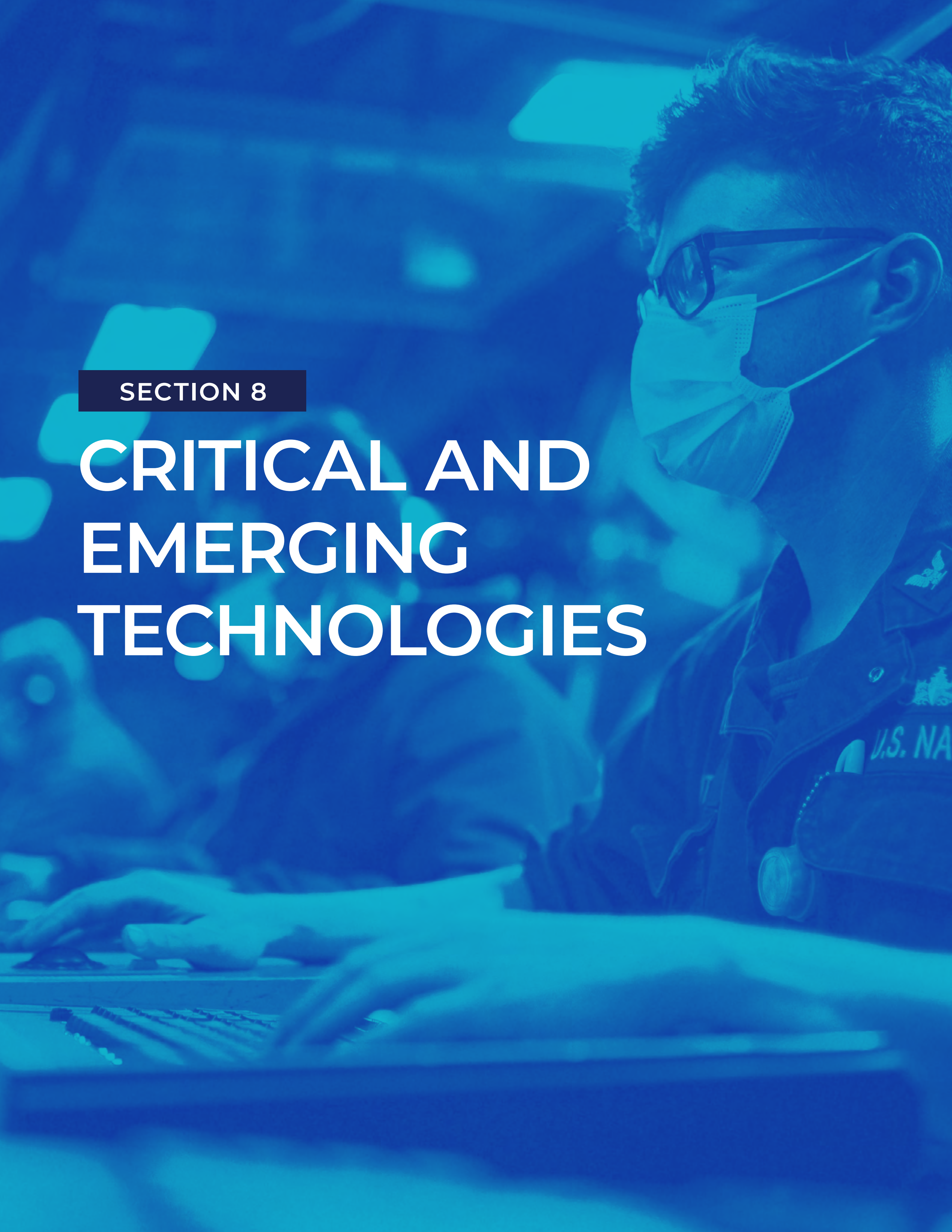


Figure 7.26: Graphic representation of the "Industrial Skills Workforce Development Ecosystem" as envisioned by the National Imperative for Industrial Skills.

SECTION 8

CRITICAL AND EMERGING TECHNOLOGIES



CRITICAL AND EMERGING TECHNOLOGIES

Introduction

The Technology, Manufacturing, and Industrial Base (TMIB) Office within OUSD(R&E) is responsible for creating strategies within the industrial base to develop, manufacture, and sustain current and emerging technologies to retain U.S. advantage. TMIB uses emerging technology assessments to translate technology requirements into manufacturing and industrial base requirements. Figure 8.1 outlines the assessment methodology employed by TMIB to provide a full overview of the technology from a manufacturing and industrial base point of view and create technology and industrial base protection and promotion strategies.

Technology Characterization

- Determine military advantage, assess technical maturity, and understand challenges
- Understand near-peer & adversary perspectives, strategies, investments

→

Development & Testing

- Assess government and industry laboratories and engineering centers
  - Identify requirements for workforce skills, engineering tools, facilities, technical challenges
  - Identify test requirements-infrastructure, skills, tools

Production & Supply Chain

- Assess industry production capabilities & supply chain capacities
- Identify critical companies and expertise, existing relationships, mergers and acquisitions

→

Future State of Technology

- Assess future state of technologies, capabilities, and interdependencies
- Identify economic strategies/ investments, scalability of emerging technologies, and maintain technological advantage

Figure 8.1: Types of Technology and Manufacturing Studies

These strategies protect and promote the DIB by mitigating risks, exploiting opportunities identified in emergent technology assessments, and providing support for the development and execution of technology modernization activities and priorities.

The following section of the report includes an overview of the critical and emergent technologies currently in the research and development phase, including current and future initiatives to promote and protect the technology innovation base.

Biotechnology

Biotechnology, or biotech, refers to the engineering of biological systems and processes to produce a wide range of products, as well as utilizing biological data to enable technological advances. DoD investments in biotechnology will result in enhancements to warfighting materiel and systems, warfighter health and performance, military medicine, and chemical and biological defense. For example, biotechnology can enable the Department to: source mission-critical materials without relying on fragile supply chains; develop materials with novel properties to enhance performance in systems ranging from hypersonics to ships and submarines; and greatly reduce logistical timelines and burden for deployment and resupply by providing point-of-need manufacturing. The mastery of this emerging technology will have an outsized impact on national security. It is critical that the United States and its allies prevail in the race for biotech, as China has publicly stated that it intends to “win” the bio-revolution and signaled willingness to use biotechnology against their adversaries without respect for protocols, conventions, or human rights.

The DoD Biotechnology modernization strategy identifies initial key areas to develop to create a pipeline to rapidly transition science and technology (S&T) toward fieldable products and capabilities, as shown in Figure 8.2.

A deliberate shift toward bioindustrial manufacturing could reduce DoD dependence on sole source and foreign suppliers through the use of engineered organisms as factories to produce a wide range of downstream products, including materials that cannot be manufactured using alternative approaches. However, DoD efforts have focused largely on developing capability at the laboratory level, and commercial applications of engineering biology are still in early stages of market expansion. A clear limitation in growth of this technology segment relates to facilities and know-how for scaling biomanufacturing from the

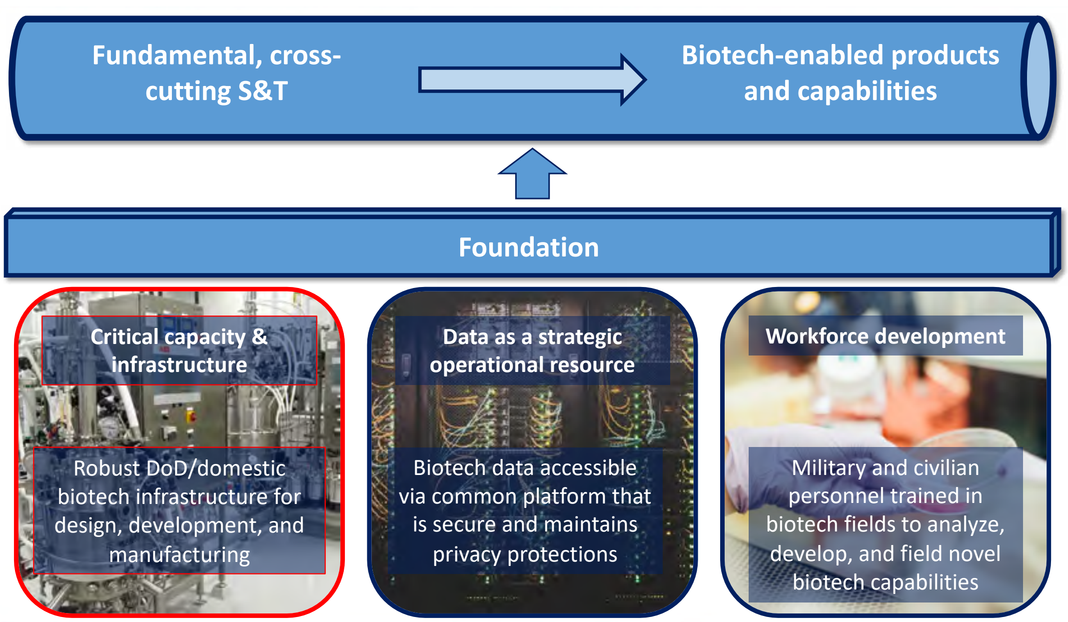


Figure 8.2

laboratory to commercial production; a valley-of-death exists for most companies between federally funded proof-of-concept work and demonstration, scale-up, and production.

To mitigate this challenge, the DoD Manufacturing Technology Office, along with the Principal Director for Biotechnology within OUSD (R&E), awarded a 7-year Cooperative Agreement worth $87 million to BioMADE to develop a Manufacturing Innovation Institute dedicated to biomanufacturing for non-biomedical applications. Focus areas for BioMADE will include: 1) the development of better tools for scale-up manufacturing, 2) improvements in down-stream processing techniques, and 3) the ability to rapidly assess and characterize biomanufactured products. Collectively, these efforts will reduce the cost and time to achieve robust biomanufacturing, with a focus on fostering and sustaining a globally competitive U.S. manufacturing base.

As biotechnology continues to develop, the DoD faces several key risks related to gaps in domestic workforce, national and international standards, and robust biosecurity to prevent misuse of the technology by adversaries. The coronavirus pandemic further underscores U.S. and global vulnerabilities to biological threats. The DoD can play a key role in contributing to national and international standards for responsible use of biotechnology, and ensuring that the technology is broadly available, safe, and secure by developing innovative approaches to address biosafety, biosecurity, and biocontainment.

To support Biotechnology development, OUSD(R&E) TMIB is leading two assessments to quantify: 1) domestic bioindustrial manufacturing capacity, and 2) the current and future biotechnology workforce. These assessments aim to develop an understanding of gaps and needs, and create recommendations for mitigation measures necessary to ensure a robust bioindustrial manufacturing base and advance the broader U.S. bioeconomy.

Fully Networked Command, Control, and Communications

Fully Networked Command, Control, and Communications (FNC3) technology encompasses the capability to acquire, process, and disseminate information across force elements.[73] The DoD requires reliable interconnection of diverse platforms and systems across all domains and operating environments as defined in the NDS. Existing capabilities require sufficient protection against threats that are increasing in pervasiveness and effectiveness. OUSD(R&E) will mature and transition the overall FNC3 architecture and associated technologies via a strategy that fosters distinct but inter-related R&D efforts across the physical, network, and application layers. The DoD FNC3 strategy will result in a resilient DoD-wide command, control, and communications (C3) system, while also enabling interoperability and connectivity between every system and platform.[74]

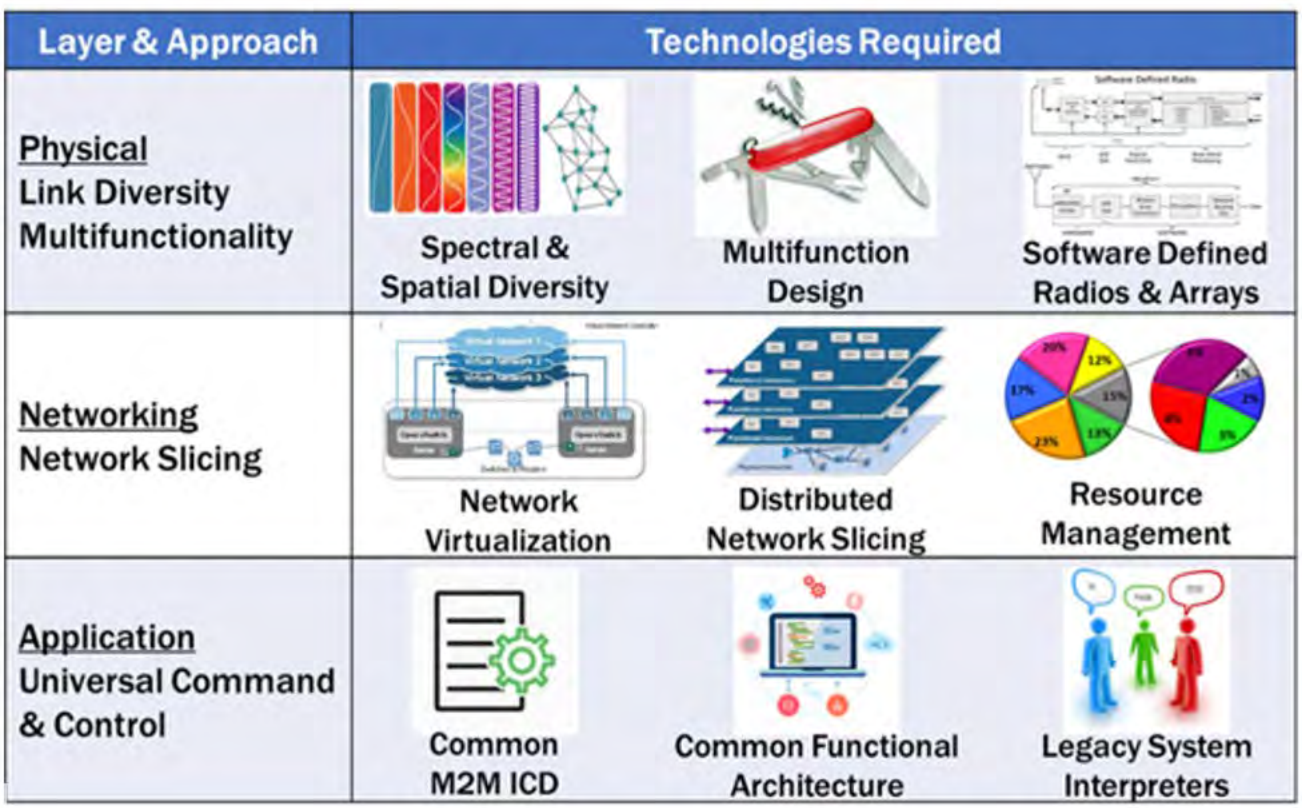


Figure 8.3: FNC3 Strategy[75]

The existing C3 innovation and industrial bases are healthy. However, while commercial products benefit from the use of open architectures, common interfaces, and fixed infrastructure, DoD C3 systems require unique, military-specific applications to be effective. Today's military C3 systems were designed and developed with incompatible requirements and are unable to efficiently exchange information.[76] DoD will leverage existing commercial technologies and best practices to solve the two biggest challenges facing the DoD's existing C3 systems: interoperability and resilience in highly contested environments. The FNC3 strategy takes advantage of all available link diversity to provide resilience while also promoting interoperability and connectivity between every system and platform.[77]

To transition capabilities to the warfighter, FNC3 is coordinating with key DoD stakeholders, including the OUSD(A&S), DoD CIO, the Joint Staff, Space Development Agency, and the Services to guide the transition of FNC3 capabilities into appropriate acquisition programs, standards, and operational architectures. The Joint All-Domain Command and Control (JADC2) Cross-Functional Team chartered by the Deputy Secretary of Defense has adopted the FNC3 strategy as its long-term technological baseline. JADC2 will also provide the ability to connect distributed sensors, intelligence, information, data, and effects from all domains to tactical and strategic decision makers; JADC2 will provide this capability at the scale, tempo, and timing required to accomplish the commander's intent, agnostic to domains, platforms, or functional lanes.[78]

DoD will continue to collaborate with industry stakeholders to identify and implement C3 industrial base vulnerability mitigation efforts, leveraging investment programs such as Defense-Wide Manufacturing Science & Technology (DMS&T), ManTech, IBAS, and DPA Title III to protect the FNC3 industrial base from challenges, and to bridge the gap between S&T and production.

In FY2020, OUSD(R&E) TMIB initiated a multi-phased industrial base assessment focused on discovering commercial trends that support the FNC3 strategy; determining capabilities and vulnerabilities related to delivering the technologies required; identifying risks and opportunities; and making recommendations to enhance the existing C3 supplier base. Initial findings include actionable approaches to achieving interoperability across DoD-wide platforms (including legacy) using analytics, network management techniques, modular approaches to interoperable architectures, and data management strategies. The FY2021 assessment outcomes will identify DoD and commercial technology development investment trends, and will provide recommendations on how to improve the DoD FCN3 strategy by leveraging what industry has already invested in, and by focusing next on military-unique capabilities that must be incentivized.

Hypersonics

Hypersonic weapons achieve sustained flight within the atmosphere with speeds near, or above, five times the speed of sound. There is a focus on the tactical capability that these types of weapons bring to theater or regional conflicts. These weapons provide quick response and high speed, are highly maneuverable, and difficult to find, track, and kill. DoD is modernizing our offensive and defensive force structure to both utilize and deter this capability. Example programs for the U.S. investment in hypersonics strike systems are shown in Table 8.4.

The Department is identifying issues, risks, and opportunities to advance hypersonics capabilities with the objective of creating near- and long-term investments strategies. DoD's ability to develop and field hypersonic capabilities requires a robust industrial base positioned to design and test hypersonic systems. IB capability must also sustain the anticipated U.S. production demand in support of the DoD strategy for accelerated development and fielding of hypersonic strike weapons as shown in Figure 8.5.

Hypersonic Development Program	Service/Agency	Capability
Long Range Hypersonic Weapon	US Army	Intermediate Range Strike
Conventional Prompt Strike	US Navy	Intermediate Range Strike
Air Launched Rapid Response Weapon(ARRW)/Tactical Boost Glide (TBG)	US Air Force/DARPA	Medium Range Strike
Hypersonic Air-breathing Weapon Concept	US Air Force/DARPA	Medium Range Strike
STANDARD Missile-6 (SM-6 Blk1B)	US Navy	Medium Range Strike

Table 8.4: Hypersonics Programs

Accelerated Development and Fielding of Hypersonic Strike Weapons			
Phase 1: Concept and Technology R&D *Develop the enabling technologies and concepts necessary to underpin future hypersonic systems*	Phase 2: Weapon System Rapid Prototypes *Accelerate future hypersonic weapon system prototype development*	Phase 3: Accelerated Fielding Plan *Field hypersonic strike weapon prototype capabilities in meaningful numbers*	Phase 4: POR Fielding Plan *Establish programs of record to build warfighting inventory and implement capability phasing plans*
Foundational S&T, Industrial Base and T&E Investment Plans			

Table 8.5: Hypersonics Development and Transition Phases

In 2019, the Defense Contract Management Agency's Industrial Analysis Group (DCMA IAG) and the Air Force's Office of Commercial Economic Analysis performed studies focused on the capabilities, capacity, and financial health of the hypersonics IB. Major findings of the reports included the need for immediate and continued investments in infrastructure, development activities, manufacturing, and workforce development to ensure a healthy and resilient IB. Recent industrial base assessments have also identified capabilities essential to achieve a robust hypersonics industrial base, including:

- Stable sources of critical materials such as ceramic matrix composite material sources (fibers, pitch resin, etc.)
- Industry access to test facilities and broad access to test results
- An ability for multiple hypersonics programs to compete for the same supply chain of traditional weapons system prime and sub-tier contractors
- Access to proprietary processes in a small number of critical small businesses
- A robust technical workforce of weapon systems engineers and supporting skilled trades workers
- Robust and resilient verified design tools and techniques

The development of the Hypersonics Science and Technology roadmap has also identified a short list of immediate investment opportunities that are required to increase the capability and health of the hypersonics IB.

In July 2020, a Presidential Determination for use of DPA authorities for the industrial base production of ultra-high and high temperature composites for hypersonics, strategic missiles, and space launch systems was signed to address future capacity needs. Additionally, further investment opportunities are being explored and implemented to advance manufacturing technologies for additive manufacturing of high temperature metals, ceramic matrix composites, and modeling and simulation methods. The OSD ManTech office projects Manufacturing of Carbon-Carbon Composites for Hypersonic Applications will continue to advance methods and processes to more affordably and rapidly produce carbon-carbon components for hypersonic systems. These investments will greatly improve the ability of the industrial base to design and test systems, and provide quantities needed for near-term demonstration and early operational capability milestones. They will also contribute to the ability to produce larger production quantities in the future.

In support of the Principal Director for Hypersonics, the TMIB office within OUSD(R&E) and the OUSD(A&S) Industrial Policy office are working to develop an IB roadmap and conduct assessments in support of the acceleration of hypersonic strike capability described in the Figure 8.5. This effort will identify actions and investment strategies necessary to meet the hypersonics capability required to meet DoD's goals. To execute this, a Hypersonics War Room (HSWR) was established with members from OSD and the Services. The HSWR conducts deep dives into the industrial base, especially at the sub-tier level, to visualize the emerging results of the roadmap development and mitigation activities. This effort has and will continue to focus on the current supply chain to identify areas of opportunity. Additional planned and future IB assessments will facilitate data gathering and analytics, and support fact-based decisions on investments in key areas of the hypersonics IB. Future work to develop requirements and acquisition strategies for Programs of Record will be informed by the HSWR to help accelerate delivery of operational capabilities to the warfighter.

Microelectronics

Microelectronics is a subfield of electronics that relates to the study, manufacture, and microfabrication of electronic designs and components with very small feature sizes. Typically, this refers to micrometer-scale to nanometer-scale products. These devices are typically made from semiconductor materials and many components of normal electronic design are available in a scaled down microelectronic equivalent. These include transistors, capacitors, inductors, resistors, diodes, insulators, and conductors.

Microelectronics have evolved rapidly as the demand for inexpensive and lightweight equipment has increased; they have also been incorporated into countless DoD systems. However, the DoD modernization ability is jeopardized by foreign microelectronics (ME) production, actions, and investments. To mitigate this, DoD must develop and deliver next generation microelectronic technologies to enhance lethality, ensure critical infrastructure, and achieve economic competitiveness.[79]

In a recent DoD News article, "DoD Adopts 'Zero Trust' Approach to Buying Microelectronics," Dr. Lewis, the DoD's Director of Research and Engineering for Modernization, stated that microelectronics are in nearly everything, including the complex weapons systems DoD buys, such as the F-35 joint strike fighter. He further stated, "Our goal is to allow the Department of Defense to purchase on the commercial curves...that will put us on...par with our strategic competitors."[80]

Microelectronics are critical to advancement of emerging technologies like AI, 5G and quantum computing, as well as critical components in weapons systems. Commercial market forces continue to lead in the consumption of microelectronics and therefore are driving the industry.

FY2019 Total Global Semiconductor Demand Share by End Use [81]

Communications 33%	Computer 28.5%
Consumer Products 13.3%	Automotive 12.2%
Industrial 11.9%	Government 1.3%

Figure 8.6

To respond to market forces, the microelectronics industry must always be state-of-the-art. Approximately every two years, the industry moves to the next technology node, bringing benefits which generally include improved size, weight, speed, and power consumption. The current SOTA for microprocessors is five nanometers, and is reserved for the highest volume commercial customers. Unfortunately, these improvements have resulted in increased costs, particularly in the area of design.

The United States still leads in the design of SOTA microelectronics, but Asia has nearly 80 percent of the outsourced aspects of semiconductor production. This includes foundries, and assembly and test functions. "The U.S. currently maintains a stable chip manufacturing footprint, but the trend lines are concerning. There are commercial fabs in 18 states, and semiconductors rank as our nation's fifth-largest export. However, significant semiconductor manufacturing incentives have been put in place by other countries, and U.S. semiconductor manufacturing growth lags behind these countries due largely to a lack of federal incentives."[82] During FY2020, the microelectronics sector experienced an increase in the numbers of both CFIUS and export control cases. The majority of the cases were related to components for 5G. The health of the U.S.-based microelectronics industry is being balanced against policy changes to protect the technology.

DoD relies on the Defense Microelectronics Activity Trusted Foundry Program to provide access to trusted microelectronics and services through their network of accredited suppliers. DoD plans to make use of chiplets and advanced packaging to fill the need in the short term, until there is either a domestic source of SOTA microelectronics, or Quantifiable Assurance reaches sufficient maturity to allow the use of any foundry. The Trusted and Assured Microelectronics program is pursuing an effort to both define Data-Driven Quantifiable Assurance and create the methodology for a zero-trust risk-based approach for supply chain protection and assured access to SOTA microelectronics technology and electronic components.

The Defense Advanced Research Projects Agency (DARPA) Electronics Resurgence Initiative is attempting to forge collaborations among commercial industry, the DIB, universities, and the DoD to innovate a fourth wave of electronics progress. The five year, up to $1.5 billion initiative, to enable far-reaching improvements in electronics performance, is halfway to completion with much of the focus area in microelectronics.[83]

DoD is continuing to collaborate to identify and implement mitigation efforts. OUSD(A&S) and OUSD(R&E) are leveraging several investment programs such as DMS&T, ManTech, IBAS, and DPA Title III, to address microelectronics industrial base challenges and bridge the gap between S&T and production. The OUSD(R&E) TMIB will assist in creating strategies to promote the health of the industrial base, advance technology maturation, monitor supply chain risks, and identify issues, risks, and opportunities related to the development, manufacturing, and sustainment of related manufacturing technologies.

Machine Learning/ Artificial Intelligence (AI)

Artificial intelligence refers to the theory and development of systems able to perform tasks that normally require human intelligence, including perception, learning and reasoning, human-robot interaction, and other major processing and reasoning tasks, with the aim to improve efficiency and effectiveness across DoD.[84,85] Machine learning (ML) refers to the field of computer science concerned with creating programs that "learn" from data using a large and evolving set of techniques grounded in statistics and mathematical optimization. AI uses machine learning technologies to enable a multitude of capabilities.[86] DoD is currently developing AI for various military applications, such as intelligence, surveillance, and reconnaissance, logistics, cyber operations, command and control, and semiautonomous and autonomous vehicles.

While military AI technology is still in a stage of infancy, DoD is pursuing AI algorithms developed for ISR and for autonomous vehicles as two key AI capabilities, among others. The Army, Air Force, DARPA, DISA, Navy, and OSD all have AI/ML development projects in progress to further mature AI technology. For example, the U.S. Air Force program Project Maven integrates AI into systems for insurgent target identification through the use of AI algorithms, computer vision, and machine learning,[87] with the goal of automating the processing, exploitation, and dissemination typically done by human analysts, thus increasing efficiency.[88] DARPA has AI/ML programs, such as the Air Combat Evolution (ACE) program, which is developing an AI fighter pilot with human-machine teaming to reduce the cognitive load on the pilot during dogfights.[89] The U.S. Army is researching reinforcement learning approaches to enable swarms of unmanned aerial and ground vehicles to accomplish various missions, minimizing performance uncertainty. The U.S. Army Research Laboratory is also investigating deep recurrent neural networks to improve the learning and prediction algorithm for optimal coordination of autonomous air and ground vehicles.[90]

The DoD AI strategy identifies initial key areas to develop to maintain a competitive advantage in AI, including AI capabilities, determining a common foundation, cultivating the AI workforce, engaging in partnerships, and leading in AI assurance. In particular, a common foundation across DoD with a joint AI development platform and DoD shared data, AI evaluations, and AI solutions will enable the rapid transition of AI research breakthroughs to edge developers.

As AI/ML technology continues to grow in terms of development and strategic importance, the DoD AI/ML industrial base faces several key risks: gaps in U.S.-based human capital, variable ease of adaptability of commercial AI technology, and potential product security issues. Product security is one of the main risks for AI/ML systems, as they are vulnerable to theft and exploitation due to being primarily software-based. The U.S.-based human capital gap is also a risk, with DoD and the defense industry facing challenges in recruiting and retaining personnel with AI expertise compared with the commercial sector. In addition, there has been a decline in the domestic AI workforce due to the rise of international graduates in U.S. research institutions and universities, who then frequently return to work overseas or at companies in competition with U.S. AI/ML companies.[91]

DoD also faces a challenge in leveraging commercial technology for military applications, as innovation in AI is currently dominated by private companies that work with open-source, general purpose AI software libraries. There is a wide variance in how easily commercial AI technology can be adapted for DoD, with certain algorithms requiring only minor data adjustments and others needing significant changes in order to be used in complex military environments. In addition, existing DoD processes may be at odds with commercial companies' safety and performance standards and their acquisition processes. These factors can inhibit the smooth transfer of commercial AI technology to DoD.[92,93]

DoD continues to identify and implement mitigation strategies to support AI/ML development and is leveraging ManTech investment programs to further develop technologies in the AI/ML investment area. TMIB is leading an AI/ML industrial base assessment to develop recommendations for the design of a DoD AI/ML open-market model, based on feedback from industry and other stakeholders. This assessment has the goal of increasing competition and reducing development cost to move more viable capabilities into DoD.

Quantum

Quantum Information Science is the study of how quantum physics can be exploited for the collection, manipulation, storage, retrieval, analysis, movement, dissemination, and protection of information. DoD research indicates that advancing capabilities of quantum technologies will benefit critical mission spaces.[94] DoD is interested in military applications of quantum information science that will provide technological advantage over alternative approaches.[95] Consequently, there is a push toward ultra-sensitive devices that increasingly rely on quantum phenomena to achieve advances in precise timing and navigation, sensing, computing, and networking.[96]

The Department is currently pursuing four key technical areas: atomic clocks, quantum sensors, quantum computers, and quantum networks.[97] Atomic clocks and quantum sensors will deliver new and assured precision, position, navigation, and timing capabilities, as well as improved intelligence, surveillance, and reconnaissance, allowing our forces to continue operations in GPS-denied theaters. Quantum computers are projected to provide high-performance computing, solving hard mathematical problems that are intractable for a traditional computer. Quantum networks are expected to profoundly impact a number of DoD missions, including timing, sensing, computation, and communications in the long-term, potentially delivering resource multiplying effects for other quantum technologies to solve DoD's challenging analytical problems.[98]

Some of these areas have reached higher technology readiness levels (e.g., atomic clocks and vapor cell magnetometers), while others are in the earliest stages of proof-of-principle development (e.g., quantum computers and entangled quantum networks).[99] For example, in the case of quantum sensor technologies, commercial companies are starting to make quantum products, and the technology is progressing towards military utility. Although atomic clocks and magnetometers have been in use, other sensors (e.g., gyros, accelerometers, and gravimeters) are still in development and not yet fieldable. Other quantum technologies such as quantum computers and quantum networks are still in their infancy and exist primarily in labs.

Additionally, these quantum technologies differ in the anticipated impact to the military. As Figure 8.7 depicts, technologies vary from low military impact with low readiness level (e.g., entangled sensor networks) to high military impact with high readiness levels (e.g., GPS atomic clocks).[100]

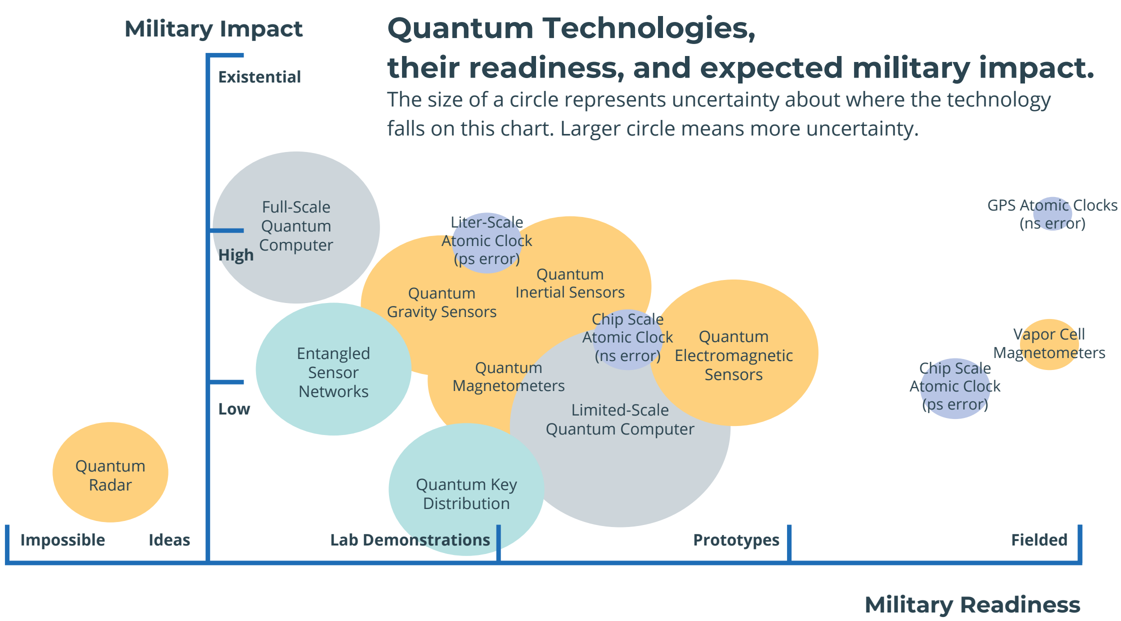


Figure 8.7 Quantum Technologies Military Readiness

To mature quantum technology, the OUSD(R&E) Roadmap for Quantum Science highlights key long-term military challenges with technical goals, including:

- Synchronized timing in denied environments;
- Precision targeting, positioning, and navigation in denied environments;
- Military advantage for intelligence, surveillance, and reconnaissance;
- Access to high performance computing for military applications; and
- Survey cryptographic solutions for military communications.

For example, the U.S. is reliant on precision time-keeping and communications synchronization. Atomic clocks provide a non-GPS alternative to position, navigation, and timing solutions in denied environments and offer size, weight, and power improvements over currently available timing solutions. Therefore, one key focus area is to mature atomic clocks with novel characteristics of military relevance and reduced cost. To this end, the DoD is making substantial investments in the development of novel atomic clock technologies, as well as low-cost, chip-scale atomic clocks.

Various actions the Department is taking to mitigate national security risks to quantum technology include: monitoring the development of a potential "quantum winter", actively promoting realistic expectations of the maturity of the science, staying abreast of the health of the quantum science industrial base and workforce, and continuing to partner with academia and industry to develop quantum science. The term "quantum winter" has been coined to describe a possible time period in which the public hype of the potential in quantum computing outpaces the maturity of the applications. Gartner's "hype cycle" describes the effect of inflated expectations and ensuing disillusionment, which has been seen before in emerging technology areas.[101] This may cause U.S. investors to reduce their investments, negatively affecting large companies and start-ups, making them vulnerable to acquisition by strategic competitor nations, and resulting in the loss of intellectual property, equipment, and talent. DoD assesses that current elevated levels of commercial investment are unsustainable, given the limited commercial utility of quantum computing. Existing levels are only sustainable if there is a major breakthrough, and DoD continues to monitor the situation to keep abreast of and mitigate developments.

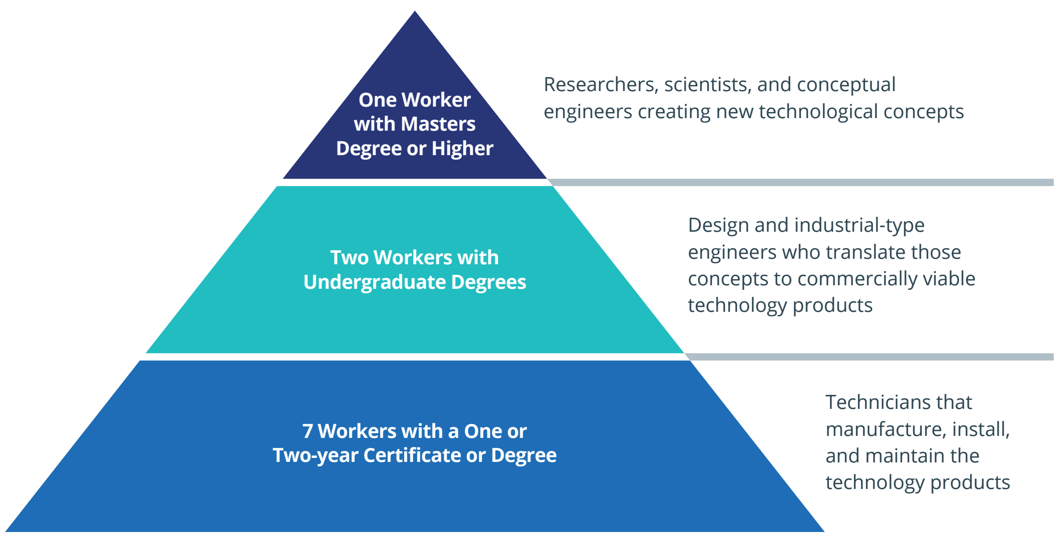
DoD is in a position to help the country weather a "quantum winter" by maturing and transitioning practical applications for quantum technology, thereby decreasing the perception gap. DoD will continue to issue realistic timelines for quantum technology development. For example, industry claims that quantum desktops will be available in five years; these claims are unreasonable and DoD is in a position to clarify this information. As an additional measure, DoD is also tracking the health of the quantum science industrial base and workforce.

It is important for DoD to understand the current health of the quantum science industrial base to mitigate risks. Quantum information science is a relatively new technical focus area for consumers, with an emerging supply chain. To gain this understanding, DoD is sponsoring a RAND Corporation assessment of the robustness of the U.S. industrial base in quantum technology. Potential focus areas for this assessment include: the robustness of supply chains; academic research activity; commercial deployment; strength of international collaborations; technological breadth of investments; dedicated public funding (total investment and sustained level of funding over time); academic, industry, and/or government integration; and prioritization by national leadership.[102]

DoD's legacy of more than twenty years of quantum information science research, including both internally at Service labs and by funding external talent, has created a wide breadth and scope of expert-quality quantum workforce nationally. Continuation of these efforts will allow the pool of talent to encompass the full quantum product life-cycle. Figure 8.8 illustrates the generalized job ratio and role requirements of the workforce necessary to support the product's full life cycle.

In the coming decades, as technology matures and moves through its life-cycle from concept to commercialization, the challenge will lie in shaping the workforce to address the specific needs that will arise.

Since much of quantum technology is early in its lifecycle, DoD has endeavored to balance technology promotion efforts and technology protection efforts. A correct balance would allow for the industrial base to have access to the best talent available globally, while mitigating the risks of technology transfer to strategic competitor nations. The DoD is in the process of assessing and understanding what the future quantum workforce will comprise. The study will identify projected gaps in industry-level capabilities, competencies, and occupations required to fulfill mission objectives. This assessment will also make recommendations for broad-based strategies to mitigate those gaps.[103]



Gray, K. & Herr, E. (2006). Other Ways to Win: Creating Alternatives for High School Graduates. Third Edition. Thousand Oaks: Corwin Press

Figure 8.8: U.S. Job Ratio for the Product Life-Cycle Workforce

Directed Energy (DE)

Directed Energy is an umbrella term referring to technologies that produce concentrated electromagnetic (EM) energy and atomic or subatomic particles. A directed energy weapon (DEW) is a system using DE primarily as a means to incapacitate, damage, disable, or destroy enemy equipment, facilities, and/or personnel.[104]

DoD is currently pursuing two key types of DEWs: high energy lasers (HEL), which offer precise laser beams that can reversibly dazzle or permanently burn and damage targets; and high power microwaves (HPM), which produce radio- and microwave-frequency beams that can engage multiple targets at a time and disrupt their electronic systems. Both weapon systems offer the distinct advantages of deep magazine, low cost-exchange ratio, and speed-of-light engagement, and can be employed across all warfighting domains to counter threats of evolving quantity (e.g., swarms of unmanned aerial systems or fast inshore attack craft), speed (e.g., hypersonics), and lethality (e.g., highly maneuverable cruise missiles and intercontinental ballistic missiles).[105]

The U.S. Army, Navy, Air Force, Marines, Special Operations Force, and other DoD Agencies have development programs underway to mature both HEL and HPM weapon systems.[106] For instance, the Navy has installed Optical Dazzler Interdictor (ODIN) counter-sensor lasers aboard three Arleigh Burke-class guided missile destroyers, the first of which was USS Dewey. Five additional installations will follow in the next couple of years.[107] Multiple DEWs, including the High Energy Laser (HELWS), High Power Microwave (PHASER), and Tactical High Power Operational Responder (THOR), have also been recently deployed overseas for 12-month field assessments in which Warfighters will evaluate their performance and benefit.[108] Table 8.9 shows other operational experiments. Results of these assessments will provide insight on the DE capability to counter UAS and shape the way forward for their use.

HELWS	Raytheon HEL using invisible beams of light to neutralize hostile UAS; mounted on a Polaris MRZR all-terrain vehicle
PHASER	HPM developed by Raytheon that uses microwave energy to disrupt drone guidance systems, with the capability to address UAS swarms; mounted on a shipping container-like box
THOR	Counter-swarm HPM developed by AFRL, intended for airbase defense; stores in a 20-foot transport container

Table 8.9: DEWs deployed for operational experimentation[109]

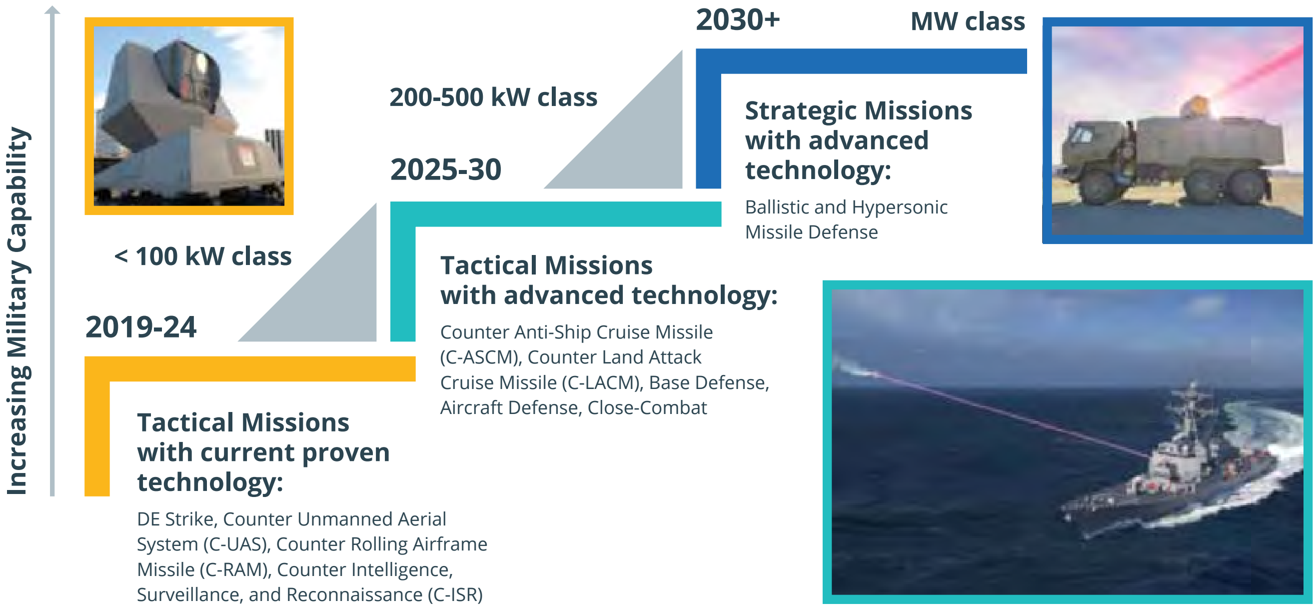


Figure 8.10: DoD HEL Roadmap[112]

Overall, DoD is focusing its near-term efforts on fielding capabilities for tactical missions with proven technologies. However, as Figure 8.10 shows, the DE technology roadmap includes the development of advanced technologies extending into the next decade. Among the DoD roadmap efforts[110] is the HEL Scaling Initiative which intends to increase HEL power levels from around 150 kW, as is currently feasible, to around 300 kW, a level at which cruise missiles could potentially be intercepted, with the potential to scale to 500+ kW.[111]

To facilitate the implementation of these future technologies, the roadmap also establishes a DE reference architecture to identify components and subsystems around which DoD can standardize. Such standards[113] will enable a modular open systems approach and reduce costs by allowing components to be bought and used by multiple programs.[114]

As the DoD demand for DEWs increases, it faces key industrial base risks related to supplier financial health, specialized equipment and skills, production capacity, foreign dependence, and single source suppliers. The primary challenge is adapting commercially available production methods to meet DE-specific products, while accomplishing high-rate, low cost production.

Fabrication of many DE components necessitates a high degree of touch labor using highly specialized skills and equipment unsuitable for any level of quantity production due to the significant cost and lead times involved.[115] This is further exacerbated by the many single and sole source suppliers currently providing critical DE components. While these suppliers are adequate for a number of demonstrator systems, there is a risk that they will not be able to meet program needs as the Military Services ramp up DE system production rates.

Domestic manufacturing insufficiencies have increased the U.S. dependency on foreign goods, such as raw substrate materials for optics and laser components, and tooling and equipment required for manufacturing of DE components. Not only does this dependence expose the supply chain to foreign influence, but it also has the potential to impact component and other downstream activity lead times, and the ability to meet necessary yield rates.

Underlying a number of industrial base risks are shortfalls in the workforce. The U.S. faces a diminishing supply of clearable labor with the advanced education and training necessary for designing, producing, and stewarding DE systems. The DoD DE community faces workforce skill gaps across the board, as the emergence of new weapon technologies, coupled with retirements, has caused a significant mismatch between skill requirements and workforce capabilities. Recruitment and retention of critical skill sets are concerns, partially because of sharp competition for labor with the private sector. Training the new workforce is essential, and improving the organic industrial base's opportunity to recruit already-trained artisans would have significant and immediate impacts on productivity and readiness.

DoD is continuing to collaborate to identify and implement mitigation efforts, leveraging several investment programs such as DMS&T, ManTech, IBAS, and DPA Title III, to apply towards DE industrial base challenges and bridge the gap between S&T and production. The TMIB office is also leading a DE industrial base assessment to identify issues, risks, and opportunities related to the development, manufacturing, and sustainment of this technology. The assessment findings will be used to create strategies to promote the innovation base and advance technology maturation.

5th Generation (5G)

The 5th generation (5G) of cellular networking infrastructure will use a combination of frequencies from multiple bands to maximize throughput. In addition to traditional macro cell towers, 5G will also use a large number of much smaller micro cells for new millimeter wave spectrum bands to create a blanket of ultrahigh-speed network coverage, providing significant improvements in capacity and latency that will enable connections to and control of many types of devices, not just cellphones. 5G will bring about wireless, ubiquitous connectivity across humans, machines, and the Internet of Things. Representative emerging and future applications are listed in Tables 8.11 and 8.12. Some commercial carriers have already started rolling out 5G networks in the U.S.

DoD will adapt 5G and next generation technologies to "operate through" congested and contested spectrum, in spite of compromised networks, to ensure maximum readiness, lethality, and partnering among allies. 5G prototyping and experimentation will be conducted in collaboration with the defense industry and commercial suppliers to accelerate U.S. prominence in the 5G global ecosystem.[116]

Segment	Drivers	Enablers	5G Requirement
Education	Remote delivery Immersive experiences	Video streaming Augmented reality/ Virtual reality	Large bandwidth Low latency
Manufacturing	Industrial automation	Massive IoT networks	High connection density Ultra reliability Low power consumption
Healthcare	Remote diagnosis and Intervention Long term monitoring	Video streaming Augmented reality/ Virtual reality Embedded devices, Advanced robotics	Low power High throughput Low latency
Smart Grid	Intelligent demand/ supply control Powerline communication	IoT sensors and networks	High reliability Broad coverage of network Low latency
Entertainment	Immersive gaming and media Industry Multimedia experience at 4k, 8K res.	Video streaming Augmented reality/ Virtual Reality	Large bandwidth Low latency

Table 8.11: Emerging applications and services enabled by 5G[117]

Segment	Drivers	Enablers	5G Requirement
Automotive / Autonomous Cars	Collision avoidance Intelligent navigation and transportation systems	Vehicle-to-vehicle (V2V) Vehicle-to-infrastructure (V2I) and other intelligent transport systems (ITS)	Large bandwidth and low latencies (< 5 ms) and high connection reliability (99.999%)
Smart Cities	Connected utilities, Transportation, Healthcare, Education and all amenities	Massive IoT networks Automation Cloud infrastructure Artificial intelligence	Large bandwidth High throughput High connection density Low latencies

Table 8.12: Envisaged Future Applications[118]

To support the new 5G capabilities, more of the radio frequency spectrum must be made available. The Federal Communications Commission is working to make additional spectrum available for 5G services and have prioritized auctioning high-band and mid-band spectrum.

Commercial 5G

U.S. commercial carriers are rolling out 5G across the low-band, mid-band, and high-band ranges of frequencies. However, the coverage is not widespread, particularly in the high-band, and it may not be available in all markets for a few more years. In addition, few devices are commercially available to take advantage of the new technology, although that is changing rapidly.

There are several new technologies that are becoming mainstream and enable the next generation of applications. Though many of these enablers have been in industry for a while, there are new applications utilizing these technologies and generating business value. Key enablers and their impact on 5G are as follows:

Robotics and drones — Industrial automation and healthcare will be two main areas where advancements in robotics will play a major role. In addition, an important use case for 5G will be drones and autonomous aerial vehicles. For example, future UAVs will deliver products and perform surveillance, disaster relief, etc. Currently, the ecosystem is exploring the use of 4G networks to enable complex flight operations that are safe (e.g., avoiding collisions with buildings, airplanes, and each other). 5G enhancements will further enable this effort and disrupt many current business practices.[119]

Virtual/augmented reality — A new set of end-user devices enabled with virtual-reality capabilities, augmented reality (with digital view on a physical view), and haptic feedback are becoming popular with education, gaming, and real-world simulations. These devices are wirelessly connected and need low latency and high reliability to enable real-time experiences.[120]

AI — Advances in deep learning have allowed for very complex algorithms being applied in everyday applications. The petabytes of data generated by networks and services on the internet and otherwise have made this possible. AI will drive applications like autonomous cars, robotics, automation, and several intelligent applications on mobile devices. AI will also be the key driver for self-optimizing networks that will allow 5G networks to respond to issues of congestion, failures, and traffic spikes.[121]

Department of Defense

Recently, DoD announced the award of over $600 million in contracts to 15 prime contractors to perform testing and evaluation of 5G technologies at five military installations across the United States. Work on the test sites will last approximately three years, with the sites expected to be set up within the first year and full-scale experimentation planned by year two. The photograph in Figure 8.13 is the AN/FPS-117 engineering facility at Hill Air Force Base, Utah – one of the 5G testing sites.[122]

Figure 8.13: The AN/FPS-117 engineering facility at Hill Air Force Base, Utah, one of the DoD 5G testing sites[123]

There are three key thrust areas that the military is pursuing in regards to 5G networking: *Accelerate, Operate Through, and Innovate. Accelerate* includes the hastening of DoD's use of 5G technologies; *Operate Through* ensures that DoD networks are secure and will have the ability to operate wherever and whenever the military goes; and *Innovate* focuses on next generation technologies (6G, 7G, etc.) to position the U.S. for the future. 5G technology is vital to maintaining the U.S. military and is a transformational technology critical to DoD modernization.[124] The economic advantages of 5G technology will be the advent of ubiquitous connectivity, and the connectivity of everything, everyone, everywhere through wireless communications.

Autonomy

"Autonomy" describes systems capable of performing assigned tasks without continuous human control. Autonomous systems include a level of perception and decision-making that allows them to adapt their performance to changing conditions, rather than completing procedural tasks. These systems have limited human guidance, though they are dependent on human guidance at some level.[125]

The strategic goals for DoD's autonomous system portfolio include building a more lethal force, strengthening the operational pull for autonomy, and accelerating DoD adoption of autonomous capabilities. To achieve these goals, DoD has identified two key areas: Manned-Unmanned Teaming (MUM-T); and Machine-Machine Teaming (M2M). MUM-T is a systems architecture that enables synchronized performance of the warfighter, manned and unmanned vehicles, robotics, and sensors to achieve enhanced situational understanding, greater lethality, and improved survivability.[126] Similarly, M2M involves synchronizing machines, such as manned and unmanned vehicles, robots, and sensors.

In the near-term, the DoD is focusing on the development of autonomous robotic platforms, swarm agents, and autonomous ISR applications. The Army, Air Force, DARPA, DISA, Defense Threat Reduction Agency, Navy, OSD, and USSOCOM all have autonomy development and research projects to further mature autonomy technology. For example, the U.S. Army began a research project on ground robot autonomous systems with the ability to receive demonstration commands from a human, enabling increased human-machine teaming.[127] The U.S. Army also has the Robotic Combat Vehicle program and with their Ground Vehicle Systems Center, they have developed autonomous software for their unmanned vehicles to enable them to autonomously explore, follow a human-designated route, and adapt to unplanned obstacles.[128]

As DoD increases its demand for autonomous systems, the Department faces several key industrial base risks, particularly related to foreign dependencies and the gap in U.S.-based human capital. Foreign dependencies exist on the technologies needed to enable autonomy, leading-edge graphics processing units (GPUs), field-programmable gate arrays (FPGAs), and application-specific integrated circuits (ASICs) – many of which have AI-specialized versions – as Taiwan and South Korea control a large percentage of chip fabrication factories. However, even for U.S.-based semiconductor manufacturing, there is a reliance on rare earth metal imports, which can cause long lead times and high expenses in the development and fabrication of autonomous systems.[129,130]

DoD also faces a gap in human capital, due to the displacement of U.S. students in autonomy at research institutions and universities by international graduates. This gap is also caused by the large proportion of international graduates who return overseas or work for foreign companies that compete with U.S. companies.

In addition, one of the main risks the Autonomy sector faces are threats of intellectual and corporate theft. Autonomy relies heavily on software, which is frequently threatened by theft and exploitation due to network vulnerabilities. Both hardware and software components of autonomous systems face persistent, advanced threats, network penetration, and forced technology transfer and theft.[131]

DoD continues to identify and implement mitigation strategies aimed at enabling autonomy development, and leverages the ManTech investment program to further develop technologies in the autonomy area, particularly in human machine teaming and collaborative robotics. The Advanced Robotics for Manufacturing Institute (ARM) is a public-private partnership leading collaboration in robotics and workforce innovation that is working to accelerate U.S.-based autonomy development and manufacturing. DoD is also continuing to oversee the health of the autonomy industrial base and monitor supply chain risks.

Cyber

DoD defines cyberspace as a global domain within the information environment, consisting of: the interdependent network of information technology (IT) infrastructures and resident data, including the Internet; telecommunications networks; computer systems; and embedded processors and controllers. All aspects of DoD joint operations rely in part on cyberspace, which is the domain within the information environment that consists of the interdependent network of IT infrastructures and resident data. It includes the Internet, telecommunications networks, computer systems, and embedded processors and controllers. Cyberspace operations (CO) refer to the employment of cyberspace capabilities to achieve objectives in or through cyberspace.[132]

Cyber is a unique military operational domain with significant security challenges and potential leap-ahead capabilities for military operations, requiring enhanced command and control, situational awareness, and autonomous operations.[133] The ability to gain and maintain the U.S. technological edge in cyberspace in the face of rapid evolution is essential to maintaining mission readiness. To ensure the country's safety in the cyber era, priority actions of the U.S. government include: identifying and prioritizing cyber risks; building defensible government networks; deterring and disrupting malicious cyber actors; improving information sharing and sensing; deploying layered defenses; improving attribution, accountability, response, integration, and agility; and strengthening cyber workforce.

- Preserving U.S. overmatch in and through cyberspace is an explicit objective of the 2018 National Cyber Strategy.[134] These actions are categorized as offensive, defensive, and cyber security:[135]
- Offensive DoD Cyber Strategy focuses on increasing force lethality through accelerated capability development, innovation, agility, automation, and analysis; deterrence; alliances and partnerships; organizational practices; and workforce issues, including force structure, training, and qualifications.
- Defensive options including design for security, resilience, and survivability; training, awareness; and cyber hygiene. Design for resilience applies at all levels, from the simplest components and their underlying technologies to the most complex integrated system of systems, as well as all enabling technologies that make them possible.
- Cybersecurity refers to the prevention of damage to, protection of, and restoration of computers, electronic communications systems/services, and wire communication, including information contained therein, to ensure its availability, integrity, authentication, confidentiality, and nonrepudiation (DoDI 8500.01).

The U.S. influence in cyberspace is linked to its technological leadership. Accordingly, the U.S. government is making a concerted effort to protect cutting-edge technologies, including from theft by our adversaries, and to support those technologies' maturation, and, where possible, reduce U.S. companies' barriers to market entry.[136] DoD is focused on preventing cyber vulnerabilities within the cyber operations infrastructure, the industrial base, enterprise IT and business systems, and infrastructures required for integration and testing. Other DoD objectives include defending U.S. critical infrastructure, both DoD and non-DoD assets, and securing DoD information and systems against malicious cyber activity. The March 2020 U.S. Cyberspace Solarium Commission report advocates a strategic, "layered cyber defense," approach aimed at promoting responsible behavior by U.S. personnel, enhancing cyber resilience and security to deny benefits of cyber-attacks, and imposing costs to adversary attacks short of armed conflict.[137] The report also suggests continual assessment of cyber vulnerabilities of all U.S. weapon systems, and an overall force structure assessment in light of continuously increasing mission requirements and expectations for cyber defense.[138]

The United States must protect sensitive emerging technology R&D from adversaries who seek to acquire intellectual property and gain an unfair advantage. To achieve this, DoD will invest in cyber defense, resilience, survivability, and the continued integration of cyber capabilities into the full spectrum of military operations. Investments will prioritize developing resilient, survivable, federated networks and information ecosystems from the tactical level up to strategic planning. Investments will also prioritize capabilities to gain and exploit information, deny competitors those same advantages, and enable the DoD to provide attribution while defending against and holding accountable state or non-state actors during cyberattacks.

The present and future cyber workforce will require, in addition to the basic cybersecurity and software engineering knowledge, a much broader and deeper understanding of analytics and key technologies, such as autonomy, human-machine interaction, and artificial intelligence. Key focus areas include acknowledging a need to address cyber defense with an "Always-On" 24/7/365 mentality. Continuing to add security controls on top of security controls (*e.g.,* multi-factor authentication) only provides limited symptomatic relief without addressing the need for people to change the way they think about being responsible for security. The DoD is collaborating with the NSA to develop curricula for learning and development, laboratory and training exercises, research opportunities, and competitions, to provide the future cyber workforce with relevant experiences in the practice and leadership of cyber security and resilience. These efforts will facilitate both the growth and readiness of the DoD cyber workforce.

SECTION 9

SUPPORTING ACTIONS AND AUTHORITIES

Defense Priorities and Allocations System

Program Objective

The purpose of the Defense Priorities and Allocations System (DPAS) is to assure the timely availability of industrial resources to meet current national defense and emergency preparedness program requirements, and to provide an operating system to support rapid industrial response in day-to-day operations and national emergencies. The Defense Production Act of 1950 authorized the President to require preferential treatment of national defense programs. DPAS establishes procedures for placement of priority ratings on contracts, defines industry's responsibilities under rated orders, and sets forth compliance procedures.

Rating Determinations

All prime contracts, subcontracts, or purchase orders in support of an authorized program are given a priority rating.

A DX rating is assigned to those programs of the highest national priority. Per DoD 4400.1-M, USD(A&S) has authority to validate the request for a DX rating. If deemed necessary, the USD (A&S) will nominate the suggested program for a DX rating to the Secretary of Defense for approval. The DPAS team continues to educate the Services and DoD agencies on DPAS authorities including the differences and applicability of DO, DX, and SPA. The Department strives to minimize the use of DX ratings and SPAs because they can be disruptive to the commercial and Defense industrial base. Additionally, overuse of DX ratings will dilute the strength and effectiveness of the priority and therefore negatively impact the ability of the Department to surge in the event of a National Emergency; if everything is a priority, then nothing is a priority.

DO Rating	DX Rating	Special Priorities Assistance (SPA)
A DO priority rating gives the DoD preference over all unrated orders Because of DoD's mission, all procurement contracts should contain a "DO" priority rating DO rated orders have equal priority among other DO rated orders, but have priority over unrated orders	Assigned to programs with the highest national defense urgency Takes preference over DO rated orders and unrated orders with the same delivery dates DOES NOT move the order in front of orders with the same rating with earlier delivery dates ONLY the Secretary or Deputy Secretary of Defense can grant a DX priority rating designation to systems or programs with the highest national defense urgency	SPAs alleviate schedule delivery conflicts during high demand periods where there are competing requirements for the same resources SPA requests should be timely for the DoD or the Department of Commerce to effect a meaningful problem resolution, and must establish that: 1. There is an urgent need for the item; and 2. The applicant has made a reasonable effort to resolve the problem

Security of Supply Arrangements

DPAS Ratings are only enforceable for companies subject to U.S. law. Since the U.S. DIB sources from a global market, the DoD enters into Security of Supply Arrangements (SOSAs) with several nations to ensure the mutual supply of defense goods and services. These bilateral arrangements allow the DoD to request priority delivery for DoD contracts, subcontracts, or orders from companies in these countries. Similarly, the arrangements allow the signatory nations to request priority delivery for their contracts and orders with U.S. firms. The DoD currently holds nine SOSAs with U.S. allies and partners, and continues to evaluate opportunities to expand SOSAs to other allied countries.

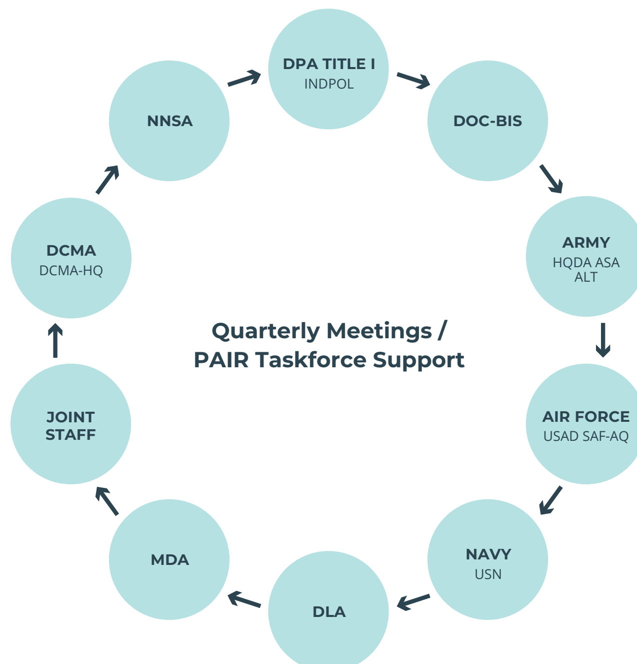
FY2020 Accomplishments

In 2020, the DPAS program worked closely with the DoD Services and industry partners to resolve a number of Industrial Base issues, resulting with little to no impact to DoD programs. In 2020, a number of DoD programs experienced delivery date conflicts which were resolved amicably between the DoD and its suppliers through education, communication, and cooperation. This outreach lead to the resolution of a potential production shutdown impacting DoD, and Allied readiness, and industry partners.

Established in 2019, the DPAS Enterprise Board (EB) continues to work collaboratively to provide a more responsive process to address national security requirements, including an enterprise-level approach to evaluate DX ratings, and assigning resources to mitigate competing cross-service requirements. The EB has added two new Services members to increase visibility and collaboration among OSD and the Services.

COVID-19 Actions

In response to COVID-19, the Department of Defense, in conjunction with FEMA and HHS, worked to prioritize production and construction equipment using the DPAS authority. The DPAS team worked closely with the DPA Title III Office to award and fund industrial expansion projects, and ensure the awardees were able to receive the production and construction equipment needed to meet the demands of the nation. DPAS, or DPA Title I, continues to support the whole-of-government effort to combat the coronavirus pandemic.



DPA Title III

Program Objective

The Office of Industrial Policy administers the DPA Title III program, consistent with the Secretary of Defense's duties as the Fund Manager under 50 U.S.C. 4501 *et seq.* Title III provides the President broad authority to ensure timely availability of domestic industrial resources essential for the execution of the U.S. National Security Strategy through the use of tailored economic incentives, including:

- Purchases/Purchase commitments,
- Developing production capabilities and commercializing emerging technology,
- Loans/Loan guarantees, and
- Installing Production Equipment in Government- or Privately-Owned Facilities.

The Title III program predominantly executes against defense industrial base shortfalls. However, the program has a broader statutory mandate, authorizing non-defense agencies to mitigate their industrial shortfalls pertaining to homeland security and critical infrastructure, in sectors defined by the Department of Homeland Security.

Throughout FY2020 in response to the national emergency from COVID-19, the DPA Title III program executed at unprecedented scale and speed to mitigate industrial shortfalls within the DIB and the healthcare sectors. Using supplemental appropriations from the CARES Act, the DPA Title III program allocated $676 million to DIB mitigation, $213 million to the healthcare sector, and $100 million to a Federal Credit Loan program, to make loans supporting the national response and recovery to the COVID-19 outbreak or the resilience of any relevant domestic supply chain.

Overview

Legislative Authority: Title III of the Defense Production Act of 1950

Established: 1950, reauthorized in 2018

Oversight: A&S Industrial Policy

Presidential Actions

Under the program's peace-time functions, the President must issue a determination and notify Congress of an industrial base shortfall prior to initiating investment actions under Title III. In FY2020, the President issued one determination, related to high temperature materials for hypersonic weapons.

The President also issued a Proclamation declaring a national emergency with respect to the COVID-19 disease. This declaration, combined with the Public Law 116-136, authorized the use of extraordinary authority under Title III for rapid, large-scale investments to prevent, prepare for, and respond to COVID-19 (see 2020 Overview). The President also declared a national emergency under the International Emergency Economic Powers Act, concerning adversarial exports of critical minerals.

Sustain Critical Protection	Commercialize R&D Investments	Scale Emerging Technologies
"To create, maintain, protect, expand, or restore domestic industrial base capabilities essential for the national defense."	"From Government sponsored research and development to commercial applications;" and "from commercial research and development to national defense."	"For the increased use of emerging technologies in security program applications and the rapid transition of emerging technologies."

Investment Areas

DPA Title III projects address three broad priority areas, as defined in section 303(a) of the Defense Production Act:

FY20 Presidential Actions:

1. Presidential Proclamation 9994: Declaring a National Emergency concerning the Novel Coronavirus Disease (COVID-19) Outbreak
2. Executive Order 13911: Delegating Authority under the Defense Production Act with respect to Health and Medical Resources to respond to the spread of COVID-19
3. Executive Order 13922: Delegating Authority under the Defense Production Act to the Chief Executive Officer of the United States International Development Finance Corporation to respond to the COVID-19 Outbreak
4. Presidential Determination: Ultra ultra-high and high temperature composites
5. Executive Order 13953: Addressing the Threat to the Domestic Supply Chain from Reliance on Critical Minerals from Foreign Adversaries and Supporting the Domestic Mining and Processing Industries

2020 Overview

- At end of FY2020, DPA Title III portfolio included 87 projects, leveraging over $2.1 billion in government and industry funding to increase the lethality and readiness of the nation by strengthening the DIB and responding to the coronavirus pandemic
- In support of E.O. 13806, President issued one Presidential Determination supporting the hypersonic industrial base
- New projects in FY2020 strengthening the domestic industrial base in key sectors, including rare earths, microelectronics, strategic materials, space, aircrafts, and power storage.

Appropriations on the DPA Fund Since FY2010, in Millions [139]

Fiscal Year	Law	Appropriation Amount	
2010	P.L. 111-118, 123 Stat. 3422	$150.7	*a. In FY2014, FY2015, and FY2016, Congress also authorized DOE to transfer up to $45 million to the DPA Fund from each FY appropriation from the Energy Efficiency and Renewable Energy account. These transfers were made by DOE, for a total of $135 million.*
2011	P.L. 112-10, 125 Stat. 51	$34.3	
2012	P.L. 112-74, 125 Stat. 800	$170.0	
2013	P.L. 113-6, 127 Stat. 291	$223.5	
2014	P.L. 113-76, 128 Stat. 98	$60.1a	
2015	P.L. 113-235, 128 Stat. 2246	$51.6a	
2016	P.L. 114-113, 129 Stat. 2345	$76.7a	
2017	P.L. 115-31, 131 Stat. 242	$64.1	
2018	P.L. 115-141, 132 Stat. 458	$67.4	
2019	P.L. 115-245, 132 Stat. 2995	$53.6	
2020	P.L. 116-93	$64.4	

Committee on Foreign Investment in the United States

Legislative Authority: § 721 of the Defense Production Act of 1950

Established: 1988

Oversight: Foreign Investment Review, A&S INDPOL

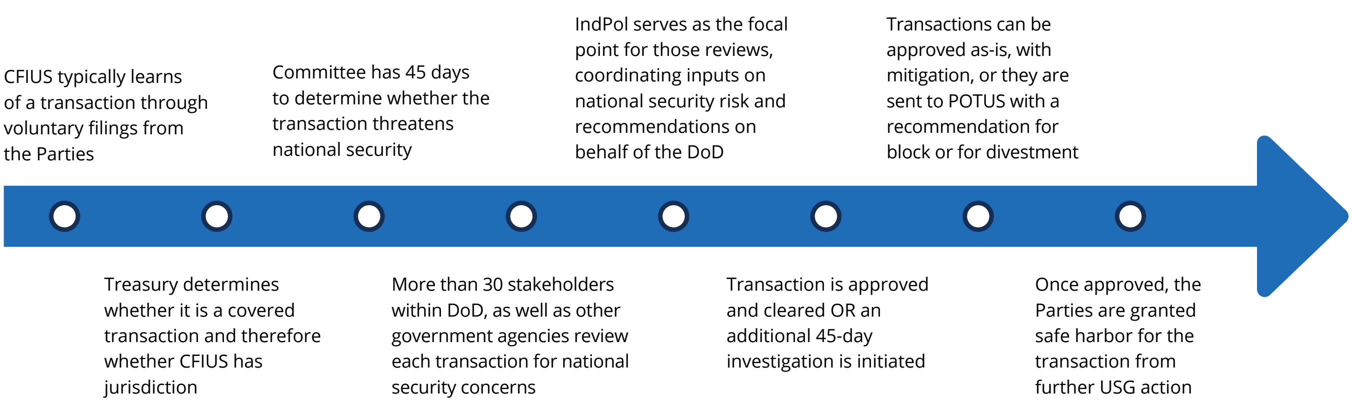
Objective

The Committee on Foreign Investment in the United States (CFIUS) is an interagency committee authorized by statute to review certain transactions, mergers, and acquisitions that either could result in foreign control of a U.S. business or real estate property, or which are non-passive, non-controlling investments in certain critical or emergent technology companies. In 1988, Congress enacted the Exon-Florio amendment adding section 721 to the Defense Production Act of 1950, which authorized the U.S. President to investigate the effect of certain foreign acquisitions of U.S. companies on national security and to suspend or prohibit acquisitions that might threaten to impair national security. The President delegated this investigative authority to CFIUS.

CFIUS is comprised of nine voting member agencies (the Department of the Treasury (CFIUS Chair); the Departments of Commerce, Defense, Energy, Homeland Security, Justice, and State; the U.S. Trade Representative; and the White House Office of Science and Technology Policy), two ex-officio members, and five White House offices.

Within the Office of Industrial Policy, the Foreign Investment Review (FIR) team serves as the DoD's CFIUS representative and acts as the principal advisor to USD(A&S) on foreign investment in the U.S. As the DoD CFIUS representative and central point of contact, FIR coordinates departmental participation across more than 30 DoD component organizations (DoD stakeholders) to identify, review, investigate, mitigate, and monitor inbound foreign direct investment in the U.S. FIR relies on DoD stakeholders for the technical expertise needed to analyze the threats, vulnerabilities, and consequences associated with foreign investment into the U.S.

Review Process



FIRRMA

On August 13, 2018, President Trump signed the Foreign Investment Risk Review Modernization Act (FIRRMA) into law. FIRRMA expands the scope of reviewable transactions to address a new set of national security concerns and strengthens the ability of CFIUS to protect national security.

Before FIRRMA, CFIUS jurisdiction had remained virtually unchanged in the 30 years since Congress first passed the Exon-Florio Amendment (the statutory cornerstone of CFIUS). Since that time, the nature of foreign investments in the U.S. and the national security landscape have shifted significantly.

FIRRMA expanded CFIUS jurisdiction to four new types of covered transactions: certain real estate interests; non- controlling "other investments" in certain U.S. businesses; changes in a foreign investor's rights; and any other transaction, transfer, agreement, or arrangement designed or intended to evade or circumvent the application of previous rules governing CFIUS.

1. Critical Technology: The definitions and standards for critical technology were not updated with the Rules. However, subsequent Notice of Proposed Rulemaking to update the standards for filing critical technology-related mandatory declarations was published on May 21, 2020. The Department of Commerce continues its rulemaking efforts to characterize emerging and foundational technologies and to align associated critical technologies with applicable export control laws.
2. Critical Infrastructure: FIRRMA expands CFIUS jurisdiction to review non-controlling investments in U.S. businesses that own, operate, manufacture, supply, or service certain components of the defense industrial base, energy infrastructure, communications networks, financial services, transportation services, and water and wastewater systems.
3. Sensitive Personal Data: The rules expand CFIUS jurisdiction to review non-controlling investments in U.S. businesses that collect sensitive personal data. Sensitive personal data includes financial information, health information, communications, geolocation data, biometric or genetic data, and security clearance information.
4. Real Estate: FIRRMA allows review of commercial real estate transactions within certain proximities to named military installations.

FIRRMA does not change the longstanding open investment policy of the U.S. The U.S. continues to welcome foreign investment as a vital part of a robust economy.

Office of Small Business Programs

Objective

The Office of Small Business Programs (OSBP) maximizes prime and subcontracting opportunities for small business to respond to current and future Warfighter requirements. The complexity of DoD requirements and contracting processes can preclude new entrants to the defense market. This is particularly true of small businesses that do not have the manpower and resources necessary to navigate and compete for defense contracts.

The October 2019 DoD Small Business Strategy focuses on three objectives:

1. Creating and implementing a unified management structure across DoD's small business workforce.
2. Ensuring that the Department's small business activities align with the 2018 National Defense Strategy and other guiding documents.
3. Strengthening DoD's ability to support the warfighter through supporting small businesses

The following programs help bring new business into the DIB by creating a pathway for non-traditional contractors to participate and succeed.

MPP

Legislative Authority: §831 of the FY1991 NDAA

Established: 1990

Oversight: Industrial Policy

IIP

Legislative Authority: 25 USC Section 1544

Established: 1997

Oversight: Industrial Policy

Mentor Protégé Program

DoD's Mentor Protégé Program (MPP) has successfully helped more than 190 small businesses fill unique niches and become part of the military's supply chain. The MPP supports eligible small businesses to expand their footprint in the defense industrial base and become reliable government contractors. Protégés work side by side with established defense contractors to develop technical capabilities. Mentors, typically large defense contractors, can leverage the nimble and agile nature of small businesses and their technologies, services, and cutting-edge products to improve innovation in major defense acquisition programs.

Indian Incentive Program (IIP)

While Native Americans have a long history of contributing to the U.S. military, Indian reservations and Alaska Native Villages suffer some of the worst poverty in the country. In an effort to strengthen Native American economic development, Congress authorized Federal contracting agencies to encourage the use of Native American owned subcontractors. The Indian Incentive Program (IIP) incentivizes contracting with Indian Organizations, Indian-Owned Economic Enterprises, Native Alaska and Native Hawaiian Small Business Concerns by providing a five percent incentive to prime and sub-tier contractors who subcontract with eligible firms. Since FY2015, the IIP has funded more than 650 rebates totaling $100 million in incentive payments, which leveraged more than $2 billion in subcontract performance by Native-owned firms.

FY2020 Overview

Project Spectrum: In FY2020, OSBP partnered with US Cyber Command to develop Project Spectrum, an initiative designed to provide training and conduct risk assessments to enhance awareness of cybersecurity threats among small manufacturers and universities in the DIB. Its three main elements include:

1. The ecosystem of government partners and stakeholders pooling resources and working collaboratively to increase cybersecurity in the DIB;
2. Awareness and training of the DIB, including preparedness for the Department's latest cybersecurity requirements; and
3. Tools and services that lower the barrier to small and medium-sized companies obtaining and maintaining cybersecurity compliance.

To date, 20,000 small businesses have received training and more than 35 cybersecurity tools were evaluated.

Cybersecurity Education Diversity Initiative (CEDI): The CEDI Project is a collaboration between the National Security Agency's National Centers of Academic Excellence in Cybersecurity (NCAE-E) Program Management Office and the MPP program. It assists Minority Serving Institutions (MI) and Historically Black College and Universities (HBCU) with no existing cybersecurity programs with obtaining access to consultation and educational resources from designated NCAE-E institutions, thus expanding access to quality cybersecurity education and mentoring to students in all 50 states. This collaboration allows the OSBP MPP to provide participating protégés with technical assistance on cybersecurity at HBCUs and MIs.

Small Business Training Week: In September 2020, OSBP hosted the largest-ever virtual Small Business Training Week for the acquisition community. 1,056 attendees represented Small Business Professionals, Program Directors, Contracting Officers, and Program Managers. The training week's theme was "Refocus on Rebuilding a More Resilient Small Business Community," emphasizing the Department's direction to better align the small business industrial base to the DoD's mission. Topics aligned with current innovation gaps and provided practical ways for small business professionals and the broader acquisition workforce to understand their roles and take action.

Coronavirus Pandemic Response

The DoD OSBP team addressed the effects of COVID-19 early on in the pandemic, retooling the office's functions and outreach efforts. USD(A&S) Ellen Lord, referred to OSBP as the "Information Hub," providing up-to-date information to the small business industrial base. OSBP established industry calls and webinars with industry association partners to maintain a pulse on the private sector and provide direct information to small businesses on a broad range of topics including: COVID-19 resources, cybersecurity, foreign investment, and successful teleworking practices. OSBP also reinvigorated its outreach to industry. The OSBP website, defense.business.gov, became the central communication portal for DoD small business resources and updates, and social media channels were used to quickly disseminate information to the widest possible audience.

Industrial Base Analysis and Sustainment

Objective

The Industrial Base Analysis and Sustainment (IBAS) Program strengthens the DIB in the era of great power competition. It works to create a modern Industrial Base with the capacity to respond at will to national security requirements. IBAS investments fortify and forge traditional and emerging sectors to improve IB readiness. These investments are strategically catalyzing in critical areas that lack momentum.

IBAS Program Priorities:

- ***Ready the Modern DIB:*** Advance and sustain traditional defense manufacturing sectors
- ***Prepare for the Future:*** Identify, attract, and cultivate emerging defense sectors
- ***Assess and Shape the Risk:*** Mitigate supply chain vulnerabilities within the Global DIB
- ***Build and Strengthen:*** Build partnerships in the Global DIB

Investment Strategy

The IBAS office directs investment by identifying strategy/focus areas, obtaining resources, and overseeing the execution of projects to strengthen the defense industrial base by ameliorating industrial base and manufacturing issues. All projects are evaluated for industrial base risk using a framework of risk assessment methodologies and tools, including fragility and criticality risk criteria to develop feasible and effective course of actions. Key areas of IBAS investment include:

- Advancing and sustaining traditional and emerging defense manufacturing sectors
- Preserving critical and unique manufacturing and design skills
- Supporting and expanding reliable sources, and
- Identifying and mitigating supply chain, cyber, manufacturing, and trade skills vulnerabilities

Overview

Legislative Authority: 10 U.S. Code § 2508. Industrial Base Fund

Established: FY2014

Oversight: Industrial Policy

Cornerstone

The Cornerstone Other Transaction Authority (OTA) is a government-run, integrated contract vehicle used to create dynamic relationships across the DIB using the IBAS authorities. The Cornerstone OTA authority originates from 10 U.S. Code 2371b - Authority of the DoD to carry out prototype projects. Cornerstone focuses on “prototype” projects, capabilities, and capacities in support of a range of defense industrial base requirements across 19 sectors.

FY2020 Investments

In FY2020, IBAS continued to address issues from the E.O. 13806 report findings and priority programs, partnering on investments and shared interest areas.

IBAS FY2020 Budget

$10M	$94M
IBAS Core Budget	Congressional additions for new efforts

IBAS Investments	
Boron Carbide	Expand DIB by establishing second U.S. source to mitigate foreign supply chain risk
Heavy Rare Earths Elements Supply Chain Resiliency	Establish U.S. capacity to mitigate foreign supply chain risk. Engineering study to inform production scale up
Rare Earth Elements from Coal Ash	Prototyping effort for rare earth elements extraction from coal ash *(in negotiations)*
DE Supply Chain Analysis and Readiness Study	Establish resilient DE supply chain
Radar Affordability Working Group Land & Sea Systems	Expand DIB suppliers for critical radar subcomponents to mitigate risks to cost and readiness
Silicon Interposer	Establish secure domestic production capability
Lead-Free Electronics	Establish public-private partnership-led electronics manufacturing consortium. First task: establish standards to mitigate risks of using lead-free electronics in high-performance systems *(in negotiations)*
Critical Energetics Working Group	Support to Joint Army, Navy, NASA, Air Force (JANNAF) Executive Committee
Advanced Armor-Piercing Penetrators	Improve supply chain resiliency for tungsten penetrators used in munitions
Machine and Advanced Manufacturing: America's Cutting Edge (ACE)	Joint DoD-DOE machine tool hub to improve U.S. machine tools competitiveness: advance machine tool capabilities for DoD-specific application; lower barriers to entry for small and medium manufacturers to adopt new machine tools
Automated Textile Manufacturing	Integrate automated manufacturing capability with advanced, high-end fibers
Supply Chain Analysis 1-3	Subscription services and tools to enable supply chain vulnerability detection and risk management efforts *(one award pending)*
Hypersonics Supply Chain Analysis and Readiness Study	Study support for Hypersonics War Room (R&E)
Mobile Nuclear Reactor Supply Chain Analysis & Readiness Study	Assessment of design elements, manufacturability, manufacturing process, and supply chain for mobile power source
Submarine Workforce Development	Public-private partnership with NE states to mitigate shortfalls within submarine-building supply chain
Interdisciplinary Center for Advanced Manufacturing	University-led consortium effort to reduce barriers preventing small and medium manufacturers from adopting advanced manufacturing capabilities and processes
Precision Optics Manufacturing	Effort to advance domestic precision optics manufacturing capability and workforce development pipeline *(in negotiations)*
Machine and Advanced Manufacturing: Workforce Component	Not-for-profit institute-led effort to develop and provide advanced machine tools training programs for small and mid-sized manufacturers
Manufacturing Engineering: Hypervelocity Prototype for Welding	Not-for-profit led regional welding workforce accelerated pipeline development for the ship/submarine sector
Manufacturing Engineering: Vermont	University-led regional engineering and critical manufacturing technician workforce pipeline development
Manufacturing Engineering: Texas Engineering Experiment Station	University-led regional manufacturing workforce pipeline development for Texas defense supply chain requirements
Manufacturing Engineering: System Engineering Technicians	University-led regional systems-engineering manufacturing technician workforce pipeline development
Manufacturing Engineering: Electronics Manufacturing & Technical Education	Small business-led electronics technician workforce pipeline development
**this table presents new IBAS FY2020 efforts (Note: Awards expected prior to report publication for those in negotiations or competition).*	

Warstopper Program

Objective

The Warstopper Program is the Department's primary program for consumable items in sustainment. It works to provide industry an incentive to support the sustainment of items that industry would otherwise not have a business case to support.

Warstopper Program Priorities:

- Sustainment readiness investments that allow for go-to-war material to be available during a surge.
- Preserve industrial capability for known go-to-war requirements of sustainment items that are in jeopardy of not being viable.
- Conduct DIB risk analysis for consumable items in sustainment to inform investment

Warstopper Program Criteria:

- Mission Critical Materials and Supplies
- Low Peacetime Demand – High Wartime Demand
- Limited Shelf Life – Long Production Lead Time

Investment Strategy

The Program provides an industrial strategy to meet go-to-war consumable items in sustainment. It is a deliberate strategy to off-set the buy and hold war reserve strategy as well as securing fragile consumable sustainment items with go-to-war requirements. This usually involves implementing contracting strategies for the following:

- Secure commercially available go-to-war material in the quantity and timeliness (example: pay management fees to guarantee the quantity and early delivery)
- Increase manufacturer and distributor capability to provide go-to-war consumable items material (example: stage raw material and long lead time parts or provide additional equipment)
- Preserving cold production needed for go-to-war consumable items (example: fund a company's fixed cost to sustain a production line)

Overview

Legislative Authority: Responds to requirements in E.O. 13603.

Established: FY1993 in response to FY1993 NDAA

Oversight: DLA

FY2020 Investments

In FY2020, Warstopper continued to provide risk mitigating investments for critical go-to-war items and sectors.

$72.7M

FY2020 Funding

Readiness Investments

Supply Chain	Project	Use	Impacted NSNs
Land	Preposition Steel Grade 9260	Aircraft Landing & Recovery Equipment (ALRE)	1
Maritime	Tungsten Rhenium Ingots	Electron Tube	119
Maritime	Generalized Emulation of Microcircuits (GEM)	Digital Microcircuits; 5V Logic Family Devices	445
Medical	Medical Corporate Exigency Contracts (CEC)	Pharma/Supplies/Equipment	7,223
Subsistence	UGR GFE Maintenance	Unit Group Rations	10
Subsistence	VMI Submarine Forces Pacific	Rations/Food Resupply of Pacific Theater	200
Subsistence	Buffer Stock Investment	Flameless Ration Heaters	1

Upstream Buffer Investments

Supply Chain	Material or Component	Usage	Impacted NSNs
Aviation	Steel Grade 300M	Torsion Bars and Aircraft Landing Gear	295
Aviation	Steel Grade M50; 440C & 52100	Bearings	942
Aviation	Titanium 6AL-4V & 5AL-2.5SN	Aircraft Structural Parts	8,611

Preservation of Capabilities/Capacities Investments

Supply Chain	Initiative/Targeted Systems	Impacted NSNs
Aviation	Aircraft/Aerospace	2,001
Aviation	Bomber/B-1, B-52	5,474
Aviation	Engine/TF-33, B-52	1,500
Energy	Launch/Gaseous Nitrogen	1
Energy	Satellite/Hydrazine	1
Energy	Satellite/Dinitrogen Textroxide (N204)	1

Small Business Innovation Research & Small Business Technology Transfer

Overview

Combined SBIR/STTR Budget: $1.8B (annually)

Oversight: Office of Small Business Technology Partnerships (SBTP)

Legislative Authorities: 15 USC Section 638

Program Objective

The statutory purpose of the SBIR program is to strengthen the role of innovative Small Business Concerns (SBCs) in Federally-funded research or research and development (R/R&D) to:

- Stimulate technological innovation
- Involve small business to meet Federal R/R&D needs
- Foster and encourage participation by socially and economically disadvantaged SBCs, and by women-owned SBCs, in technological innovation;
- Increase private sector commercialization of innovations derived from Federal R/R&D to increase competition, productivity, and economic growth.

In addition to the broad goals of the SBIR program, the statutory purpose of the STTR program is to stimulate a partnership of ideas and technologies between innovative SBCs and non-profit Research Institutions. By providing awards to SBCs for cooperative R/R&D efforts with Research Institutions, the STTR program assists the U.S. small business and research communities by supporting the commercialization of innovative technologies.

Small Business Innovation

SBIR encourages domestic small businesses to engage in Federal R/R&D on initiatives that have the potential for commercialization. Through a competitive awards-based program, SBIR enables small businesses to explore their technological potential, provides the incentive to profit from commercialization, stimulates high-tech innovation from non-traditional contractors, and encourages entrepreneurial spirit as the Federal agencies meets its specific R&D needs. As required by statute, each Federal agency with an extramural budget for R/R&D in excess of $100,000,000 must participate in the SBIR Program and reserve a minimum percentage of its R/R&D budgets for small business R/R&D contracts.

Small Business Technology Transfer Program

The Small Business Technology Transfer Program (STTR) is intended to stimulate a partnership of ideas and technologies between innovative SBCs and non-profit Research Institutions. By providing awards to SBCs for cooperative R/R&D efforts with Research Institutions, the STTR program assists U.S. small business and research communities by supporting the commercialization of innovative technologies. STTR expands funding opportunities in the federal innovation R&D arena. Central to the program is expansion of public/private sector partnerships to include joint venture opportunities for small businesses and non-

PHASE I

Project Feasibility—determines the scientific, technical, and commercial merit and feasibility of proposals.

~1,300 awards/year

PHASE II

Project development to prototype (the major R&D effort)—funding the prototyping and demonstration of the most promising Phase I projects.

~950 awards/year

PHASE III

Commercialization (the goal of each SBIR/STTR effort)—Phase III work must be funded by sources outside the SBIR/STTR Program.

Funding exceeded $15B

profit research institutions. Unique to the STTR program is the requirement for the small business to formally collaborate with a research institution in Phase I and Phase II. STTR's most important role is to bridge the gap between basic R&D and commercialization of resulting innovations. STTR is regulated by the same statue as SBIR, requiring participation based extramural budget for R/R&D.

4,367	$2.06B
Total Contracts Awarded in FY2020	Total Amount Awarded in FY2020

*These figures are accurate based on FY20 contract actions as of the date of preparation of this document and do not reflect final numbers for the 2020 Fiscal Year

FY2020 Overview

- In June 2020, the Office of Small Business Technology Partnerships (SBTP) office launched the OSD Transitions SBIR/STTR Technologies Pilot Program, which will help enable and accelerate the incorporation and transition of SBIR/STTR Phase II technologies to the Warfighter. Since June, the program has funded $39.4M on 24 projects
- In August 2020, the DoD SBIR/STTR Innovation Portal integrated with Login.gov to increase security, efficiency, and user experience for Small Business Concerns.
- In October 2020, the SBTP Office hosted its inaugural DoD SBIR/STTR Virtual Symposium. The Symposium appealed to a broad audience aiming to do business with the Department. Registrants and participants represented all 50 states and the territories of Puerto Rico and the U.S. Virgin Islands. Participants included: government personnel, large business, prime contractors, small business, support contractors, and university/academia. Approximately 1,110 unique visitors logged in to view and participate in the symposium.

FY2021 Goals

The Small Business and Technology Partnerships (SBTP) office's primary goal is to increase awareness of the SBIR and STTR Programs within the Department and encourage small innovative businesses to work with DoD to solve National Security challenges. The following objectives will help achieve this goal:

- Implement legislative changes to the SBIR/STTR programs in accordance with the FY2020 NDAA;
- Engage with other DoD and Federal stakeholders on SBIR/STTR best practices;
- Participate in outreach events across the country to educate the small business community on the SBIR/STTR programs;
- Enhance the Defense SBIR/STTR Innovation Portal (DSIP) based on feedback from users and stakeholders;
- Identify and establish relationships with new partners.

COVID-19 Response

March 2020, SBTP formed a COVID-19 Response working group. The group's purpose was to strategize on how the SBIR/STTR programs could utilize funding to quickly respond to the coronavirus pandemic and determine if funding through as the CARES Act could be utilized to fund COVID-19 related research and development. The Missile Defense Agency and Defense Logistics Agency, respectively, provided additional funding to companies e-Spin Technologies and AAPlasma, who converted their current SBIR technologies for use in PPE gear. The SBTP office provided $7.38 million to DARPA to further develop COVID-19 technologies in partnership with the Texas Air National Guard. Additionally, the office is reviewing $13.5 million in potential funding for COVID-related projects from the Defense Health Agency.

Rapid Innovation Fund

Objective

The Rapid Innovation Fund (RIF) operated via Congressional Add until funding ceased in FY2020. There is no expectation the RIF will receive future funds or be reinstated. The RIF continues to be managed by OUSD(R&E) Small Business and Technology Partnerships (SBTP) through closeout.

The RIF was established as a competitive, merit-based program designed to rapidly transition innovative technologies into defense acquisition and use. Projects are drawn from Small Business Innovation Research/Technology Transfer (SBIR/STTR) initiatives, defense laboratory and academia efforts, and other non-conventional sources. The RIF is a major benefactor to small businesses and SBIR/STTR follow-on efforts, acting as a direct-to-Phase III conduit. Program objectives include:

- Accelerating or enhancing a military capability,
- Reducing development, acquisition, sustainment, or lifecycle costs of defense acquisition programs or fielded systems,
- Reducing program technical risk, and
- Improving timeliness and thoroughness of test and evaluation.

In FY2018, the RIF re-aligned objectives to address critical security needs based on the 2018 National Defense Strategy (NDS). In FY2019, the RIF adapted requirements to cover the NDS modernization priority areas supported by OUSD(R&E). Prior efforts focused on general warfighting needs and Reliance 21.

Overview

Authority: National Defense Authorization Act, Public Law 116-92, Section 878

Established: 2011

Permanently Authorized: 2017

FY2011-FY2019 RIF Highlights

>$2.2B Invested in Department of Defense requirements from Air Force, Army, Navy & over 30 OSD organizations	**85%** Small Business Awards
	57% SBIR/STTR Phase III Awards
20,600 Whitepapers	**~1,500** Proposals
~1,000 Contract Awards	**$2.1M** Average Value

++ Financial statistics from TechLink "Defense Rapid Innovation Fund: An Assessment of RIF Effectiveness FY 2011-16"

RIF Source Selection Process

Individual projects limited to $3-6M* each and 24-month performance period

STEP I

Issue annual broad agency announcement for whitepaper (WP) solicitation

STEP II

Invite highest-rated WPs for full proposals

STEP III

Award highest-rated full proposals

* Higher cost projects cannot exceed 25 percent of the total budget

Recent Accomplishments

SBTP delivered milestone RIF FY2020 National Defense Authorization Act Congressional report on FY2017 through FY2019 RIF efforts and overall program effectiveness in June 2020

- Data from a TechLink study determined RIF is highly successful at meeting program objectives, transitioning approximately 60 percent of projects to-date with more than three times return on investment

Streamlined financial process to shorten timelines

- Simplified funds request paperwork and process
- Implemented financial deadlines: Check-ins at 30, 60, 90 day marks; award within 90 days
- Awarded contracts on average within 74 days

Increased RIF Office oversight from proposal through contract award phases

- Cradle-to-grave project tracking to link program and financial team efforts
- Monthly financial updates to decrease risk from contract issues
- Quarterly updates from RIF Office to program managers
- Quarterly performance project performance reviews with all RIF program managers

Awarded FY2019 selections from Army, Air Force, Navy, and OSD-affiliated Organizations, including selections by OUSD(R&E) Modernization Principal Directors

- Awarded over 60 percent of FY2019 funding to projects within OUSDR&E modernization priority areas

Modernization Principle Director Projects		
AI/ML	6 awards	$15.8 M
Autonomy	6	$13.8 M
Cybersecurity	7	$13.1 M
Directed Energy	4	$11.2 M
Hypersonics	4	$8.9 M
Microelectronics	3	$8.9 M
Networked C3	8	$20.3 M
Space	2	$6 M
Total	**40**	**$98 M****

Services and OSD Projects		
AI/ML	6 awards	$11.9 M
Autonomy	4	$10.7 M
Biomedical & Human Systems	4	$9.3 M
Cybersecurity	2	$3.8 M
Energy & Power	4	$9.7 M
Materials & Manufacturing	7	$18.8 M
Microelectronics	3	$8.9 M
Networked C3	6	$16.6 M
Platforms: Air, Ground & Sea	4	$8.3 M
Sensors	9	$22.9 M
Weapons Tech	2	$3.1 M
Other	3	$6.8 M
Total	**54**	**$131 M**

** Funding does not include project administration costs

FY2019 Investments

$250M	2,212	153	94	~$2.4M
Total FY 2019 appropriations	Whitepapers	Proposals	Awards	Average award value

Manufacturing Technology Program

Objective

The DoD ManTech Program was created to further national security objectives through the development and application of advanced manufacturing technologies and processes. The program strives to reduce the acquisition and supportability costs of defense weapon systems and reduce manufacturing and repair cycle times across the life cycles of such systems.

DoD ManTech comprises component ManTech investment programs operated out of OSD, Army, Navy, Air Force, Defense Logistics Agency, and Missile Defense Agency. The OSD ManTech Office is responsible for administering the DoD ManTech Program by providing central guidance and direction to the component ManTech programs.

Overview

Legislative Authority: Title 10, U.S. Code §2521

Established: 1956

Oversight: OUSD(R&E), Office of Strategic Technology Protection and Exploitation

The various ManTech programs collaborate to identify and integrate joint requirements, conduct and develop joint program planning and strategies, and avoid duplication. While the Military Services invest in more targeted projects, OSD ManTech focuses on cross-cutting defense manufacturing needs – those that are beyond the ability of a single service to address – and stimulates the early development of manufacturing processes and enterprise business practices concurrent with science and technology development.

Investment Priority Areas

	Long Range Precision Fires; Next Generation Combat Vehicle; Future Vertical Lift; Network; Assured Positioning, Navigation, and Timing; Air and Missile Defense; Soldier Lethality; Synthetic Training Environment
	Metals Processing and Fabrication; Electronics Processing and Fabrication; Composites Processing and Fabrication; Manufacturing Enterprise; Energetics Manufacturing
	Advanced Concepts; Future Factory; Digital Enterprise; Additive Manufacturing; Low-Cost Attritable Systems; Networked Command, Control, & Communications (C3) Systems; Hypersonic Strike
	Advanced Microcircuit Emulation; Battery Network; Castings/Forgings; Military Unique Sustainment Technology; Subsistence Network; Defense Logistics Information Research; Additive Manufacturing
	High Temperature; Refractory Alloys; Thermal Protection Systems; Advanced Ceramic Composites; Printed Sensor Microsystems; Next Generation Electronics; Flexible Hybrid; Electronics; Biocarbon-based Supercapacitors; Additive Manufacturing
	Metals; Electronics; Composites; Advanced Manufacturing Enterprise; Energetic Materials; USD(R&E) Modernization Priorities: 5G, Artificial Intelligence and Machine Learning, Autonomy, Biotechnology, Cyber, Directed Energy, FNC3, Hypersonics, Microelectronics, Quantum Science, Space

DoD Manufacturing Innovation Institutes

The OSD ManTech Office also sponsors nine manufacturing innovation institutes (MII) with headquarters and hubs across the country. Each institute is a public-private partnership designed to overcome the challenges faced by manufacturing innovators in a variety of technology areas. The DoD MIIs connect organizations and activities to enable the affordable and rapid transition and delivery of defense-essential technologies. While each institute operates in its own unique ecosystem, the institutes offer common capabilities that:

- Provide access to state-of-the-art tools and equipment that are otherwise beyond the reach of most businesses,
- Implement targeted education and workforce development training programs, and
- Encourage project investments in applied research & industrially-relevant manufacturing technologies.

Industry partners, commercial manufacturers, start-up businesses, higher education institutions, and state and local economic developers join as members of the institutes for the opportunity to collaborate with each other and DoD in a pre-competitive environment.

The DoD Manufacturing Innovation Institutes bring new technologies to U.S. warfighters through:

$1.12B	$1.93B	865	1,270
Initial and follow-on Federal investment	Matching funds from industry, academia, and state governments	DoD-Sponsored education and R&D projects	Institute members from industry, academia, and state governments

Hart-Scott-Rodino

Objective

The Hart-Scott-Rodino (HSR) Act was established to avoid some of the difficulties and expenses encountered when challenging anticompetitive mergers and acquisitions after the fact. It is often impossible to restore competition fully once a merger takes place, and any attempt to reestablish competition is usually very costly for the parties and the public.

The HSR Act requires parties to certain mergers or acquisitions notify the Federal Trade Commission (FTC) and the Department of Justice (DoJ) before consummating a proposed acquisition. Once FTC and DoJ are notified, the parties must wait a specific period of time (generally 30 days) while these enforcement agencies review the proposed transaction. The review period enables the FTC and DOJ to determine which acquisitions are likely to be anti-competitive and to challenge them at a time when remedial action is most effective.

Determining Reportability

The HSR requires both acquiring and acquired persons to file notifications under the Program if all of the following conditions are met:

1. As a result of the transaction, the acquiring person will hold an aggregate amount of voting securities, non-corporate interests (NCI) and/or assets of the acquired person valued in excess of $200 million (as adjusted), regardless of the sales or assets of the acquiring and two acquired persons;
2. As a result of the transaction, the acquiring person will hold an aggregate amount of voting securities, NCI and/or assets of the acquired person valued in excess of $50 million (as adjusted) but at $200 million (as adjusted) or less;

Overview

Authority: Hart-Scott-Rodino Antitrust Improvements Act of 1976, 15 U.S.C. 18a. 7a of the Clayton Act

Effective: September 5, 2978

3. One party has sales or assets of at least $100 million (as adjusted); and
4. The other party has sales or assets of at least $10 million (as adjusted).

Case Study

In June 2019, Raytheon and United Technologies Corporation (UTC) two major defense suppliers announced their pending merger of equals with the transaction valued at $121 billion, resulting in the creation of one of the largest defense contractors by revenue. Both companies served as prime contractors and subcontractors to multiple customers within the DoD, notably the Army, Navy, Air Force, and the U.S. Special Operations Command. Shortly after announcing their intent to merge, the companies filed the HSR premerger review documents. The DoD worked closely with the DoJ, the lead antitrust agency for the case, during the entirety of the review to meet with the companies and other industry members to gauge the impact on competition, as well as facilitate discussions with DoD stakeholders to examine all identified overlapping capabilities. The review, including review of divestitures, carried into FY2020.

The review revealed that the overlap in three of the companies' businesses would present a potential threat to competition within the defense industrial base, specifically for airborne radios, military GPS, and Electro-Optical/Infra-Red sensors. As a result, one companyRaytheon was required to divest its airborne radios business, and another companyUTC was required to divest its GPS business and its optics business. The investigation was carried out by both the DoD and DoJ to approve potential buyers for the divested businesses. In January 2020, it was announced that a major global defense firm BAE Systems would purchase the airborne radio and military GPS businesses. In April 2020, it was announced that a technologyAmergint company would purchase the optics business. Following the second request in March 2020, DoJ filed a consent decree, approving the merger on the condition that the pending divestitures be completed. The merger officially closed in April 2020 with the airborne radio, military GPS, and Optics divestitures closing in May 2020, July 2020, and September 2020.

FY2020 HSR Actions

- In FY2020, the DoD assessed 23 transactions as part of the HSR premerger review process. Of those 22 transactions, 20 were investigations initiated in FY2020 and two were continuing investigations or mitigation efforts from previous fiscal years. There was a slight decrease in overall transactions between FY2019 and FY2020, possibly due to the impact of the coronavirus pandemic.
- Two transactions assessed in FY2020 were abandoned: Hexcel/Woodward and Carlisle Companies/Draka Fileca.
- The average value of the transactions (disclosed financial terms included) was $622 million, excluding United Technologies' $120 billion merger with Raytheon, which was announced in FY2019 and completed in FY2020.
- The large majority of the transactions involved companies in the Aerospace and Defense sector. Three transactions involved companies in the Industrials sector and two transactions involved companies in the Services sector.
- Major HSR actions from FY2020 include: United Technologies/Raytheon (announced in FY2019), CPI/GD SATCOM (announced in FY2019), Huntington Ingalls/Hydroid, and Leidos/Dynetics.

Trusted Capital

Program Objective

The Trusted Capital program connects companies critical to the defense industrial base with vetted trusted capital and capability providers.

Companies critical to the DoD require access to rapid funding from capital providers at key development stages. Without this funding, capability providers in the DoD supply chain become susceptible to strategic funding from adversaries that leverage capital to exploit technology transfer.

The Trusted Capital Marketplace is a forum to convene trusted sources of private capital with innovative domestic companies. The companies have been down-selected by the military services and operate in emerging technology sectors critical to the U.S. defense industrial base – strengthening domestic manufacturing through, and limiting foreign access to, critical technology. Trusted Capital Marketplace participants include:

- AFWERX
- Army Futures Command
- Defense Innovation Unit
- NavalX
- U.S. Special Operations Command

Capability Providers: Capability Providers are companies that specialize in developing and providing products and services in key technology sectors and subsectors. These companies offer key capabilities and have been down selected by the military services or the DoD innovation programs for inclusion in the Trusted Capital program so they can raise additional investment funding for growth.

Capital Providers: Capital Providers are vetted sources of strategic capital. Capital providers invest in companies to increase the capability of the defense industrial base to support the DoD production needs and the availability of emerging technologies.

Overview

Oversight: OUSD(A&S)/Chief Information Security Officer

Website: https://www.acq.osd.mil/tc

Established: 2020

Sectors Of Focus

- Advanced Computing
- Advanced Conventional Weapons Technologies
- Advanced Engineering Materials
- Advanced Manufacturing
- Advanced Sensing
- Aero-Engine Technologies
- Agricultural Technologies
- Artificial Intelligence
- Autonomous Systems
- Biotechnologies
- CBRN Mitigation Technologies
- Communication and Networking Technologies
- Data Science and Storage
- Distributed Ledger Technologies
- Energy Technologies
- Human-Machine Interfaces
- Medical and Public Health Technologies
- Quantum Information Science
- Semiconductors and Microelectronics
- Space Technologies

Why Trusted Capital?

The 2018 National Defense Strategy called for the DoD to strengthen its military advantage through three lines of effort: Lethality, Partnerships, and Reform.

The Trusted Capital program is aligned with the NDS:

- Trusted Capital Marketplace increases Lethality
- Innovation Tours with Industry build Partnerships
- Incentives for Capital Providers supports Reform

The Trusted Capital program's lines of effort will cultivate new partnerships with the private sector to provide opportunities for innovation, ensuring a more efficient, lethal force and enduring competitive edge.

How do I participate in the DoD Trusted Capital program?

Capital Providers will be able to apply via the Trusted Capital Marketplace website. Capability Providers will have the ability to submit white papers through the Trusted Capital Website and then must be down selected by a DoD Military Service through their acquisitions processes. Once a company has been down selected, the Military Service may offer the company the opportunity to apply to the Trusted Capital program and will provide companies with a link to access the online Trusted Capital application portal.

SECTION 10

APPENDIX

Appendix A: Industrial Base Map

This appendix contains controlled unclassified information, and business confidential and proprietary content, and will be provided to Congress as an annex to this report.

Appendix B: Industrial Base Studies and Assessments

This appendix contains controlled unclassified information, and business confidential and proprietary content, and will be provided to Congress as an annex to this report.

SECTION 11

ACRONYMS

11. ACRONYMS

5G	Fifth generation
A&D	U.S Aerospace and Defense Industry
ACE	America's Cutting Edge
AESA	Actively Electronically Scanned Array
AFRL	Air Force Research Laboratory
AI	Artificial intelligence
AMT	Association for Manufacturing Technology
ARM	Advanced Robotics for Manufacturing Institute
ASIC	Application-specific integrated circuits
C2	Command and Control
C3	Command, Control, and Communications
CAGR	Combined Annual Growth Rate
CARES Act	Coronavirus Aid, Relief, and Economic Security Act
CBC	Chemical Biological Center
CBDP	Department of Defense Chemical and Biological Defense Program
CBRN	Chemical, Biological, Radiological, and Nuclear
CBRND	Chemical, Biological, Radiological, and Nuclear Defense
CDI	Covered defense information
CEMWG	Critical Energetic Materials Working Group
CFIUS	Committee on Foreign Investment in the United States
CHIPS	Creating Helpful Incentives to Produce Semiconductors
CIO	DoD's Chief Information Officer
CITE	Center of Industrial and Technical Excellence
CMMC	Cybersecurity Maturity Model Certification
CO	Cyberspace Operations
CUI	Controlled Unclassified Information
CV	Combat Vehicles
DARPA	Defense Advanced Research Projects Agency
DCMA	Defense Contract Management Agency
DE	Directed Energy
DevSecOps	Development, security and operations
DEW	Directed Energy Weapon
DFARS	Defense Federal Acquisition Regulations Supplement

DFC	U.S. International Development Finance Corporation
DIB	Defense industrial base
DISA	Defense Information Systems Agency
DIU	Defense Innovation Unit
DLA	Defense Logistics Agency
DMS&T	Defense-Wide Manufacturing Science & Technology
DMSMS	Diminishing manufacturing sources and material suppliers
DoC	Department of Commerce
DoD	Department of Defense
DOE	Department of Energy
DoJ	Department of Justice
DPA	Defense Production Act
DTTI	Defense Technology and Trade Initiative
EB	DPAS Enterprise Board
EBITDA	Earnings before Interest, Tax, Depreciation, and Amortization
EM	Electromagnetic
EMS	Electronic manufacturing service
EO	Executive Order
EW	Electronic Warfare
FAANG	Facebook, Amazon, Apple, Netflix, and Google
FEMA	Federal Emergency Management Agency
FGPA	Field-programmable gate arrays
FIR	Foreign Investment Review
FIRRMA	Foreign Investment Risk Review Modernization Act
FNC3	Fully Networked Command, Control, and Communications
FTC	Federal Trade Commission
FY	Fiscal Year
FYDP	Future year defense program
GaN	Gallium Nitride
GOCO	Government-owned, contractor-operated
GOGO	Government-owned, government-operated
GPU	Graphics processing units
HBCU	Historically Black College and Universities
HEL	High energy lasers
HHS	Department of Health & Human Services

HPM	High power microwaves
HSR	Hart-Scott-Rodino Act
HSWR	Hypersonics War Room
IAG	Defense Contract Management Agency's Industrial Analysis Group
IB	Industrial Base
IBAS	Industrial Base Analysis & Sustainment Program
IBC	Industrial Base Council
IC	Integrated circuit
IC	Intelligence Community
IoT	Internet of things
IP	Intellectual Property
IPT	integrated product team
ISR	intelligence, surveillance, and reconnaissance
IT	Information technology
JADC2	Joint All-Domain Command and Control
JATF	Joint Acquisition Task Force
JGPD-HME	Joint General Purpose Decontaminant for Hardened Military Equipment
JIBWG	Joint Industrial Base Working Group
JRIBWG	Joint Radar Industrial Base Working Group
LEP	Life Extension Program
LOE	Line of effort
LSRM	Large solid-rocket motor
M&A	Mergers & Acquisitions
M2M	Machine, machine teaming
ManTech	Manufacturing Technology Program
ME	Microelectronics
MI	Minority Serving Institution
MII	Manufacturing Innovation Institutes
MILDEPS	Military Departments
MINSEC	Microelectronics Innovation for National Security and Economic Competitiveness
ML	Machine Learning
MMIC	Monolithic Microwave Integrated Circuits
MOA	Memorandum of Agreement
MUM-T	Manned-Unmanned Teaming
NACE-E	National Centers of Academic Excellence in Cybersecurity

NASA	National Aeronautics and Space Administration
NAVSEA	Naval Sea Systems Command
NCI	Non-corporate interests
NDAA	National Defense Authorization Act
NdFeB	Neodymium Iron Boron
NDS	National Defense Stockpile
NDS	National Defense Strategy
NIST	National Institute of Standards and Technology
NSS	National Space Strategy
NTIB	National Technology and Industrial Base
ODASD(MR)	Office of the Deputy Assistant Secretary of Defense for Materiel Readiness
ODIN	Optical Dazzler Interdictor
OEA	USD(A&S) Office of Economic Adjustment
OECD	Organization for Economic Co-operation and Development
OIB	Organic Industrial Base
OLED	Organic light emitting diode
OSAT	Outsourced semiconductor assembly and test
OSBP	Office of Small Business Programs
OSD	Office of the Secretary of Defense
OTA	Other Transaction Authority
OUSD(A&S)	Office of the Undersecretary of Defense for Acquisition and Sustainment
OUSD(R&E)	Office of the Under Secretary of Defense for Research and Engineering
PBA	Pine Bluff Arsenal
PLAA	People’s Liberation Army
PLAN	People’s Liberation Army Navy
PPBE	Planning, programming, budgeting and execution
PPE	Personal protective equipment
PPP	Public Private Partnership
PrCB EA	DoD Executive Agent for Printed Circuit Board and Interconnect Technology
PrCB	Printed circuit board
PrCBA	Printed circuit board assembly
QA	Quality Assurance
R&D	Research & Development
R/R&D	Federal Research/Research and Development
RAMP	Rapid Assured Microelectronics Prototypes

RDT&E	Research, Development, Testing, and Engineering
RF/OE	Radio frequency and optoelectronic
RIF	Rapid Innovation Fund
RSRP	Radar Supplier Resiliency Plan
S&T	Science and technology
SBC	Small Business Concern
SBIR	Small Business Innovation Research Program
SBTP	Office of Small Business Technology Partnerships
SHIP	State-of-the-Art Heterogeneous Integration Prototype
SIBWG	Space Industrial Base Working Group
SLP	Substrate-like printed circuit board
SMM	Small and medium-sized manufacturers
SOTA	State-of-the-art
STEM	Science, technology, engineering, and mathematics
STTR	Small Business Technology Transfer Program
sUAS	Small Unmanned Aircraft Systems
SWAP	Software Acquisition and Practices
TEA	Technical execution area
TKA	Tail Kit Assembly
TMIB	Technology, Manufacturing, and Industrial Base
TWTA	Traveling Wave Tube Amplifiers
TWV	Tactical Wheeled Vehicles
U.S.	United States
UAE	United Arab Emirates
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
USD(A&S)	The Undersecretary of Defense for Acquisition and Sustainment
WG	Working group
YTD	Year-to-date

SECTION 12

SOURCES

12. SOURCES

1. National Security Strategy of the United States of America, December 2017, https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf
2. Stephen J. Rose, Manufacturing Employment: Fact and Fiction, April 2018, URBAN INSTITUTE (citing its author's calculations from 1960, 1980, and 2000 censuses, the Conference Board Total Economy Database Data, and 2015 American Community Survey)
3. An evolution often described as the "Last Supper," after the Pentagon dinner where Secretary Les Aspin and his deputy (and eventual successor) William Perry urged greater consolidation of the already-shrinking post-Cold War defense industry.
4. Public Remarks, Deputy Secretary of Defense Robert Work at the Royal United Services Institute, Whitehall, London, September 2015, https://www.defense.gov/Newsroom/Speeches/Speech/Article/617128/royal-united-services-institute-rusi/
5. National Security Strategy, December 2017.
6. Antonio Varas, Raj Varadarajan, Jimmy Goodrich, & Falan Yinug, "Government Incentives and U.S. Competitiveness in Semiconductor Manufacturing," Boston Consulting Group & Semiconductor Industry Association, (September 2020), Caution-https://web-assets.bcg.com/27/cf/9fa28eeb43649ef8674fe764726d/bcg-government-incentives-and-us-competitiveness-in-semiconductor-manufacturing-sep-2020.pdf
7. Defense Production Act Title III, https://www.businessdefense.gov/Programs/DPA-Title-III/
8. 25 Mid-Tier includes: a combination of 25 U.S. and Foreign based U.S. DoD Suppliers that are publicly traded. Compiled using FPDS data on prime obligations and Defense News Top 100 list of defense suppliers based on revenue for 2020 (Companies: L3Harris Technologies Inc, Leidos Holdings Inc, Airbus SE, Thales SA, Huntington Ingalls Industries Inc, Leonardo SpA, Rolls-Royce Holdings PLC, Qinetiq Group PLC, General Electric Co, Elbit Systems Ltd, Ball Corp, Science Applications International Corp, ViaSat Inc, Textron Inc, Moog Inc, Curtiss-Wright Corp, Oshkosh Corp, Aerojet Rocketdyne Holdings Inc, TransDigm Group Inc, Singapore Technologies Engineering Ltd, Serco Group PLC, Rheinmetall AG, Melrose Industries PLC, Saab AB, Safran SA)
9. "How Important Is The U.S. Government To Boeing's Revenue?," https://dashboards.trefis.com/no-login-required/pFxcKTVr/How-Important-is-the-US-government-to-Boeing-s-Revenue ?fromforbesandarticle=ba200102
10. "Drone Manufacturer Market Shares: DJI Leads the Way in the U.S.," https://www.droneii.com/dronemanufacturer-market-shares-dji-leads-the-way-in-the-us
11. "May Passenger Demand Shows Slight Improvement," https://www.iata.org/en/pressroom/pr/2020-07-01-02/
12. Ibid.
13. "U.S-China Economic and Security Review Commission The 13th Five-Year Plan," https://www.uscc.gov/ sites/default/files/Research/The%2013th%20Five-Year%20Plan_Final_2.14.17_Updated%20(002).pdf
14. 2017 County Business Patterns, United States Census Bureau
15. Ibid.
16. NSWC Crane, Counterfeit Electronic Part Trends, Created using ERAI-provided data
17. "New Rule Expands Counterfeit Reporting", https://www.nationaldefensemagazine.org/articles/2020/1/13/new-rule-expands-counterfeit-reporting
18. U.S. Department of Commerce, U.S. Bare Printed Circuit Board Industry Assessment 2017, Data updated in 2020 by DoD Executive Agent for Printed Circuit Board and Interconnect Technology.

19. "EMS 2019 in Review: Trade Wars Batter Supply Chains, Profits,"
20. Benchmark, Space Systems, https://www.bench.com/space
21. "TTM Tecnologies, Inc. Announces Opening of Advanced Technology Center in Chippewa Falls, Wisconsin," https://www.globenewswire.com/news-release/2020/02/25/1990456/0/en/TTM-Technologies-Inc-Announces-Opening-of-Advanced-Technology-Center-in-Chippewa-Falls-Wisconsin.html
22. "Aerospace and Defense Deals Insights: Midyear 2020," https://www.pwc.com/us/en/industries/industrial-products/library/aerospace-defense-quarterly-deals-insights.html
23. "Summit Interconnect, INC. Acquires Integrated Technology LTD. (ITL Circuits)", https://www.summit-pcb.com/press-releases/summit-interconnect-inc-acquires-integrated-technology-ltd-itl-circuits/
24. "NTI-100 2019: A Not-So-fabulous Year for Fabricators", https://www.pcdandf.com/pcdesign/index.php/editorial/menu-features/14933-a-not-so-fabulous-year-for-fabricators
25. "2020 Trends in Electronics Sourcing," https://www.businesswire.com/news/home/20200519005327/en/Supplyframe-Electronics-Sourcing-Report-Highlights-Innovation-Imperative-Amid-COVID-19.
26. Ibid.
27. "The Impact of the Coronavirus (COVID-19) Epidemic on Electronics Manufacturers: March Update," https://www.ipc.org/emails/gr/corona-virus-report2.pdf.
28. "Department of Defense Announces $197.2 Million for Microelectronics," https://www.defense.gov/Newsroom/Releases/Release/Article/2384039/department-of-defense-announces-1972-million-for-microelectronics/
29. "DOD Can Lead Microelectronics Manufacturing Back to U.S.", https://www.defense.gov/Explore/News/Article/Article/2320194/dod-can-lead-microelectronics-manufacturing-back-to-us/.
30. World Electronic Circuits Council (WECC), WECC Global PCB Production Report for 2015.
31. World Electronic Circuits Council (WECC), WECC Global PCB Production Report for 2018.
32. GP Ventures, "199", http://gp-ventures.com/199-2/
33. "Do Trade Wars and Mergers Portend a Coming Changing of the Guard?", https://www.circuitsassembly.com/ca/editorial/menu-features/31430-ems-top-50-1906.html
34. Ibid.
35. "EMS 2019 in Review: Trade Wars Batter Supply Chains, Profits", https://www.circuitsassembly.com/ca/editorial/menu-features/33470-ems-2019-in-review-trade-wars-batter-supply-chains-profits.html
36. "Mid-2019 PCB and EMS M&A Round-up", http://gp-ventures.com/mid-2019-pcb-and-ems-ma-round/, 08/22/2019
37. Semiconductor Industry Association Brief to OSD Industrial Policy, June 2020.
38. "Global Semiconductor Sales Increase 5.8 Percent Year-to-Year in May; Annual Sales Projected to Increase 3.3 Percent in 2020, 6.2 Percent in 2021", https://www.semiconductors.org/global-semiconductor-sales-increase-5-8-percent-year-to-year-in-may-annual-sales-projected-to-increase-3-3-percent-in-2020-6-2-percent-in-2021/
39. "Worried About Chinese Backdoors, Lord Pushes for New Tech Strategy", https://breakingdefense.com/2020/09/worried-about-chinese-backdoors-lord-pushes-for-new-tech-strategy/
40. Comparison of Global Machine Tool Producing and Consuming Nations by Value, https://www.gardnerintelligence.com/report/world-machine-tool
41. Ibid.

42. "When the machine stopped: A cautionary tale from industrial America," ISBN-10: 0875842089

43. "Trade Balances for Machine Tool Sector Nations," https://www.gardnerintelligence.com/report/world-machine-tool

44. "The Hazards of Global Supply Chains," https://www.asme.org/getmedia/82c9f3bd-9622-4677-97a8-0cff5a4c3a8d/ps20-13-asme_hazards_of_global_supply_chains.pdf

45. "Net Orders for U.S. Consumption of Manufacturing Technology," https://www.amtonline.org/article_display.cfm?article_id=205180

46. Language contained in the NDAA for FY2019 directs the Secretary of Defense to deliver a comprehensive strategy to the congressional defense committees for improving the depot infrastructure of the military departments with the objective of ensuring that the depots have the capacity and capability to support the readiness and material availability goals of current and future DoD weapon systems. The language requires that the strategy include a review of the current conditions and performance of each depot, a business-case analysis comparing the minimum investment necessary required under Section 2476e of title 10, United States Code, with the actual investment needed to execute the planned mission and a plan to improve the conditions and performance utilizing this data.

47. See https://media.defense.gov/2018/oct/05/2002048904/-1/-1/1/assessing-and-strengthening-the-manufacturing-and%20defense-industrial-base-and-supply-chain-resiliency.pdf.

48. 2020 Department of Defense China Military Power Report

49. World Steel Association, https://www.worldsteel.org/

50. Ibid.

51. Assessing and Strengthening the Manufacturing and Defense Industrial base and Supply Chain Resiliency of the United States, https://media.defense.gov/2018/oct/05/2002048904/-1/-1/1/assessing-andstrengthening-the-manufacturing-and%20defense-industrial-base-and-supply-chain-resiliency.pdf

52. Executive Order on Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States, https://www.whitehouse.gov/presidential-actions/ presidential-executive-order-assessing-strengthening-manufacturing-defense-industrial-base-supply-chainresiliency-united-states/

53. "STEM crisis or STEM surplus? Yes and yes", https://doi.org/10.21916/mlr.2015.14

54. Report was provided in response to Senate Report 115-290, Pages 199-200, Accompanying S.3159, the Department of Defense Appropriations Bill for Fiscal Year 2019

55. 2018 "Deloitte and The Manufacturing Institute skills gap and future of work study," http://www. themanufacturinginstitute.org/~/media/E323C4D8F75A470E8C96D7A07F0A14FB/DI_2018_Deloitte_MFI_ skills_gap_FoW_study.pdf

56. "STEM Occupations: Past, Present, and Future", https://www.bls.gov/spotlight/2017/science-technologyengineering-and-mathematics-stem-occupations-past-present-and-future/pdf/science-technologyengineering-and-mathematics-stem-occupations-past-present-and-future.pdf

57. Under Secretary of Defense for Acquisition and Sustainment, Software Acquisition Pathway Interim Policy Review, https://www.acq.osd.mil/ae/assets/docs/USA002825-19%20Signed%20Memo%20(Software).pdf

58. DoD Enterprise DevSecOps Initiative, https://software.af.mil/dsop

59. U.S. and Global STEM Education, https://www.nsf.gov/statistics/2018/nsb20181/digest/sections/u-s-andglobal-stem-education

60. Report was provided in response to Senate Report 115-290, Pages 199-200, Accompanying S.3159, the Department of Defense Appropriations Bill for Fiscal Year 2019
61. “The Importance of International Students to American Science and Engineering,” http://nfap.com/wp-content/uploads/2017/10/The-Importance-of-International-Students.NFAP-Policy-Brief.October-20171.pdf
62. “In the wake of Northrop-Orbital merger, Aerojet’s solid rocket engine business teetering on the brink”, https://spacenews.com/in-the-wake-of-northrop-orbital-merger-aerojets-solid-rocket-engine-businessteetering-on-the-brink/
63. Avon Rubber Completes Acquisition Of 3m’s Ballistic Protection Business,” https://www.avon-rubber. com/media-centre/press-releases/press-releases1/avon-rubber-completes-acquisition-of-3m-s-ballisticprotection-business/#currentPage=1
64. Russian Ministry of Defense, http://eng.mil.ru/en/news_page/country/more.htm?id=12071791@egNews
65. Ibid.
66. “‘Iron Man’ Suit To Fall Short Of Its Goals (Updated),” https://www.nationaldefensemagazine.org/articles/2019/2/6/special-ops-iron-man-suit
67. World Bank, https://data.worldbank.org/, Central Intelligence Agency, https://www.cia.gov/library/publications/the-world-factbook/rankorder/rankorderguide.html
68. Defense Space Strategy Summary, https://media.defense.gov/2020/Jun/17/2002317391/-1/-1/1/2020_DEFENSE_SPACE_STRATEGY_SUMMARY.PDF?source=email
69. “Evaluation of China’s Commercial Space Sector,” https://www.ida.org/research-and-publications/publications/all/e/ev/evaluation-of-chinas-commercial-space-sector
70. “The Global Commercial Market for Orbital Launch Services.” Distribution C. April 2020.
71. “The Contest for Innovation: Strengthening America’s National Security Innovation Base in an Era of Strategic Competition,” https://www.reaganfoundation.org/media/355297/the_contest_for_innovation_report.pdf
72. Award summaries available at https://www.oea.gov/Defense-Manufacturing-Community-Support-Program
73. Office of the Undersecretary for Defense for Research & Engineering, Modernization Priorities, https://www.cto.mil/modernization-priorities/
74. M. Zatman, Fully Networked Command, Control, and Communication: Infrastructure Supporting the National Defense Strategy (NDS), 2020
75. Ibid.
76. Ibid.
77. M. Zatman, “FNC3 Road to Dominance Overview (Workshop Opening Remarks),” 2020
78. M. Zatman, Fully Networked Command, Control, and Communication: Infrastructure Supporting the National Defense Strategy (NDS), 2020
79. Office of the Undersecretary for Defense for Research & Engineering, Modernization Priorities, https://www.cto.mil/modernization-priorities/
80. Ibid.
81. “2020 State of the U.S. Semiconductor Industry,” https://www.semiconductors.org/wp-content/uploads/2020/06/2020-SIA-State-of-the-Industry-Report.pdf
82. “CHIPS for America Act Would Strengthen U.S. Semiconductor Manufacturing, Innovation,” https://www.semiconductors.org/chips-for-america-act-would-strengthen-u-s-semiconductor-manufacturing-innovation/
83. “DOD Adopts ‘Zero Trust’ Approach to Buying Microelectronics,” https://www.defense.gov/Explore/News/Article/Article/2192120/dod-adopts-zero-trust-approach-to-buying-microelectronics/.

84. "Emerging Military Technologies: Background and Issues for Congress," https://crsreports.congress.gov/product/pdf/R/R46458

85. Maintaining Technology Advantage, "Artificial Intelligence TAPP Appendix A-1," 2020.

86. " Maintaining the Competitive Edge in Artificial Intelligence and Machine Learning." https://www.rand.org/pubs/research_reports/RRA200-1.html

87. " Artificial Intelligence and National Security," https://crsreports.congress.gov/product/pdf/R/R45178/9

88. "Big Data at War: Special Operations Forces, Project Maven, and Twenty-First-Century Warfare," https://mwi.usma.edu/big-data-at-war-special-operations-forces-project-maven-and-twenty-first-century-warfare/

89. "AI To Fly In Dogfight Tests By 2024: SecDef," https://breakingdefense.com/2020/09/ai-will-dogfight-human-pilots-in-tests-by-2024-secdef/

90. "Army advances learning capabilities of drone swarms," https://www.army.mil/article/237978/army_advances_learning_capabilities_of_drone_swarms

91. " Keeping Top AI Talent in the United States," https://cset.georgetown.edu/wp-content/uploads/Keeping-Top-AI-Talent-in-the-United-States.pdf

92. " Artificial Intelligence and National Security," https://crsreports.congress.gov/product/pdf/R/R45178/9

93. "Recommendations on Export Controls for Artificial Intelligence," https://cset.georgetown.edu/wp-content/uploads/Recommendations-on-Export-Controls-for-Artificial-Intelligence.pdf

94. "Executive Summary of the Defense Science Board Report on Applications of Quantum Technologies."

95. "USD(R&E) Technology Roadmap Quantum Science" Briefing, May 20200

96. OUSD(R&E)/ST&E/S&T, Quantum Technology Area Protection Plan, September 2020

97. "USD(R&E) Technology Roadmap Quantum Science" Briefing, May 2020

98. "Fiscal Year 2019 Industrial Base Capabilities Report to Congress."

99. OUSD(R&E)/ST&E/S&T, Quantum Technology Area Protection Plan, September 2020

100. "USD(R&E) Technology Roadmap Quantum Science" Briefing, May 2020

101. "Understanding Gartner's Hype Cycles," https://www.gartner.com/en/documents/3887767/understanding-gartner-s-hype-cycles

102. Assessing and Comparing the Robustness of the U.S. Industrial Base in Quantum Technology: Kickoff Briefing Addendum."

103. "MITRE Statement of Work: DIB Workforce Assessment," October 2020

104. "Emerging Military Technologies: Background and Issues for Congress," https://crsreports.congress.gov/product/pdf/R/R46458

105. "Maintaining Technology Advantage, 2020 Directed Energy TAPP Appendix A-1."

106. "Advancing High Energy Laser Weapon Capabilities."

107. "The ODIN Shipboard Laser: Science Fiction No More." https://jnlwp.defense.gov/Press-Room/In-The-News/Article/2213173/the-odin-shipboard-laser-science-fiction-no-more/

108. AFRL gives warfighters new weapons system."https://www.whs.mil/News/News-Display/Article/2138161/afrl-gives-warfighters-new-weapons-system/

109. Ibid.

110. "Emerging Military Technologies: Background and Issues for Congress," https://crsreports.congress.gov/product/pdf/R/R46458

111. "Advancing High Energy Laser Weapon Capabilities."

112. Ibid.

113. Ibid.

114. "DoD Drafts Guidelines for Laser Design," https://breakingdefense.com/2020/08/dod-drafts-guidelines-for-laser-design/

115. "Army Rapid Capabilities and Critical Technologies Office Manufacturing Technology Overview."

116. Office of the Undersecretary for Defense for Research & Engineering, Modernization Priorities, https://www.cto.mil/modernization-priorities/

117. IEEE 5g and Beyond Technology Roadmap White Paper," https://futurenetworks.ieee.org/images/files/pdf/ieee-5g-roadmap-white-paper.pdf .

118. Ibid.

119. Ibid.

120. Ibid.

121. "FCC 5G," https://www.fcc.gov/5G

122. "DOD Kicks Off World's Largest Dual-Use 5G Testing Effort," https://www.defense.gov/Explore/News/Article/Article/2378047/dod-kicks-off-worlds-largest-dual-use-5g-testing-effort/

123. Ibid.

124. "Defense Department Press Briefing on 5G Communications Technology Testing and Experimentation," https://www.defense.gov/Newsroom/Transcripts/Transcript/Article/2208939/defense-department-press-briefing-on-5g-communications-technology-testing-and-e/ (accessed 16 Oct 2020)

125. "Report of the Defense Science Board Summer Study on Autonomy." Undersecretary of Defense (USD), Acquisition, Technology, and Logistics (AT&L).

126. "Manned-Unmanned Teaming: A Great Opportunity or Mission Overload?" https://www.japcc.org/manned-unmanned-teaming/

127. "Army robots get driver education for difficult tasks," https://www.army.mil/article/237248/army_robots_get_driver_education_for_difficult_tasks (accessed October 8, 2020)

128. "The Army's got a Universal Robot Driver," https://breakingdefense.com/2019/11/the-armys-universal-robot-driver/

129. "AI Chips: What They Are and Why They Matter," https://cset.georgetown.edu/research/ai-chips-what-they-are-and-why-they-matter/

130. "New Challenges Facing Semiconductors," https://irds.ieee.org/topics/new-challenges-facing-semiconductors

131. "Artificial Intelligence and National Security," https://crsreports.congress.gov/product/pdf/R/R45178/9

132. "Joint Chiefs of Staff Publication 3-12, Cyber Operations," https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_12.pdf

133. Office of the Undersecretary for Defense for Research & Engineering, Modernization Priorities, https://www.cto.mil/modernization-priorities/

134. "2018 National Cyber Strategy," https://www.whitehouse.gov/wp-content/uploads/2018/09/National-Cyber-Strategy.pdf

135. "Defense Primer: Cyberspace Operations," https://fas.org/sgp/crs/natsec/IF10537.pdf

136. "2017 National Security Strategy of the United States of America,"https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf

137. "Cyberspace Solarium Commission Report," https://www.solarium.gov/report

138. Ibid.

139. "The Defense Production Act of 1950: History, Authorities, and Considerations for Congress," https://crsreports.congress.gov/product/pdf/R/R43767

IMAGE SOURCES

Page

Cover	Photo By: Joshua Armstrong, Air Force https://www.defense.gov/observe/photo-gallery/igphoto/2002085551/
7	Photo By: Air Force Senior Airman Keith Holcomb https://www.defense.gov/observe/photo-gallery/igphoto/2002556357/
8	Photo By: Navy Petty Officer 2nd Class Taylor DiMartino http://www.defense.gov/observe/photo-gallery/igphoto/2002460143/
21	Photo: by Senior Airman Franklin R. Ramos, U.S. Air Force/Released https://www.flickr.com/photos/39955793@N07/12234809043/in/photolist-29QD6SM-2gfJxj7-2gfK3JR-SV81N5-p6VUva-nknxXp-oYAEyU-KoTXjk-ps1jtf-VynNBa-p68mPW-p4jVME-p67tke-TCrQfB-dtmgHo-LYDrrQ-L4TkLU-Uh2fmS-p68oV9-JGXTLk-popuxw-ps2Zni-VHE4eb-MQ9Qxy-ojhQLN-2guVzva-daEqmD-ddHWY5-e4U6b4-pMDyJv-LeGao3-jD9Atv-VVZvtA-e5ZAgk-Lt3vp7-p7Jmn9-bGVyun-p7JUo1-oR2K59-e5a8Gk-e13pAK-bEwYun-daEoLx-bNQuAH-bDd6va-bDhAtr-9dycGi-85sNFD-84GAhq-7gPNde
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26	Photo By: Army Sgt. Sarah Sangster http://www.defense.gov/observe/photo-gallery/igphoto/2002559196/
31	Photo By: Joshua Armstrong, Air Force https://www.defense.gov/observe/photo-gallery/igphoto/2002526348/
32	Photo By: Marine Corps Lance Cpl. Mackenzie Binion https://www.defense.gov/observe/photo-gallery/igphoto/2002456042/
35	Photo By: Army Sgt. John Schoebel http://www.defense.gov/observe/photo-gallery/igphoto/2002557041/
36	Photo By: Navy Petty Officer 3rd Class MacAdam Weissman http://www.defense.gov/observe/photo-gallery/igphoto/2002559799/
39	Photo by: Ens. Jalen Robinson https://www.flickr.com/photos/39955793@N07/32853273557/in/photostream/
40	Photo By: Marine Corps Cpl. Brennan Beauton http://www.defense.gov/observe/photo-gallery/igphoto/2002559200/
49	Photo By: Air Force Senior Airman Bryan Guthrie https://www.defense.gov/observe/photo-gallery/igphoto/2002557114/

50 Photo By: Navy Petty Officer 3rd Class Nicholas Huynh
http://www.defense.gov/observe/photo-gallery/igphoto/2002353486/

115 Photo By: Navy Petty Officer 1st Class Devin Langer
https://www.defense.gov/observe/photo-gallery/igphoto/2002508788/

116 Photo By: Todd Maki, Air Force
https://www.defense.gov/observe/photo-gallery/igphoto/2002551733/

163 Photo by Sgt. Jesse Pilgrim
https://www.flickr.com/photos/39955793@N07/48631270737/

167 Photo By: Jeff Spotts
https://www.defense.gov/observe/photo-gallery/igphoto/2002551086/

173 Photo: by Sgt. Dustin D. Biven
https://www.flickr.com/photos/39955793@N07/48631279807/

139 Photo By: Army Master Sgt. Becky Vanshur
https://www.defense.gov/observe/photo-gallery/igphoto/2002558184/

METRIC

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DEPARTMENT OF DEFENSE HANDBOOK

GENERAL GUIDELINES FOR ELECTRONIC EQUIPMENT

This handbook is for guidance only. Do not cite this document as a requirement.

AMSC N/A AREA SESS

FOREWORD

1. This handbook is approved for use by all Departments and Agencies of the Department of Defense

2. This handbook is for guidance only. This handbook cannot be cited as a requirement. If it is, the contractor does not have to comply.

3. This handbook is the technical baseline for the design and construction of electronic equipment for the Department of Defense. It captures in one document, under suitable subject heading, fundamental design guidelines for multiple general electronic specifications. The opportunity to focus on a single document, afforded to contractors, results in substantial savings to the Government. This handbook was prepared by, and is regularly updated through, the cooperative efforts of Government and industry. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

DOD-E-8983	Electronic Equipment, Aerospace, Extended Space Environment, General Specification for.
MIL-F-18870	Fire Control Equipment, Naval Ship and Shore, General Specification for.
MIL-PRF-28800	Test Equipment for Use with Electrical and Electronic Equipment, General Specification for.
MIL-HDBK-2036	Electronic Equipment Specifications, Preparation of.

4. Comments, suggestions, or questions on this document should be addressed to (Defense Supply Center, Columbus, ATTN: DSCC-VSC, P.O. Box 3990, Columbus, OH 43218-3990) or emailed to (mailto:DSCC.PartsSupport@dla.mil). Since contact information can change, you may want to verify the currency of this address information using the ASSIST Online database at https://assist.dla.mil.

CONTENTS

CONTENTS

CONTENTS

1. SCOPE

1.1 Guidelines applicable to electronic equipment. This handbook provides guidance and lessons learned in the selection of documentation for the design of electronic equipment. This handbook is for guidance only and cannot be cited as a requirement. If it is, the contractor does not have to comply.

1.2 Revision of guidelines. Revisions of individual guidelines are indicated by a date below the guideline number located at the bottom of the page. When the basic document is revised, those guidelines not affected by change retain their existing date.

1.2.1 Redating. Although individual guidelines are reviewed and updated or validated at least once every eighteen months, guidelines are not redated unless technical changes are made.

1.3. Method of reference. Guidelines contained herein should be referenced by specifying this handbook and the guideline number for guidance only.

1.4 Interrelationship of guidelines. Each guideline is intended to cover some discipline in the design of equipment, such as a procedure, a process, or the selection and application of parts and materials. Many of these disciplines, however, cannot retain a clear-cut separation or isolation from others so that when guidelines of MIL-HDBK-454 are referenced in a specification some guidelines will undoubtedly have a direct interrelationship with other guidelines. This interrelationship should be taken into consideration when referencing these guidelines.

2. APPLICABLE DOCUMENTS.

2.1 Individual guidelines. See section 2 of each individual guideline for a listing of applicable documents. Documents referenced in the individual guidelines apply to the extent specified herein.

(Copies of these documents are available online at https://assist.dla.mil .)

2.2 Industry addresses. Addresses for obtaining documents referenced in the guidelines but not obtainable from the Government are as follows:

Symbol	Address
AGMA	American Gear Manufacturers' Association 1500 King Street, Suite 12 Arlington VA 22314
AIA	Aerospace Industries Association 1000 Wilson Boulevard, Suite 1700 Arlington, VA 22209-3928
AMS ARP	Society of Automotive Engineers, Inc. 400 Commonwealth Drive Warrendale PA 15096
ANSI	American National Standards Institute 11 West 42nd Street New York NY 10036
ASME	American Society of Mechanical Engineers 22 Law Drive P.O. Box 2900 Fairfield NJ 07007-2900
ASM	American Society for Metals Metals Park OH 44073
ASTM	American Society for Testing and Materials 100 Barr Harbor Drive West Conshohocken PA 19428-2959
AWS	American Welding Society 550 NW LeJeune Road Miami FL 33126
EIA	Electronic Industries Alliance 2500 Wilson Blvd. Arlington VA 22201-3834
GEIA	Government Electronics and Information Association 777 East Eisenhower Parkway Ann Arbor, MI, USA 48108
IEEE	Institute of Electrical and Electronics Engineers IEEE Service Center 445 Hoes Lane PO Box 1331 Piscataway NJ 08855-1331
IPC	Institute for Interconnecting and Packaging Electronic Circuits 2215 Sanders Rd. Suite 200 South Northbrook IL 60062

NAS	National Standards Association 1200 Quince Orchard Boulevard Gaithersburg MD 20878
NFPA	National Fire Protection Association Batterymarch Park Quincy MA 02269-9101
UL	Underwriters Laboratories, Incorporated 333 Pfingsten Road Northbrook IL 60062

3. DEFINITIONS

3.1 Airborne, space, aerospace. "Airborne" denotes those applications peculiar to aircraft and missile or other systems designed for operation primarily within the earth's atmosphere; "space" denotes application peculiar to spacecraft and systems designed for operation near or beyond the upper reaches of the earth's atmosphere; and "aerospace" includes both airborne and space applications.

3.2 Other definitions and terms. Other definitions and terms are defined in the individual guidelines

4. GENERAL GUIDELINES

4.1 Application. The guidelines contained herein are intended to provide uniform guidelines applicable to electronic equipment, unless otherwise specified in the guideline.

4.2 Use of selection and application standards. When a selection and application standard is invoked in a guideline, the devices or parts selected should conform to the applicable military specifications referenced in the standard.

5. DETAIL GUIDELINES

5.1 Individual guidelines for electronic equipment. The individual guidelines for electronic equipment are located after section 6.

6. NOTES

6.1 Subject term (key word) listing.

Cable selection
Corona protection
Encapsulation
Fasteners
Flammability
Fungus protection
Interchangeability of parts
Marking
Materials selection
Microelectronics
Nomenclature
Parts selection
Printed wiring
Safety
Soldering
Substitutability of parts
Thermal design
Waveguides
Wire selection
Workmanship

6.2 Changes from previous issue. Marginal notations are not used in this revision to identify changes with respect to the previous issue due to the extent of the changes.

GUIDELINE 1

SAFETY DESIGN CRITERIA - PERSONNEL HAZARDS

1. Purpose. This guideline establishes safety design criteria and provides guidelines for personnel protection.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-STD-464	Electromagnetic Environmental Effects Requirements for Systems.
MIL-STD-1310	Shipboard Bonding, Grounding, and Other Techniques for Electromagnetic Compatibility and Safety.
MIL-STD-1425	Safety Design Requirements for Military Lasers and Associated Support Equipment.
MIL-STD-1472	Human Engineering.
DOD Manual 6050.5	DoD Hazardous Materials Information System Procedure.
10 CFR 20	Code of Federal Regulations, Title 10, Chapter I, Part 20.
21 CFR 1000-1050	Code of Federal Regulations, Title 21, Chapter I, Parts 1000-1050.
29 CFR 1910	Code of Federal Regulations, Title 29, Chapter XVII, Part 1910.
ANSI N2.1	Radiation Symbol.
ANSI Z136.1	Safe Use of Lasers.
ASTM F 1166	Standard Practice for Human Engineering Design for Marine Systems, Equipment and Facilities.
IEEE C95.1	Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.
IEEE C95.2	Radio-Frequency energy and current flow Symbols.
NEMA Z535.1	Safety Colors.
NEMA Z535.2	Environmental and Facility Safety Signs.
NEMA Z535.3	Criteria for Safety Symbols.
NEMA Z535.4	Product Safety Signs and Labels.
NEMA Z535.5	Safety Tags and Barricade Tapes (for Temporary Hazards).
NFPA 70	National Electrical Code.

3. Definitions.

3.1 Battleshort. A switch used to bypass normal interlocks in mission critical equipment; (e.g., equipment which must not be shut down or the mission function will fail) during battle conditions.

3.2 Chassis, electrical equipment. The chassis is a structural item fabricated in such manner as to facilitate assemblage and interconnection of electrical or electronic items for the specific purpose of providing a basis for electrical or electronic circuits. It normally has drilled or stamped holes to accommodate the items but may include only the items necessary for its own mounting and support.

3.3 Commercial off-the-shelf (COTS) equipment. COTS equipment that can be purchased through commercial retail or wholesale distributors as is (e.g., equipment that is available as a cataloged item) or with only minor modifications that does not alter its form, fit, or functional characteristics.

3.4 Frame. The frame is any construction system fitted and united together, designed for mounting or supporting electrical or electronic parts or units.

3.5 Fail-safe. The design feature of a part, unit, or equipment which allows the item to fail only into a non-hazardous mode.

3.6 Interlock. An interlock is an automatic switch which eliminates all power from the equipment when an access door, cover, or plate is removed.

3.6.1 Bypassable interlock. A bypassable interlock is an automatic switch with a manually operated electrical bypass device to allow equipment maintenance operations on energized equipment.

3.7 Leakage current. Leakage current is that current which flows through the equipment conductive paths to a solidly grounded source.

3.8 Procuring activity. A unit of the Department of Defense (DoD) which originates a procurement document for equipment or hardware.

4. General guidelines.

4.1 COTS equipment. COTS equipment that has been listed or certified to an appropriate commercial standard by a Nationally Recognized Test Laboratory (NRTL) (e.g., Underwriter's Laboratories (UL), Canadian Standards Association (CSA), or TUV Rheinland (TUV)) should be considered as having met the provisions of this guideline and from a product safety perspective, should be accepted for use without further modification. COTS equipment which has any modifications, and is required to meet commercial standards, should be recertified a NRTL.

4.2 Fail-safe. The design and development of all military electronic equipment should provide fail-safe features for safety of personnel during the installation, operation, maintenance, and repair or interchanging of a complete equipment assembly or component parts thereof.

4.3 Bonding in hazardous areas. Electronic equipment to be installed in areas where explosive or fire hazards exist should be bonded in accordance with MIL-STD-464 for aerospace systems, MIL-STD-1310 for shipboard systems, and NFPA 70, for facilities, or as otherwise specified in the equipment specification.

4.4 Temperature. At an ambient temperature of 25°C, the operating temperature of control panels and operating controls should be not greater than 49°C and not less than 12°C. The temperature of other exposed parts subject to contact by operating personnel should not exceed 60°C. The temperature of all other exposed surfaces should be not greater than 70°C.

4.5 Electrical. The design should incorporate methods to protect personnel from inadvertent contact with voltages capable of producing shock hazards.

4.5.1 Power. Means should be provided so that power may be cut off while installing, replacing, or interchanging a complete equipment, assembly, or part thereof. Interface with electrical power sources should be in accordance with the applicable regulations or requirements. If a main power switch is provided, it should be clearly labeled as such and should cut off all power to the complete equipment. Equipment that utilizes Uninterruptable Power Supplies (UPS) should have provisions to isolate the supply from the equipment.

4.5.2 Ground. The design and construction of equipment, excluding self-powered equipment, should ensure that all external parts, surfaces, and shields, exclusive of antenna and transmission line terminals, are at ground potential at all times during normal operation. The design should include consideration of ground currents and voltage limits (possible arcing) established on a basis of hazardous location. Antenna and transmission line terminals should be at ground potential, except for Radio Frequency (RF) energy on their external surfaces.

4.5.2.1 Self-powered equipment. Self-powered equipment should have all external surfaces at the same potential.

4.5.2.2 Grounding methods. Plugs for use with metal cased portable tools and equipment should have provisions for automatically grounding the metal frame or case of tools and equipment when the plug is mated with receptacle, and the grounding pin should make first, break last. Ground connections to shields, hinges, and other mechanical parts should not be used to complete electrical circuits. Any external or interconnecting cable, where a ground is part of the circuit, should carry a ground wire in the cable terminated at both ends in the same manner as the other conductors. In no case, except with coaxial cables, should the shield be depended upon for a current-carrying ground connection. Static and safety grounds should not be used to complete electrical circuits. A point on the electrically conductive chassis or equipment frame should serve as the common tie point for static and safety grounding. The path from the tie point to ground should:

a. Be continuous and permanent.

b. Have ample carrying capacity to conduct safely any fault currents that may be expected to be imposed on it by internally generated faults.

c. Have impedance sufficiently low to limit the potential above ground and to facilitate the operation of the over current devices in the circuits, and;

d. Have sufficient mechanical strength of the material to minimize possibility of ground disconnection.

4.5.2.3 Hinged or slide-mounted panels and doors. Hinges or slides should not be used for grounding paths. Panels and doors containing meters, switches, test points, etc., should be attached or hinged in such a manner as to ensure that they are at the same ground potential as the equipment in which they are mounted, whether in a closed or open position. A ground should be considered satisfactory if the electrical connection between the door, or panel, and the system tie point exhibits a resistance of 0.1 ohm or less, and has sufficient capacity to ensure the reliable and immediate tripping of equipment overcurrent protection devices.

4.5.2.4 Shielding. Except where a conflict with single-point shield grounding guidelines would be created, shielding on wire or cable should be grounded to the chassis or frame. The shielding should be secured to prevent it from contacting exposed current-carrying parts or grounding to the chassis or frame at any point other than the ground termination. The shielding should end at a sufficient distance from exposed conductors to prevent shorting or arcing between the conductor and the shielding.

4.5.2.5 Leakage current. The equipment leakage current should not exceed 5.0 milliamperes dc or rms. When excessive leakage currents are required by design or operational requirements, redundant grounding or double insulation methods should be incorporated.

4.5.3 Accidental contact. The design should incorporate methods to protect personnel from accidental contact with voltages in excess of 30 volts rms or dc during normal operation of a complete equipment.

4.5.3.1 Guards and barriers. All contacts, terminals, and like devices having voltages greater than 30 volts rms or dc with respect to ground should be guarded from accidental contact by personnel if such points are exposed to contact during direct support or operator maintenance. Guards or barriers may be provided with test probe holes where maintenance testing is required.

4.5.3.2 High voltage guarding. Assemblies operating at potentials in excess of 500 volts should be completely enclosed from the remainder of the assembly and equipped with non-bypassable interlocks.

4.5.3.3 Voltage measurement. When the operation or maintenance of equipment employing potentials in excess of 300 volts peak could require that these voltages be measured, the equipment should be provided with test points so that these voltages can be measured at a relatively low potential level. In no case should the potential exceed 300 volts peak relative to ground. Test points with voltages above 30 volts should have the conducting material recessed a distance no less than the diameter of the probe hole and a minimum of 1.5 mm. If a voltage divider is used, the voltage divider resistance between the test point and ground should consist of at least two resistors of equal value in parallel.

4.5.3.4 Guarding of RF voltages. Transmitter output terminals, antennas, and other devices that carry sufficient RF voltage to burn or injure personnel should be protected from accidental contact in the same manner as for ac voltages greater than 30 volts rms. (see 4.5.3.1. of this guideline)

4.5.3.5 Main power switch. The power input side of the main power switch and the incoming power line connections should be given physical protection against accidental contact.

4.5.4 Protective devices.

4.5.4.1 Interlocks. When a unit is provided with access doors, covers, or plates, these access points should be interlocked as follows:

GUIDELINE 1

a. No interlocks are required when all potentials between 30 and 500 volts are completely protected with guards or barriers to prevent accidental contact under all conditions of operation or any level of maintenance.

b. Bypassable interlocks are required when voltages in excess of 30 volts are exposed as the result of an access door, cover, or plate being opened. Note that these internal voltages are allowed to be unguarded only if they are not exposed during direct support or operator maintenance. The bypass device should be of such design that closing the associated door, cover or plate will automatically open the bypass device and leave the interlock in position to function normally. Visual means should be provided to indicate when the interlock is bypassed.

c. Non-bypassable interlocks are required when any voltage in excess of 500 volts is exposed as a result of an access door, cover, or plate being opened.

4.5.4.2 Battle short indicator. In equipment with battleshort circuitry, an audio and visual warning system should be installed in the equipment. The visual warning should be clearly visible to operating personal. The audio warning should provide a means for manual silencing and automatic reset. Catastrophic fault interlocks should not be bypassed.

4.5.4.3 Safety switches. Safety switches, which will deactivate associated mechanical drive units, should be provided for the purpose of disconnecting these units without disconnecting other parts of the equipment. Such remotely located units and assemblies should have provision for non-overrideable safety switches to allow independent disconnection in the associated equipment.

4.5.5 Discharging devices.

4.5.5.1 Automatic discharge devices. High voltage circuits and capacitors should be provided with discharging devices unless they discharge to 30 volts or less within two seconds after power removal. The particular discharging device that is chosen should ensure that the capacitor or high voltage circuit is discharged to 30 volts or less within two seconds. These protective devices should be positive acting, highly reliable, and should actuate automatically, either by mechanical release or by electrical solenoid when the door or cover is opened. When resistive bleeder networks are used to discharge capacitors, the bleeder network should consist of at least two equal valued resistors in parallel.

4.5.5.2 Shorting rods. Shorting rods should be provided with all transmitting equipment where voltages are in excess of 70 volts rms or dc. Where size permits, shorting rods should be stored within the transmitting equipment, permanently attached, and readily accessible to maintenance personnel. The permanently attached rod should be connected through a flexible stranded copper wire (covered with a transparent sleeving) to the stud provided at the transmitter main frame. Where size does not permit internal storage of the shorting rod, a grounding stud should be provided to permit attachment of a portable shorting rod. The connection to the stud should be such that accidental loosening, or high resistance to the ground is prevented.

4.5.6 Connectors. Connectors used in multiple electric circuits should be selected to preclude mismating. Where design considerations require plug and receptacles of similar configuration in close proximity, the mating plugs and receptacles should be suitably coded or marked to clearly indicate the mating connectors. Plugs and receptacles should not be of similar configuration if the major unit contains explosive items. The design of the connector should be such that the operator is not exposed to electrical shock or burns when normal disconnect methods are used. Exposed pin contacts should not be energized (hot) after being disconnected from the socket contacts.

4.6 Radiation. The design of all equipment for which a federal standard exists under 21 CFR 1000 - 1050, " The Radiation Control for Health and Safety Act of 1968", should conform to the appropriate federal standard.

4.6.1 Microwave and RF radiation. All electronic equipment or electrical devices capable of emitting microwave or RF radiation between 3 kHz and 300 GHz should be so designed, fabricated, shielded, and operated as to avoid overexposure of personnel. Exposure to RF radiation should meet the Controlled and Uncontrolled environment Maximum Permissible Exposure Levels called out in IEEE C95.1. In areas where unintended radiation levels exist, equipment design and installation in any unrestricted area accessible to personnel should meet the Uncontrolled environment requirements of IEEE C95.1. Shields, covers, doors, etc, which when opened or removed will allow microwave and RF radiation to exceed the above, should be provided with non-bypassable interlocks.

4.6.2 X radiation. All electronic or electrical devices capable of producing X radiation should be so designed, fabricated, shielded, and operated as to keep personnel exposure as low as reasonably achievable. For equipment and installation design, shielding guidelines should be maintained at all times which limit radiation levels to not greater than 2 milliroentgens (mr) in any 1 hour and 100 mr in any 7 consecutive days at the operator position or within 5 cm from the equipment (whichever is closer) in any unrestricted area accessible to personnel. In addition, these levels should be reduced whenever necessary to ensure that exposed personnel never receive an absorbed dose to the whole body or any critical organ in excess of 125 millirem for each calendar quarter or 500 millirem for each year. Other exposure should be based on application criteria and limits as required by “Nuclear Regulatory Commission Rules and Regulations”, 10 CFR 20; OSHA Regulations 29 CFR 1910 PT.96; and FDA Regulation, 21 CFR, chapter I, subchapter J, “Radiological Health”. Equipment which, when shields, covers, doors, etc, are removed, will allow X radiation to exceed 2.0 mr per hour should be provided with non-bypassable interlocks.

4.6.3 Laser radiation. Laser equipment and system design, installation, and operational and maintenance procedures should conform to 21 CFR 1040 and ANSI Z136.1. If these cannot be met because of operational requirements, an exemption should be requested from the FDA through the procuring activity, and applicable military laser safety requirements in MIL-STD-1425 will be considered.

4.7 Mechanical. The design of the equipment should provide personnel maximum access and safety while installing, operating, and maintaining the equipment. Equipment design should include provisions to prevent accidental pulling out of drawers or rack mounted equipment components. Suitable protection should be provided to prevent contact with moving mechanical parts such as gears, fans, and belts when the equipment is complete and operating. Sharp projections on cabinets, doors, and similar parts should be avoided. Doors or hinged covers should be rounded at the corners and provided with stops to hold them open.

4.7.1 Mechanical interconnection. The design should provide positive means to prevent the inadvertent reversing or mismating of fittings, couplings, fuel, oil, hydraulic, and pneumatic lines, and mechanical linkage. When prevention of mismating by design consideration is not feasible, coding or marking should be employed when approved by the procuring activity. Coding and marking will not be approved as a substitute for proper design or items involving explosive, emergency, or safety critical systems.

4.7.2 Power switch location. Equipment power switches should be selected and located so that accidental contact by personnel will not operate the switch.

4.7.3 Cathode ray tubes. Provision should be incorporated to protect personnel from injury due to implosion of cathode ray tubes.

4.7.4 Battery enclosures. Battery enclosures should be vented. The enclosure design should prevent shattering or fragmenting of enclosure parts, or covers ,in the event of a violent gas venting or rupture of battery cells causing explosive high pressure within the compartment.

4.8 Equipment safety markings. Danger, warning, caution, signs, labels, tags, and markings should be used to warn of specific hazards such as voltage, current, thermal, or physical. The signs, labels, tags, and markings should be as permanent as the normal life expectancy of the equipment on which they are affixed. Guards, barriers, access doors, covers, or plates should be marked to indicate the hazard which may be present upon removal of such devices. When possible, marking should be located such that it is not removed when the barrier or access door is removed. Additionally, hazards internal to a unit should be marked adjacent to hazards if they are significantly different from those of surrounding items. Such a case would be a high voltage terminal in a group of low voltage devices.

a. Physical hazards should be marked with color codes in accordance with NEMA Z535.1 where applicable to electronic equipment.

b. For potentials between 70 and 500 volts, warning signs, labels, or tags should be in accordance with NEMA Z535.3, NEMA Z535.4, or NEMA Z535.5 and contain the single word "WARNING", and the maximum voltage applicable (e.g., 110 VAC).

c. For potentials in excess of 500 volts, warning signs, labels, or tags should be in accordance with NEMA Z535.3, NEMA Z535.4, or NEMA Z535.5 and contain the single word "DANGER", the descriptive words "High Voltage" and the maximum voltage applicable (e.g., High Voltage 550 VAC).

d. Microwave or RF radiation warning signs, labels, or tags should be in accordance with NEMA Z535.3, NEMA Z535.4, or NEMA Z535.5, and IEEE C95.2. Labels should be provided on all radiation shields to warn personnel of the radiation hazards involved upon removal thereof. Any item, which can emit radiation levels in excess of those specified in 4.6.1, should be labeled. Minimum safe clearance distances should be clearly marked. Warning signs should be posted in all areas having electronic equipment designed to operate between 3 kHz and 300 GHz with intended electromagnetic radiation levels exceeding those in 4.6.1.

e. Laser labels.

(1) Laser labels should be in accordance with 21 CFR 1040.

(2) Military exempt laser labels: A permanent label should be affixed on all military laser systems that have been certified exempt from 21 CFR 1040 "Performance Standards for Light-Emitting Products". The label tags should be in accordance with NEMA Z535.3, NEMA Z535.4, or NEMA Z535.5, and should use the single word CAUTION, and should read:

CAUTION

This electronic product has been exempted from FDA radiation safety performance standards, prescribed in the Code of Federal Regulations, title 21, chapter I, subchapter J, pursuant to exemption no. 76 EL-01 DOD issued on 26 July 1976. This product should not be used without adequate protective devices or procedures.

f. Shields which protect personnel from X radiation should be labeled in accordance with 10 CFR 20.

g. Coding for accident prevention tags should be in accordance with NEMA Z535.5.

h. Coding for safety labels on equipment should be in accordance with NEMA Z535.4.

i. Coding for safety signs regarding facilities or the environment should be in accordance with NEMA Z535.3.

j. The marking or labeling of commodities containing radioactive materials should be in accordance with 10 CFR 20.

k. Ionizing radiation hazard symbols should be in accordance with ANSI N2.1.

l. Symbols used on hazard warning signs, labels,or tags should be IAW NEMA Z535.2.

4.9 Hazardous and restricted materials.

4.9.1 Gases or fumes. The materials, as installed in the equipment and under service conditions specified in the equipment specification, should not liberate gases which combine with the atmosphere to form an acid or corrosive alkali, nor should they liberate toxic or corrosive fumes which would be detrimental to the performance of the equipment or health of personnel. The materials also should not liberate gases which will produce an explosive atmosphere.

4.9.2 Mercury. Materials and parts containing mercury should not be used unless use of mercury is specifically required or approved by the procuring activity.

4.9.3 Radioactive materials. Use of radioactive materials should conform to Nuclear Regulatory Commission regulations and should require approval of the procuring activity. Radium should not be used to achieve self-luminosity.

4.9.4 Glass fibers. Glass fiber materials should not be used as the outer surface or covering on cables, wire, or other items where they may cause skin irritation to operating personnel. When maintenance procedures require access to glass fibers, such as insulation, a proper caution note should be provided.

4.9.5 Cadmium. Cadmium plating, and devices using cadmium, should not be used unless specifically approved by the procuring activity.

5. Detail guidelines.

5.1 Human engineering. Human engineering factors affecting safety should be considered when establishing general or detailed design criteria. Rigorous detailed operational or maintenance procedures are not acceptable substitutes for an inherently safe design. Hazard and safety requirements of MIL-STD-1472 or ASTM F 1166 (for marine systems, equipment, and facilities) should be used as a guide.

5.2 Electrical. Proper instructions in accident prevention and first-aid procedures should be given to all persons engaged in electrical work to fully inform them of the hazards involved.

5.2.1 Shock hazards. Current, rather than voltage, is the most important variable in establishing the criterion for shock intensity. Three factors that determine the severity of electrical shock are: (1) quantity of current flowing through the body; (2) path of current through the body; and (3) duration of time that the current flows through the body. The voltage necessary to produce the fatal current is dependent upon the resistance of the body, contact conditions, and the path through the body. (See table 1-I). Sufficient current passing through any part of the body will cause severe burns and hemorrhages. However, relatively small currents can be lethal if the path includes a vital part of the body, such as the heart or lungs. Electrical burns are usually of two types, those produced by heat of the arc which occurs when the body touches a high-voltage circuit, and those caused by passage of electrical current through the skin and tissue. While current is the primary factor which determines shock severity, protection guidelines are based upon the voltage involved to simplify their application. In cases where the maximum current which can flow from a point is less than the values shown in table 1-I for reflex action, protection guidelines may be relaxed.

GUIDELINE 1

TABLE 1-I. Probable effects of shock.

Current values (milliamperes)		Effects
AC 25 Hz to 400 Hz	DC	
0 to 1	0-4	Perception
1 to 4	4-15	Surprise
4 to 21	15-80	Reflex action
21 to 40	80-160	Muscular inhibition
40 to 100	160-300	Respiratory block
Over 100	Over 300	Usually fatal

5.2.2 Insulation of controls. All control shafts and bushings thereof should be grounded whenever practicable. Alternatively, the control knobs, or levers, and all attachment screws that can be contacted during use should be electrically insulated from the shaft.

5.2.3 Grounding to chassis. Ground connection to an electrically conductive chassis, or frame, should be mechanically secured by soldering to a spot welded terminal lug or to a portion of the chassis, or frame, that has been formed into a soldering lug, or by use of a terminal on the ground wire and then securing the terminal by a screw, nut, and lock-washer. The screw should fit in a tapped hole in the chassis, or frame, or it should be held in a through-hole by a nut. When the chassis, or frame, is made of steel, the metal around the screw hole should be plated or tinned to provide a corrosion resistant connection. When aluminum alloys are used, the metal around the grounding screw, or bolthole, may be covered with a corrosion resistant surface film only if the resistance through the film is not more than 0.02 ohm. Hardware used for mounting of meters, switches, test points, etc., should be grounded, whenever possible.

5.2.4 Accidental contact. Suitable protective measures are defined in table 1-II.

5.2.4.1 High current protection. Power sources capable of supplying high current can be hazardous regardless of the voltage at which they operate because of the arcing and heat generated if an accidental short circuit occurs. All power buses supplying 25 amperes or over should be protected against accidental short-circuiting by tools, jewelry or removable conductive assemblies. This may be accomplished by one or more of the following:

a. Use of guards and barriers;

b. Sufficient space separation to prevent short circuits;

c. Hazard warning - signs and labels.

5.2.4.2 Interlocks. Various equipment designs require different approaches to the use of interlocks. Interlock use does not modify any other guidelines of this handbook and will be consistent with equipment or system specifications. Equipment sub-assemblies operating in excess of 500 volts should be considered guarded from accidental contact only if they are completely enclosed from the remainder of the equipment and are separately protected by non-bypassable interlocks. (An example of equipment where such compartmentalization is desirable is a display unit which utilizes a high voltage power supply for a cathode ray tube.) Modularized, or sealed, high voltage assemblies which are opened only at depot level are exempt from interlocking guidelines when approved by the procuring activity.

5.2.4.3 Permanent terminations. Terminations such as soldered connections to transformers, connectors, splices, etc., which are normally permanent and not used during routine maintenance testing, may be protected by permanent insulation such as shrink sleeving, tubing, insulating shields, etc., provided the material is rated for the potential exposed voltage.

GUIDELINE 1

5.3 Mechanical. Design of rack-mounted equipment should maintain the center of gravity as low as possible to minimize tipping over.

5.4 Marking. DOD Manual 6050.5 references known electronic items which require marking and may be used as a guide.

5.5 Materials. Certain chemicals have been identified by OSHA as cancer-producing substances (carcinogens). Before using any materials which might contain these chemicals, they should be evaluated in accordance with 29 CFR 1910.

GUIDELINE 1

TABLE 1-II. Suitable protective measures. 1/

Voltage range	Type of protection 2/								
				Marking		Interlocks		Discharge devices	
	None 3/	Guards and barriers (4.5.3.1)	Enclosures (4.5.3.2, 4.5.4.1)	Warning (4.8b)	Danger (4.8c)	Bypassable (4.5.4.1b)	Non-bypassable (4.5.4.1c) 4/	Automatic (4.5.5.1)	Shorting rods (4.5.5.2)
0 - 30 Volts	X								
> 30 - 70 Volts		X				X		X	
> 70 - 500 Volts		X		X		X		X	X
> 500 Volts		X	X		X		X	X	X

1/ Table is for reference only. See applicable paragraph for guidance.

2/ Confine the application of headings to voltage ranges indicated. More than one option may be available on design guidance.

3/ Although no specific guidance exist for servicing 0-30 volts, designs should be reviewed for possible hazards in accordance with table 1-I.

4/ Designs may use non-bypassable interlock applications below 500 volts, but the intent here is to imply complete enclosure.

GUIDELINE 2

CAPACITORS

1. Purpose. This guideline establishes criteria for the selection and application of capacitors.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-PRF-39006/22	Capacitors, Fixed, Electrolytic (Nonsolid Electrolyte), Tantalum, (Polarized, Sintered Slug), 85° C (Voltage Derated to 125° C), Established Reliability, Style CLR79.
MIL-PRF-39006/25	Capacitors, Fixed, Electrolytic (Nonsolid Electrolyte), Tantalum, (Polarized, Sintered Slug Extended Range), 85° C (Voltage Derated to 125° C), Established Reliability, Style CLR81.
MIL-HDBK-198	Capacitors, Selection and Use of.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Selection. Capacitors should be selected and applied in accordance with MIL-HDBK-198.

4.2 Fixed, Tantalum Electrolytic. For Naval Air Systems Command, the use of wet slug tantalum capacitors (except tantalum cased units in accordance with MIL-PRF-39006/22 and MIL-PRF-39006/25) requires the approval of the procuring activity. Silver cased tantalum capacitors should not be used.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 3

FLAMMABILITY

1. Purpose. This guideline establishes criteria for the selection and application of materials with respect to flammability.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-STD-202	Electronic and Electrical Component Parts.
ASTM D 635	Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position.,
ASTM D 1000	Standard Test Method for Pressure-Sensitive Adhesive-Coated Tapes Used for Electrical and Electronic Applications,.
UL 94	UL Standard for Safety Test for Flammability of Plastic Materials for Parts in Devices and Appliances.

3. Definitions.

3.1 Flammability. Flammability is a complex characteristic which combines ease of ignition, surface flammability, heat contribution, smoke production, fire gasses, and fire endurance. Flammability is a function of chemical composition, physical configuration, temperature, availability of oxygen, and retardants or additives.

4. General guidelines.

4.1 Materials. Materials used in military equipment should, in the end item configuration, be noncombustible or fire retardant in the most hazardous conditions of atmosphere, pressure, and temperature to be expected in the application. Fire retardant additives may be used provided they do not adversely affect the specified performance guidelines of the basic materials. Fire retardance should not be achieved by use of non-permanent additives to the basic material.

5. Detail guidelines.

5.1 Flammability test. The test used to determine the flammability of material should be the test specified in the material specification. Since some materials may change state or characteristics relative to flammability during application, tests may be performed on the end item materials mixed/blended/saturated/impregnated/layered and processed to simulate the final configuration in the end equipment usage.

5.2 Other flammability test. If the specification does not have such a test, testing should be in accordance with ASTM D635, ASTM D 1000, or MIL-STD-202, Method 111, as applicable.

5.3 Other materials. Materials not covered by the above tests should be tested in accordance with a procedure approved by the procuring activity. UL 94 is a useful guide to develop test methods and offers a comparative scale to define degree of flammability.

GUIDELINE 4

FUNGUS-INERT MATERIALS

1. Purpose. This guideline identifies those materials which are acceptable non-nutrients of fungus and establishes conditions under which fungus nutrient materials are acceptable.

2. Applicable documents The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

SAE AS12500	Corrosion Prevention and Deterioration Control in Electronic Components and Assemblies.
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests.
29 CFR PT1910	Code of Federal Regulations Title 29, Chapter XVII, Part 1910.

3. Definitions.

3.1 Fungus-inert material. A material which, in all modified states and grades, is not a nutrient tofungi.

3.2 Fungicide. A substance that destroys or inhibits the growth of fungi.

4. General guidelines.

4.1 Preferred materials. Fungus-inert materials listed in group I of table 4-I are preferred for use. These materials need not be tested for fungus resistance prior to use. The appearance of a particular material in table 4-I does not constitute approval for its use except from the viewpoint of the resistance of the material to fungi.

4.2 Acceptable materials. Those materials listed in group II of table 4-I may be used, provided it has been demonstrated that they meet the guidelines of 4.4. When materials are compounded with a permanently effective fungicide in order to meet the fungus test guideline, there should be no loss of the original electronic or physical properties required by the basic material specification. Fungicides containing mercury should not be used.

4.3 Hermetically sealed applications. Fungus nutrient materials may be used untreated within hermetically sealed enclosures.

4.4 Fungus testing. Table 1-I Group II materials should be subjected to the fungus test specified in method 508 of MIL-STD-810 for a period of 28 days. Certification by a qualified laboratory or by the material producer, based on test data on record that the material meets grade O or grade 1 guidelines of table 508-I, method 508 of MIL-STD-810, is sufficient evidence of acceptability.

GUIDELINE 4

TABLE 4-I. Fungi susceptibility of materials.

Group I - Fungus-inert materials (Fungus-inert in all modified states and grades)	
Acrylics	Polyamide 1/
Acrylonitrile-styrene	Polycarbonate
Acrylonitrile-vinyl-chloride copolymer	Polyester-glass fiber laminates
Asbestos	Polyethylene, high density (above 0.940)
Ceramics	Polyethylene terephthalate
Chlorinated polyester	Polyimide
Fluorinated ethylenepropylene copolymer (FEP)	Polymonochlorotrifluoroethylene
Glass	Polypropylene
Metals	Polystyrene
Mica	Polysulfone
Plastic laminates:	Polytetrafluoroethylene
Silicone-glass fiber	Polyvinylidene chloride
Phenolic-nylon fiber	Silicone resin
Diallyl phthalate	Siloxane-polyolefin polymer
Polyacrylonitrile	Siloxane polystyrene

Group II - Fungus nutrient materials (May require treatment to attain fungus resistance)	
ABS (acrylonitrile-butadiene-styrene)	Polyethylene, low and medium density (0.940 and below)
Acetal resins	Polymethyl methacrylate
Cellulose acetate	Polyurethane (the ester types are particularly susceptible)
Cellulose acetate butyrate	Polyricinoleates
Epoxy-glass fiber laminates	Polyvinyl chloride
Epoxy-resin	Polyvinyl chloride-acetate
Lubricants	Polyvinyl fluoride
Melamine-formaldehyde	Rubbers, natural and synthetic
Organic polysulphides	Urea-formaldehyde
Phenol-formaldehyde	
Polydichlorostyrene	

1/ Literature shows that under certain conditions polyamides may be attacked by selective micro-organisms. However, for military applications, they are considered group I.

GUIDELINE 4

5. Detail Guidelines

5.1 Process-related materials. Processing materials to be tested for fungus resistance in accordance with 4.4, such as paint, ink, coatings, adhesives, lubricants, viscous damping fluids, silicone grease, etc., should be prepared in the form of 50 mm squares or circles no more than 1.6 mm thick for testing. Liquid or paste materials should be prepared by impregnating to saturation a sterile sample of glass fabric.

5.2 Parts treatment. When treatment of parts is required to form fungus-resistant materials, a Moisture and Fungus Proofing (MFP) varnish may be applied in accordance with SAE AS12500 after the part is cleaned. The MFP varnish should not be applied to any part where the treatment will interfere with performance.

5.3 Carcinogens. Certain chemicals have been identified in the Occupational Safety and Health Act (OSHA) as cancer-producing substances (carcinogens). Before using any materials which might contain these chemicals, they should be evaluated in accordance with 29 CFR 1910. Consideration of the toxicity of a substance should be given prior to material selection.

GUIDELINE 5

SOLDERING

1. Purpose. This guideline establishes the basis for soldering of electrical and electronic assemblies and non-electrical soldered connections.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

IPC/EIA J-STD-001	Requirements for Soldered Electrical and Electronic Assemblies.

3. Definitions. This section not applicable to this guideline.

4. General guidelines

4.1 Soldering of electrical and electronic equipment. Electrical and electronic equipment should be assembled, soldered, and cleaned in accordance with the guidelines of IPC/EIA J-STD-001.

4.2 Workmanship. Workmanship may be checked in accordance with IPC/EIA J-STD-001.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 6

BEARINGS

1. Purpose. This guideline establishes criteria for the selection and application of bearings.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-B-8942	Bearings, Plain, TFE Lined, Self-Aligning.
MIL-B-8943	Bearing, Journal - Plain and Flanged, TFE Lined.
MIL-B-8948	Bearing, Plain, Rod End, TFE Lined, Self-Aligning.
MIL-B-81793	Bearings, Ball, Annular, For Instruments and Precision Rotating Components.
A-A-52401	Bearing, Sleeve (Steel-Backed).
A-A-52414	Bearing, Roller, Thrust.
SAE AS13341	Process for Barrier Coating of Anti-Friction Bearings.
SAE AS81934	Bearings, Sleeve, Plain and Flanged, Self-Lubricating.
SAE AS81936	Bearings, Plain, Self-Aligning (CuBe Ball, CRES Race), General Specification for.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Selection and application. Bearings best suited to meet the physical, functional, environmental, and service life guidelines of the application should be selected from those conforming to one or more of the specifications listed below. Replacement of the bearing should be possible without use of special tools, unless such provisions would adversely affect the proper functioning or service life of the bearing.

MIL-B-81793	A-A-52414	SAE AS 13341
MIL-B-8942	A-A-52401	SAE AS 81934
MIL-B-8943		SAE AS 81936
MIL-B-8948		

4.2 Lubricant. Adequate lubricant should be provided either within the bearing or externally in the form of oil reservoirs or grease relubrication facilities, except as noted in 4.3. Where lubricant replenishment is required, precaution should be taken to prevent purged or lost lubricant from entering, and adversely affecting, the operation of the electronic equipment. Where bearings coated with preservative are installed in closed housings, the preservatives should be compatible with the lubricant used in the assembly.

4.3 Unlubricated bearings. Unlubricated bearings or bushings may be used only in applications where the presence of a lubricant would be undesirable or detrimental and the functional, environmental, and service life guidelines can be met in this condition.

4.4 Barrier coating. Bearings requiring a barrier coating should be coated in accordance with SAE AS13341.

4.5 Seals and shields. All rolling element bearings should be adequately protected by seals or shields on the bearing or installed in housings which provide adequate shielding to prevent foreign matter from entering the bearing.

4.6 Electrical grounding. Ball and roller bearings used for rotating electrically energized equipment should be electrically shunted to avoid current flow through the bearings.

4.7 Alignment. Bearings should be located to ensure proper shaft alignment and support.

5. Detail guidelines.

5.1 Self-lubricating bearings. Permanently lubricated bearings or bushings of plastic, metallic-plastic combinations, or all metallic materials, with or without dry film lubricants, may be used provided wear products produced during operation will not cause or contribute to failure of the electronic equipment or bearings.

GUIDELINE 6

5.2 Unlubricated bearings. For selection of low friction, long life, unlubricated bearings refer to MIL-B-8942, MIL-B-8943, and MIL-B-8948.

GUIDELINE 7

INTERCHANGEABILITY

1. Purpose. This guideline establishes design criteria to ensure the interchangeability of parts, subassemblies, and assemblies.

2. Applicable documents The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-HDBK-505	Definitions of Item Levels, Item Exchangeability, Models, and Related Terms.
MIL-HDBK-1547	Electronic Parts, Materials, and Processes for Space and Launch Vehicles.

3. Definitions.

3.1 Assembly, interchangeable item, part, subassembly, and substitute item. The terms assembly, interchangeable item, part, subassembly, and substitute item are defined in MIL-HDBK-505.

3.2 Standard parts. For Air Force space and launch vehicles, standard parts are as described in MIL-HDBK-1547. For all other equipments, standard parts are defined in the applicable general specification or contract.

4. General guidelines.

4.1 Design tolerances. Design tolerances should permit parts, subassemblies, and assemblies to be used in their parent assemblies without regard to the source of supply or manufacturer. Parts, subassemblies, and assemblies having the full range of dimensions and characteristics permitted by the specification governing the part, subassembly, or assembly should be usable as replacement items without selection and without departure from the specified performance guidelines of the parent items.

4.2 Parts and materials. When permission is granted to use a nonstandard part or material because the existing standard part or material is not available, the equipment should be so designed that the nonstandard part or material and the standard part or material are interchangeable. When the specification for the part or material contains substitutability or suppression information, the design should permit the substitute, or superseding parts, or materials to be used interchangeably.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 8

ELECTRICAL OVERLOAD PROTECTION

1. Purpose. This guideline establishes the criteria and philosophy for electrical overload protection.

2. Applicable documents The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-HDBK-505	Definitions of Item Levels, Item Exchangeability, Models, and Related Terms.
NFPA 70	National Electrical Code.

3. Definitions.

3.1 Class 1 equipment. Ground and shipboard, including test and check-out ground equipment.

3.2 Class 2 equipment. Manned aerospace equipment.

3.3 Class 3 equipment. Unmanned aerospace equipment.

4. General guidelines. The guidelines specified herein should apply only to equipment and systems as defined in MIL-HDBK-505 for Class 1 and Class 2 equipment.

4.1 Protection for Class 1 equipment.

4.1.1 Current overload protection. Current overload protection should be provided for primary circuits. Devices such as fuses, circuit breakers, time delays, cutouts, or solid-state current-interruption devices should be used to open a circuit whenever an overload condition occurs. No overcurrent protective device should be connected in series with any conductor which is grounded at the power source unless the device simultaneously opens all load conductors in the circuit and no pole operates independently, or as otherwise allowed by the “National Electrical Code”, NFPA 70. Protective devices for wired-in equipment should be connected to the load side of the equipment power switch (main circuit power disconnect). For portable equipment, a separable connector or the attachment plug and receptacle should serve as the main circuit power disconnect and the protective device may be on either the line side or the load side of the equipment on-off switch.

4.1.2 Fuses. Where fuses are used, at least one extra fuse of each type and rating used should be supplied and attached to the applicable units of the equipment. Panel-mounted fuse posts should be such as to permit renewal of fuses without use of tools.

4.1.3 Circuit breakers. Circuit breakers should give a visual indication when tripped. Holding the switching device closed on an overload should not prevent tripping of the breaker. Multi-pole circuit breakers should be used for three-phase equipment and should disconnect all phases if an overload occurs in any one phase. Circuit breakers should not be used as switches unless such breakers have been specifically designed and tested for that type service.

4.2 Protection for Class 2 equipment.

4.2.1 Current overload protection. Current overload protection for the equipment should be provided by fuses or circuit breakers. Circuit breakers should not be used as switches unless such breakers have been specifically designed and tested for that type service.

4.2.2 Spare fuses. When fuses are used, a minimum of one spare fuse for each size and rating, but a quantity of not less than 10 percent of the total, should be incorporated in the equipment and should be contained in the same compartment.

4.3 Protection for Class 3 equipment. Electrical overload protection should not be provided in individual boxes or systems receiving power.

GUIDELINE 8

5. Detail guidelines.

5.1 Location. Overload protection for the equipment should be provided therein. For Class 1 and Class 2 equipment, all protective devices employed in the equipment should be in a readily accessible, safe location.

5.2 Resettable circuit protectors. Circuit breakers, or other resettable devices, should be used to protect critical circuits, or where predictable overloads or surges occur because of peculiar equipment functions or operator effects which are unavoidable.

GUIDELINE 9

WORKMANSHIP

1. Purpose. This guideline establishes the acceptable workmanship criteria for electronic equipment. This guideline will define workmanship guidelines not normally covered in subsidiary specifications or drawings.

2. Applicable documents This section not applicable to this guideline.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Cleaning. After fabrication, parts and assembled equipment should be cleaned of smudges; loose, spattered, or excess solder; weld metal; metal chips and mold release agents; or any other foreign material which might detract from the intended operation, function, or appearance of the equipment.

4.2 Threaded parts or devices. Screws, nuts, and bolts should show no evidence of cross threading, mutilation, or detrimental or hazardous burrs, and should be firmly secured.

4.3 Bearing assemblies. Bearing assemblies should be free of rust, discoloration, and imperfections of ground, honed, or lapped surfaces. Contacting surfaces should be free of tool marks, gouge marks, nicks, or other surface-type defects. There should be no detrimental interference, binding, or galling.

4.4 Wiring. Wires and cables should be positioned or protected to avoid contact with rough or irregular surfaces and sharp edges and to avoid damage to conductors or adjacent parts.

4.5 Shielding. Shielding on wires and cables should be secured in a manner that will prevent it from contacting or shorting exposed current-carrying parts. The ends of the shielding or braid should be secured to prevent fraying.

5. Detail guidelines.

5.1 Containment. The harness and cable form containment means should be neat in appearance, uniformly applied, and positioned to retain critical form factors and breakout locations. The containment means, (lacing, ties, tiedown straps, etc.) should not cause the wire or cable insulation to deform so that performance characteristics are adversely affected.

5.2 Insulation. There should be no evidence of burns, abrading, or pinch marks in the insulation that could cause short circuits or leakage.

5.3 Clearance. The clearance between wires or cables and heat generating parts should be sufficient to minimize deterioration of the wires or cables.

GUIDELINE 10

ELECTRICAL CONNECTORS

1. Purpose. This guideline establishes criteria for the selection and application of electrical connectors.

2. Applicable documents The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-J-641	Jacks, Telephone, General Specification for.
MIL-P-642	Plugs, Telephone, and Accessory Screws, General Specification for.
MIL-DTL-5015	Connectors, Electrical, Circular Threaded, AN Type, General Specification for.
MIL-DTL-21097	Connectors, Electrical, Printed Wiring Board, General Purpose, General Specification for.
MIL-DTL-21617	Connectors, Plug and Receptacle, Electrical, Rectangular, Polarized Shell, Miniature Type, General Specification for.
MIL-DTL-22992	Connectors, Plugs and Receptacles, Electrical, Waterproof, Quick Disconnect, Heavy Duty Type, General Specification for.
MIL-DTL-24308	Connectors, Electrical, Rectangular, Nonenvironmental, Miniature, Polarized Shell, Rack and Panel, General Specification for.
MIL-DTL-26518	Connectors, Electrical, Miniature, Rack and Panel, Environment Resistant, 200 Degrees C Ambient Temperature, General Specification for.
MIL-DTL-28748	Connector, Plug and Receptacle, Rectangular, Rack and Panel Solder Type and Crimp Type Contacts, General Specification for.
MIL-C-28754	Connectors, Electrical, Modular, and Component Parts, General Specification for.
MIL-DTL-28804	Connectors, Plug and Receptacle, Electric, Rectangular, High Density, Polarization Center Jackscrew, General Specification for.
MIL-C-29600	Connector, Electrical, Circular, Miniature, Composite, High Density, Quick Coupling, Environment Resistant, Removable Crimp Contacts Associated Hardware, General Specifications for.
MIL-DTL-32139	Connectors, Electrical, Rectangular, Nanominiature, Polarized Shell, General Specification for.
MIL-PRF-31031	Connectors, Electrical, Plugs and Receptacles, Coaxial, Radio Frequency, High Reliability, For Flexible and Semirigid Cables, General Specification for.
MIL-DTL-38999	Connector, Electrical, Circular, Miniature, High Density, Quick Disconnect (Bayonet, Threaded, and Breech Coupling), Environment Resistant, Removable Crimp and Hermetic Solder Contacts, General Specification for.
MIL-PRF-39012	Connectors, Coaxial, Radio Frequency, General Specification for.
MIL-DTL-39024	Jack, Tip (Test Point, Panel or Printed Wiring Type), General Specification for.
MIL-PRF-49142	Connector, Triaxial, Radio Frequency, General Specification for.
MIL-DTL-55116	Connector, Miniature Audio, Five-Pin and Six-Pin, General Specification for.
MIL-DTL-55181	Connectors, Plug and Receptacle, Intermediate Power (Electrical, Waterproof), Type MW, General Specification for.
MIL-DTL-55302	Connectors, Printed Circuit Subassembly and Accessories
MIL-PRF-55339	Adapters, Connectors, Coaxial, Radio Frequency (Between Series and Within Series) General Specification for.
MIL-C-81659	Connectors, Electrical Rectangular, Crimp Contacts, General Specification for.
MIL-DTL-83503	Connectors, Electrical, Flat Cable, and/or Printed Wiring Board, Nonenvironmental, General Specification for.
MIL-DTL-83513	Connectors, Electrical, Rectangular, Microminiature, Polarized Shell, General Specification for.
MIL-DTL-83517	Connector, Coaxial, Radio Frequency for Coaxial, Strip or Microstrip Transmission Line, General Specification for.
MIL-DTL-83723	Connector, Electrical (Circular, Environment Resisting), Receptacles and Plugs, General Specification for.
MIL-DTL-83733	Connectors, Electrical Miniature, Rectangular Type, Rack to Panel, Environment Resisting, 200°C Total Continuous Operating Temperature, General Specification for.
EIA RS 297	Cable Connectors for Audio Facilities for Radio Broadcasting

GUIDELINE 10

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Selection. Intended use information contained in the individual connector specifications should be considered prior to making connector selections. Contact crimp, installing and removal tools should be in accordance with the individual connector specifications. However, contractors may use tooling as recommended by the contact or tooling manufacturer provided that the finished crimp meets all of the performance guidelines of the contact and connector specification. The variety of these tools required within a system should be kept to a minimum. Maintenance instructions and other data supplied by the contractor should list the military standard tools and contacts.

4.2 Audio frequency and communication connectors, special purpose. Connectors conforming to MIL-DTL-55116 should be used in audio frequency applications, such as head sets and chest sets, excluding pilots' helmets. For low level, three wire and audio input circuits in fixed plant non-tactical sound equipment, connectors conforming to EIA RS 297 should be used.

4.3 Connectors with thermocouple contacts. All connectors used in conjunction with thermocouples should have their contact materials identified by one of the following methods:

a. Nameplate securely attached to each connector half or mounted on the panel-mounted receptacles.

b. Insulation sleeving, or other markers, designed for attachment around wire bundles. Markers should be attached adjacent to the plug. Contact materials should be identified with abbreviations in accordance with table 10-I.

TABLE 10-I. Abbreviations for thermocouple materials.

Material	Symbol	Material	Symbol
Chromel	CR	Gold	AU
Alumel	AL	Cobalt	CO
Iron	FE	Tungsten Rhenium	W RE
Constantan	CN	Tungsten	W
Copper	CU	Iridium	IR
Platinum	PT	Rhodium	RH
Platinum Rhodium	PT RH	Iridium Rhodium	IR RH
Rhenium	RE	Molybdenum	MO

4.4 Heavy duty connectors.

4.4.1 Power connectors (40 to 200 amperes). All power connectors for any ground application should conform to MIL-DTL-22992 and should be used with heavy duty jacketed cable as specified on the insert standards. Intermediate power connectors should conform to MIL-DTL-55181.

4.4.2 General purpose and shipboard. Connectors for general purpose heavy duty applications and shipboard power applications should conform to MIL-DTL-22992. Connectors used for external applications should be pressurized and waterproof in the mated and unmated condition in accordance with the guidelines of classes C or L. Connectors used internally (within a protective enclosure such as a shelter) may be in accordance with class R provided waterproofing or pressurization is not a guideline for the application.

4.5 General utility connectors. Polarized connectors are the preferred styles and should be used where automatic grounding will be provided to ensure safety to equipment and personnel.

GUIDELINE 10

4.6 Plugs and jacks (telephone type). Telephone type jacks and plugs should conform to MIL-J-641 and MIL-P-642.

4.7 Test jacks. Test jacks should conform toMIL-DTL-39024. Jacks or receptacles for use as RF test points should be selected in accordance with 4.8.

4.8 RF connectors. RF connectors should conform to MIL-PRF-39012. Adapters used with RF connectors should conform to MIL-PRF-55339. Connectors meeting High-Reliability requirements should conform to MIL-PRF-31031. Triaxial RF connectors should conform to MIL-PRF-49142.

4.9 Connectors for printed wiring. Printed circuit connectors should conform to MIL-DTL-21097 and MIL-DTL-55302.

4.10 Connector wiring. Multiple conductors may terminate in a contact provided the sum of the cross sectional areas of the conductors does not exceed the maximum cross sectional area for which the contact is rated. Not more than one wire should be routed through any hole in the grommet of an environmentally sealed connector.

4.11 Extra contacts. The following information is applicable to all articles of equipment, except those in which it is unlikely that additional circuits will be required.

4.11.1 Quantity and location. Unused connector contacts, or contact positions for external circuits, should be provided for future use and should be located on the periphery (outer contacts) of the connector. The minimum quantity should be as specified below:

Total number of used contacts in connector	Unused contacts or contact positions required (min)
1 through 3	1 (optional)
4 through 25	2
26 through 100	4
101 and over	6

4.11.2 Extra connectors. An extra connector should not be used to meet this guideline without the approval of the procuring activity.

4.11.3 Size and rating of extra contacts. The size and rating of extra contacts should be compatible with other contacts within the connectors.

4.11.4 Crimp contact connectors. When crimp contact environmentally sealed connectors are used, all contact positions should be filled with contacts. Crimp connectors should conform to MIL-C-81659.

4.11.5 Sealing plugs. Sealing plugs should be inserted in the grommet holes of unused contacts in environmentally sealed connectors.

4.11.6 Potted connectors. For potted connectors, each unused contact should have a maximum gauge wire of 150 mm minimum length attached and identified with the contact designation for future use. For connectors external to the unit, the wire end should be suitably capped to prevent moisture from entering the connector.

4.12 Protective measures. All unmated connectors should be protected with metal or plastic caps or otherwise suitably protected during maintenance, storage, and shipment. Protective caps specified by military specifications or military standards and designed for mating with specific connectors should be used. Unmated connectors which may contain electrically "hot" circuits while in environmentally hazardous areas should be covered with moisture proof and vapor proof caps. Connectors on enclosed cabinet mounted equipment need not be provided with protective caps unless an environmental hazard exists.

GUIDELINE 10

4.13 Connectors for round conductor flat cable. Connectors for use with flexible round conductor flat cable should conform to MIL-DTL-83503.

4.14 Fireproof connectors. Fireproof and firewall connectors should be class K and should conform to MIL-DTL-83723, MIL-DTL-38999, or MIL-DTL-5015. Where it is necessary to maintain electrical continuity for a limited time under continuous flame, both the receptacle and mating plug should be class K. If flame integrity only is necessary without the need for electrical continuity, a class K receptacle should be used, but the mating plug may be of any type and class. In all cases, the plug and receptacle should be environment resisting.

4.15 Filter pin connectors. Electrical connectors incorporating filter pins should be considered for use only when conventional electrical filters are not acceptable.

4.16 Composite connectors. Miniature composite environment resisting connectors should conform to MIL-C-29600 or MIL-DTL-38999.

4.17 Rack and panel connectors. Rack and panel connectors should conform to MIL-DTL-24308, MIL-DTL-26518, MIL-DTL-28748, and MIL-DTL-83733.

4.18 Miniature type connectors. Miniature type connectors should conform to MIL-DTL-21617, MIL-DTL-32139, and MIL-DTL-83513.

4.19 Modular component parts. Modular and component parts should conform to MIL-C-28754.

4.20 High density connectors. High density connectors should conform to MIL-DTL-28804 and MIL-DTL-38999.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 11

INSULATING MATERIALS, ELECTRICAL

1. Purpose. This guideline establishes criteria for the selection and application of electrical insulating materials. Insulating materials used for encapsulation and embedment (potting) and for conformal coating are excluded from this guideline.

2. Applicable documents The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

L-P-516	Plastic Sheet and Plastic Rod, Thermosetting, Cast.
MIL-I-631	Insulation, Electrical, Synthetic-Resin Composition, Nonrigid.
MIL-I-3158	Insulation Tape, Electrical Glass-Fiber (Resin-Filled): and Cord, Fibrous-Glass.
MIL-I-3190	Insulation Sleeving, Electrical, Flexible, Coated, General Specification for.
MIL-I-17205	Insulation Cloth and Tape, Electrical, Glass Fiber, Varnished.
MIL-I-19166	Insulation Tape, Electrical, High-Temperature, Glass Fiber, Pressure-Sensitive.
MIL-I-22076	Insulation Tubing, Electrical, Nonrigid, Vinyl, Very Low Temperature Grade.
MIL-I-22129	Insulation Tubing, Electrical, Polytetrafluoroethylene Resin, Nonrigid.
MIL-I-23264	Insulators, Ceramic, Electrical and Electronic, General Specification for.
MIL-I-24092	Insulating Varnishes and Solventless Resins for Application by the Dip Process.
MIL-I-24391	Insulation Tape, Electrical, Plastic, Pressure-Sensitive.
MIL-I-24768/2	Insulation, Plastics, Laminated, Thermosetting, Glass Cloth, Epoxy-Resin (GEE).
MIL-I-24768/3	Insulation, Plastics, Laminated, Thermosetting, Glass Cloth, Epoxy-Resin (GEB).
A-A-59770	Insulation Tape, Electrical, Pressure Sensitive Adhesive and Pressure Sensitive Thermosetting Adhesive.
SAE AMS 3638	Tubing, Irradiated Polyolefin Plastic, Electrical Insulation Pigmented, Semi-Rigid, Heat-Shrinkable, 2 to 1 Shrink Ratio.
SAE AMS 3653	Tubing, Electrical Insulation Standard Wall, Extruded Polytetrafluoroethylene (PTFE).
SAE AMS 3654	Tubing, Electrical Insulation Light Wall, Extruded Polytetrafluoroethylene (PTFE).
SAE AMS 3655	Tubing, Electrical Insulation Thin Wall, Extruded Polytetrafluoroethylene (PTFE).
ASTM D 3295	Standard Specification for PTFE Tubing, Minature Beading and Sprial Cut Tubing.
ASTM D 4388	Standard Specification for Nonmetallic Semi-Conducting and Electrically Insulating Rubber Tapes.
29 CFR 1910	Code of Federal Regulations, Title 29, Chapter XVII, Part 1910.
NEMA FI 3	Calendered Aramid Papers Used for Electrical Insulation.
NEMA RE 2	Electrical Insulating Varnish.
SAE AS 81765	Insulating Components, Molded, Electrical, Heat Shrinkable, General Specification For.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Ceramics. Ceramic insulators should conform to MIL-I-23264.

4.2 Electrical tape. Tape should be selected from the types in MIL-I-3158, A-A-59770, MIL-I-17205, MIL-I-19166, MIL-I-24391, and ASTM D 4388.

4.3 Sleeving and tubing. Sleeving and tubing should conform to MIL-I-631, MIL-I-3190, MIL-I-22076, MIL-I-22129, SAE AMS 3638, SAE AMS 3653, SAE AMS 3654, SAE AMS 3655, or ASTM D 3295. MIL-I-631 should also apply to film, film tape, and sheet and sheet tape forms of insulation.

4.4 Plastic, thermosetting, cast. When used for electrical insulation, parts fabricated from cast thermosetting plastic materials should be in accordance with L-P-516.

4.5 Plastic, thermosetting, laminated. Materials selected should conform to MIL-I-24768/2 and MIL-I-24768/3 or NEMA FI 3. The preferred base is glass cloth. Electrical insulators fabricated from laminated thermosetting-plastic

GUIDELINE 11

sheets, plates, rods, and tubes (except transparent plastics) should be treated after all machining and punching operations with a suitable moisture barrier unless the plastic has a moisture absorption of 1.0 percent or less, or is used in a hermetically sealed container.

4.6 Plastic, thermosetting, molded. Molded parts which undergo subsequent machining should be vacuum impregnated with a suitable moisture barrier material and dried after all surface-breaking operations have been completed. Cotton and linen should not be used as filler material in any electrical insulator. Materials having moisture absorption of 1.0 percent or less, and those used in hermetically sealed containers, need not be impregnated.

4.7 Varnish, electrical insulating. Insulating varnish should conform to NEMA RE 2 or MIL-I-24092.

4.8 Heat shrinkable insulators. For applications requiring heat shrinkable insulators other than sleeving, such as strain relief boots or enclosure feed throughs, the material should conform to SAE AS81765.

4.9 Polyvinyl chloride. Polyvinyl chloride insulating materials should not be used in aerospace applications. Their use in other applications requires procuring activity approval.

5. Detail guidelines.

5.1 Selection criteria. Insulating materials should be selected based upon meeting or exceeding application guidelines, such as:

a. Temperature endurance.

b. Moisture absorption and penetration.

c. Fungus resistance.

d. Dielectric strength.

e. Dielectric constant.

f. Mechanical strength.

g. Dissipation factor.

h. Ozone resistance.

i. Flammability.

5.2 Carcinogens. Certain chemicals have been identified in the Occupational Safety and Health Act (OSHA) as cancer-producing substances (carcinogens). Before using any materials which might contain these chemicals, they should be evaluated in accordance with 29 CFR 1910. Consideration of the toxicity of a substance should be given prior to material selection. Consideration of hazards should address all stages of the equipment lifecycle from fabrication to assembly, to installation, use maintenance, and decomposition during failure analysis and troubleshooting.

GUIDELINE 12

FASTENER HARDWARE

1. Purpose. This guideline establishes criteria for the selection and application of fastener hardware.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

FF-N-836	Nut: Square, Hexagon, Cap, Slotted, Castle, Knurled, Welding and Single Ball Seat.
FF-R-556	Rivet, Solid, Small; Rivet, Split, Small; Rivet Tubular, Small; Flat Washer (Burr); and Cap, Rivet; General Purpose.
FF-S-85	Screw, Cap, Slotted and Hexagon Head.
FF-S-86	Screw, Cap, Socket-Head.
FF-S-92	Screw, Machine, Slotted, Cross-Recessed or Hexagon Head.
FF-S-200	Setscrews: Hexagon Socket and Spline Socket, Headless.
FF-S-210	Setscrews: Square Head (Inch) and Slotted Headless (Inch and Metric).
FF-W-84	Washers, Lock (Spring).
FF-W-92	Washer, Flat (Plain).
FF-W-100	Washer, Lock, (Tooth).
MIL-DTL-1222	Studs, Bolts, Screws and Nuts for Applications Where A High Degree of Reliability is Required; General Specification for.
MIL-R-7885	Rivets, Blind, Structural, Mechanically Locked Spindle and Friction Locked Spindle, General Specification for.
MIL-DTL-18240	Fastener Element, Self-Locking, Threaded Fastener, 250 Deg. F Maximum.
MIL-R-24243	Rivets, Blind, Nonstructural, Retained Mandrel, General Specification for.
A-A-59313	Thread, Compound; Antiseize, Zinc Dust-Petrolatum.
AIA/NAS 498	Fasteners, Alloy Steel Externally Threaded, 95 KSI Fsu, 450 Degrees F.
AIA/NAS 547	Fastener; Rotary, Quick-Operating, High Strength.
AIA/NAS 1686	Rivet, Blind, Aluminum Sleeve, Mechanically Locked Spindle, Bulbed.
AIA/NAS 1687	Rivet, Blind, Monel and Inconel Sleeve, Mechanically Locked Spindle, Bulbed.
AIA/NASM5591	Fasteners, Panel; Nonstructural.
AIA/NASM5674	Rivets, Structural, Aluminum Alloy, Titanium Columbium Alloy, General Specification for.
AIA/NASM6812	Fasteners, Externally Threaded Alloy Steel Corrosion Resistant Steel.
AIA/NASM7838	Bolt, Internal Wrenching, 160 KSI FTU.
AIA/NASM8814	Rivets, Blind, Nonstructural Type.
AIA/NASM8831	Fasteners, Alloy Steel, 450 Degrees F Externally Threaded, 180 KSI Ftu, 108 KSI Fsu, Fatigue Rated.
AIA/NASM22978	Fastener, Rotary, Quick-Operating, High-Strength.
AIA/NASM25027	Nut, Self-Locking 250 Degrees F, 450 Degrees F, and 800 Degrees F.
AIA/NASM27384	Rivet, Blind, Drive Type.
AIA/NASM33522	Rivets, Blind, Structural, Mechanically Locked and Friction Retainer Spindle, (Reliability and Maintainability), Design and Construction Requirements for.
AIA/NASM33540	Safety Wiring, Safety Cabling, Cotter Pinning, General Practices for.
AIA/NASM33557	Nonstructural Rivets for Blind Attachment; Limitations for Design and Usage.
FED-STD-H28/2	Screw-Thread Standards for Federal Services, Section 2 Unified Inch Screw Threads - UN and UNR Thread Forms.
ASME B1.1	Unified Inch Screw Threads (UN and UNR Thread Form).
ASME B1.13M	Metric Screw Threads: M Profile.
ASME B18.2.1	Square and Hex Bolts and Screws (Inch Series).
ASME B18.3	Socket Cap, Shoulder, and Set Screws, Hex and Spline Keys (Inch Series).
ASME B18.6.3	Machine Screws and Machine Screw Nuts.
ASME B18.6.7M	Metric Machine Screws.
ASME B18.21.1	Lock Washers (Inch Series).
ASME B18.22.1	Plain Washers.
ASME B18.24	Part Identifying Number (PIN) Code System Standard for B18 Fastener Products.
ASME B18.29.1	Helical Coil Screw Thread Inserts – Free Running and Screw Locking (Inch Series).
ASTM A 325	Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength.

GUIDELINE 12

ASTM A 354	Quenched and Tempered Alloy Steel Bolts, Studs, and Other Externally Threaded Fasteners.
ASTM A 449	Standard Specification for Quenched and Tempered Steel Bolts and Studs.
ASTM A 490	Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength.
ASTM D5363	Anaerobic Single-Component Adhesives (AN).
SAE AS 8879	Screw Threads - UNJ Profile, Inch Controlled Radius Root with Increased Minor Diameter.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Threaded fasteners and related parts.

4.1.1 Threaded fasteners. ASME B18 Commercial/Industrial fastener standards covering inch and metric externally threaded, internally threaded, and non-threaded fastener products should be specified in conformance with ASME B18.24 “Part Identifying Number (PIN) Code System Standard” for B18 Fastener Products.

4.1.2 Screw threads. Screw thread selection should be based on the using applications in accordance with the following.

a. Screw threads should be in accordance with FED-STD-H28/2, ASME B1.1, or ASME B1.13M in applications where the threaded fasteners are required to mate with or mount threaded commercial equipment or devices.

b. Screw threads should be in accordance with SAE AS 8879 for applications requiring high strength or high fatigue life. (Caution should be exercised where a SAE AS 8879 UNJ external thread fastener is used due to its incompatibility with the commonly used UNC, UNF or UNEF threaded nut or tapped hole.)

c. Screw thread sizes and series for general usage should be selected in accordance with SAE AS 8879.

4.1.3 Screws. Screws should conform to the specifications listed below.

a. Machine screws should conform to FF-S-92, ASME B18.6.3, or ASME B18.6.7M.

b. Cap screws should conform to FF-S-85, FF-S-86, or ASME B18.2.1.

c. Set-screws should conform to FF-S-200, FF-S-210, or ASME B18.3.

d. Self-locking screws should conform to MIL-DTL-18240. Fiber inserts should not be used as the locking device.

4.1.4 Bolts. Bolts should conform to the specifications listed below.

a. Hex bolts should conform to one of the following specifications:
ASME B18.2.1 ASTM A 325 ASTM A 490.
ASTM A 449 ASTM A 354

b. Bolt studs should conform to MIL-DTL-1222.

c. Aircraft bolts should conform to MIL-B-6812.

d. Internal wrenching bolts should conform to MIL-B-7838.

e. High tensile strength bolts should conform to NASM-8831.

f. Shear bolts should conform to NAS498.

4.1.5 Nuts. Nuts should conform to the specifications listed below.

a. General purpose nuts should conform to FF-N-836.

b. High temperature nuts should conform to MIL-DTL-1222.

c. Self-locking nuts should conform to NASM25027.

4.1.5.1 Sheet spring nuts. Sheet spring nuts should not be used without specific approval of the procuring agency.

4.1.6 Safety wiring and cotter pins. Application of safety wiring and cotter pins should conform to NASM33540.

4.1.7 Quarter turn fasteners. Quarter turn fasteners should conform to NASM5591.

4.1.8 Rotary quick operating high strength fasteners. Rotary quick operating high strength fasteners should conform to NASM22978 or NAS 547.

4.1.9. Lock washers. Lock washers should conform to the specifications listed below.

a. Spring lock washers should conform to FF-W-84 or ASME B18.21.1.

b. Tooth lock washers should conform to FF-W-100 or ASME B18.21.1.

4.1.10 Flat washers. Flat washers should conform to FF-W-92 or ASME B18.22.1.

4.1.11 Thread-locking and retaining compounds. Thread-locking and retaining compounds should conform to ASTM D 5363.

4.1.12 Antiseize compounds. Antiseize compounds should conform to A-A-59313.

4.1.13 Helical coil. Helical coil screw thread Inserts should conform to ASME B18.29.1.

4.2 Rivets.

4.2.1 Nonstructural rivets. Nonstructural rivets should conform to the following.

a. Small solid, split, tubular, and general purpose rivets should conform to FF-R-556.

b. Nonstructural blind rivets should conform to NASM8814.

c. Blind, nonstructural, retained mandrel type rivets should conform to MIL-R-24243.

4.2.2 Structural rivets. Structural rivets should conform to the following:

a. Aluminum and Aluminum Alloy solid rivets should conform to NASM 5674.

b. Structural, blind, pull-stem rivets should conform to MIL-R-7885, NAS 1686, or NAS 1687.

c. Blind, drive type rivets should conform to NASM27384.

5. Detail guidelines.

5.1 Threaded fasteners.

5.1.1 Fastening of soft materials to soft materials. The mounting or assembly of parts made of soft materials to soft materials should be accomplished by one of the following methods:

a. A through-screw or bolt secured by a self-locking nut. or plain nut, with a lockwasher.

b. A through-screw or bolt secured by a plain nut with a thread locking compound applied to the threads of the screw or bolt and nut.

c. A screw or bolt in a threaded device such as a threaded bushing; a staked, clinched or pressed-in nut; or a threaded insert. The bushing, nut, or insert should be secured to, or should be installed in, the parent structure in accordance with the applicable procedures. The engaged length of threaded inserts in the parent material should be at least one and a half times the nominal diameter of the internal thread. Where the material thickness is insufficient to accommodate a one and a half times thread diameter insert, a shorter insert may be used in applications where maximum strength is not of primary importance; or a solid threaded bushing (which provides equal strength with less length because of the greater outside diameter of the bushing) should be used. When the screw or bolt is to be installed in an aluminum alloy part, the aluminum alloy part should be provided with threaded inserts of corrosion resistant steel or other suitable materials. When the screw or bolt is to be installed in a plastic material part, the plastic part should be provided with threaded inserts. If lock washers or self-locking threaded inserts are not used, a thread-locking compound in accordance with 4.1.11 should be applied to the threads of the screw or bolt.

d. A screw or bolt in a tapped hole, with a thread-locking compound in accordance with 4.1.11 applied to the threads of the screw or bolt.

e. A stud in a tapped hole. Self-locking nuts should be avoided on stud-mounted components, unless the stud material is compatible with the strength and material of the nut used.

5.1.2 Fastening of hard materials to soft materials. In addition to the methods outlined in 5.1.1, a screw or bolt with a lockwasher may be used in a threaded bushing, staked, clinched or pressed-in nut, threaded insert or tapped hole.

5.1.3 Fastening of soft materials to hard materials. In addition to the methods outlined in 5.1.1, a self-locking screw or bolt may be used in a hole tapped into the hard material. Self-locking screws or bolts with nonmetallic locking devices should not be used where the specified service conditions or processing, such as baking of paints or soldering, might deteriorate the locking device.

5.1.4 Fastening of hard materials to hard materials. Any of the methods outlined in 5.1.1 through 5.1.3 may be used.

5.1.5 Fastening of brittle materials. Brittle castings or parts made of ceramic or other brittle materials should be properly cushioned when necessary to prevent breakage. Washers or gaskets of suitable material and compressibility should be used between the facing surfaces of the brittle part and other brittle or metal parts, when practicable, to prevent breakage or damage to the protected parts during assembly or from severe shock, vibration, or temperature changes encountered under the specified service conditions. Lead washers should not be used. Parts that are secured with threaded devices and pliable washers should not use lockwashers as the locking device and other appropriate locking devices should be considered.

5.1.6 Fastening with aluminum alloy or magnesium fasteners. The use of threaded fasteners made of aluminum alloy or magnesium to mate with threaded parts of aluminum alloy or magnesium should be avoided wherever possible. Where such is required, an antiseize compound in accordance with 4.1.12 should be used to prevent seizing of the threads.

5.1.7 Flat washers. Flat washers should be used for the following applications:

a. Between screw heads and soft materials, unless a washer head screw, or similar type that provides a bearing surface equivalent to the bearing surface of the appropriate flat washer, is being used.

b. Between a nut or lockwasher and a soft material.

c. Where lockwashers are used for securing a soft material, a flat washer should be provided to prevent marring or chipping of the material or the applied protective coating, except in areas where an electrical ground is required.

d. Except where it conflicts with electromagnetic interference considerations, a flat washer should be used between an organically finished material and lock-washers, bolt and screw heads, or nuts.

5.1.8 Thread engagement. The length of the screws and bolts installed with nuts should be such that the exposed portion is a minimum length equivalent to one and a half thread pitches plus the chamber. Maximum length should be limited by the nearest larger standard screw length. For highly stressed applications, screws or bolts should have a minimum thread engagement of one and a half times their nominal diameter in tapped parts other than nuts. In normal applications, screws or bolts should have a minimum engagement length equal to their nominal diameter in tapped parts other than nuts. When the assembly is not frequently disassembled and where maximum strength is not required, less thread engagement may be used.

5.2 Rivets. Rivets should be used in preference to other hardware for securing parts not requiring removal. Wherever the thickness of metal which accepts the heads of flush rivets is less than the height of the rivet heads, the material should be dimpled rather than countersunk. The distance from the center of rivet holes to the edges of the material, in which the rivets are placed, should not be less than one and a half times the rivet diameter. Design and limitations of rivets should be in accordance with NASM33522 and NASM33557. Rivets for joining magnesium parts should be composition 5056 anodized aluminum alloy or an aluminum alloy having equal galvanic compatibility with the magnesium being used.

5.3 Other fastening methods.

5.3.1 Set screws. One set screw may be used on a flatted shaft. Two set screws at 90° to 120° displacement should be used when the shaft is not flatted. Cone-point set screws should not be used, except when the opposing metal has been properly countersunk to receive the cone-point.

5.3.2 Access devices. Fasteners for use with access devices should be readily removable for replacement purposes without damaging the attached panel or access door.

5.3.2.1 Nonstructural applications. Quarter-turn fasteners should be used only to retain nonstructural access to devices where quick access is required.

5.3.2.2 Structural applications. Rotary, quick-operating, high strength panel fasteners should be used to retain structural access devices where quick access is required.

5.3.2.3 Threaded fasteners. Threaded fasteners used with access devices should be self-aligning, captive type hardware.

5.3.3 Screw threaded device applications.

5.3.3.1 Screws or bolts without nuts. Applications requiring the use of screws or bolts without nuts should use one of the following screw locking methods:

a. Lockwashers under the heads of the screws or bolts.

b. Self-locking screws.

c. Self-locking threaded inserts.

d. A locking or retaining compound in accordance with 4.1.11 applied to the threads.

e. Safety wire through drilled heads in accordance with 4.1.6.

5.3.3.2 Countersunk head screws. Countersunk head screws, when not secured by other locking means, should be secured by the application of a thread-locking compound in accordance with 4.1.11. Staking by means of upsetting metal is acceptable for permanent assemblies when other means are impracticable or unsatisfactory for design reasons.

5.3.3.3 Thread-forming, thread-cutting, and drive screws. Thread-forming, thread-cutting, and drive screws should not be used except for attaching identification plates.

5.3.3.4 Safety wiring and cotter pins. Safety wiring and cotter pins should not be used on terminals such as screws and threaded studs that are required to function as electrical terminals.

5.3.3.5 Thread-locking and retaining compounds. Thread-locking and retaining compounds should not be used where required electrical conductivity is impaired or failure of the compound would endanger personnel or damage the equipment.

GUIDELINE 13

STRUCTURAL WELDING

1. Purpose. This guideline establishes criteria for structural welds. Welded electrical connections are excluded from this guideline.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-STD-22	Welded Joint Design.
MIL-HDBK-730	Materials Joining.
MMPDS	Metallic Materials Properties Development and Standardization.
TACOM DWG 12479550	Arc Welding Procedures for Constructional Steel.
AWS-D 17.	Specification for Fusion Welding for Aerospace Applications.
AWS A2.4	Standard Symbols for Welding, Brazing, and Nondestructive Examination.
AWS A3.0	Standard Welding Terms and Definitions Including Terms for Adhesive Bonding, Brazing, Soldering, Thermal Cutting, and Thermal Spraying.
SAE AMS 2680	Electron Beam Welding, for Fatigue Critical Application.
SAE AMS 2681	Welding, Electron-Beam.
SAE AMS W 6858	Welding, Resistance: Spot and Seam.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Arc and gas welding. Welding by arc and gas methods should be performed by operators who have passed the applicable certification tests and have a certificate of proficiency in accordance with AWS-D17.1. Welding of aluminum, magnesium, and steel alloys should conform to AWS-D17.1.

4.2 Resistance welding. Resistance welding of joints should conform to SAE AMS-W-6858.

5. Detail guidelines

5.1 Welding. The joint areas of all parts to be welded should be cleaned of contaminants and materials which may be detrimental to obtaining satisfactory welds. Degradation of material properties in the heat affected zone caused by welding should be considered. Weldments should be stress relieved when induced stress resulting from welding, design configuration, or materials welded may be harmful. See AWS A2.4 for welding symbols, AWS A3.0 for welding terms and definitions, and MIL-STD-22 for welded joint designs. MIL-HDBK-730 provides guidance in this field of materials joining and its related processes.

5.2 Resistance welding. MMPDS may be used as a guide for spot-to-sheet edge distances and allowable strengths.

5.3 Noncritical applications. In ground equipment applications, welding procedures in accordance with Tacom Drawing 12479550 may be used where, if the weld should fail, it will not compromise personnel or equipment safety or prevent completion of the mission.

5.4 Other methods. Other welding methods, such as the electron beam process of SAE AMS 2680 and SAE AMS 2681, may be used provided approval is obtained from the procuring activity.

GUIDELINE 14

TRANSFORMERS, INDUCTORS, AND COILS

1. Purpose. This guideline establishes criteria for the selection and application of transformers, inductors, and coils.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-PRF-27	Transformers and Inductors (Audio, Power, and High-Pulse), General Specification for
MIL-PRF-15305	Coils, Fixed and Variable, Radio Frequency, General Specification for
MIL-PRF-21038	Transformers, Pulse, Low Power, General Specification for
MIL-PRF-39010	Coils, Radio Frequency, Fixed, Molded, Established Reliability, General Specification for
MIL-PRF-83446	Coils, Radio Frequency, Chip, Fixed or Variable, General Specification for
MIL-T-55631	Transformer, Intermediate Frequency, Radio Frequency, and Discriminator, General Specification for
MIL-T-83721	Transformers, Variable, Power, General Specification for
MIL-STD-981	Design, Manufacturing and Quality Standards for Custom Electromagnetic Devices for Space Applications

3. Definitions. This section not applicable to this guideline.

4. General Guidelines.

4.1 Selection. Selection of transformers, inductors, and coils should be in accordance with the following sections.

4.1.1 Transformers and Inductor. Power transformers, power inductors, audio transformers, audio inductors, high power pulse transformers, charging inductors, saturable transformers and saturable inductors should conform to MIL-PRF-27.

4.1.2 Coils, radio frequency, fixed and variable. Coils, radio frequency, fixed and variable should conform to MIL-PRF-15305.

4.1.3 Transformers, pulse, low power. Low power pulse transformers should conform to MIL-PRF-21038.

4.1.4 Coils, radio frequency, fixed, molded, established reliability (ER). ER and non-ER fixed, radio frequency, molded coils should conform to MIL-PRF-39010.

4.1.5 Coils, radio frequency, chip, fixed or variable. Requirements for fixed or variable, chip coils should conform to MIL-PRF-83446.

4.1.6 Intermediate, radio frequency, and discriminator transformers. Intermediate, radio frequency, and discriminator transformers should conform to grade 1, 2, or 4 of MIL-T-55631. The use of grade 3 transformers should be limited to hermetically sealed or encapsulated assemblies.

4.1.7 Variable transformers. Variable transformers should conform to MIL-T-83721.

4.1.8 Custom electromagnetic devices for space applications. Custom electromagnetic devices for space applications should conform to MIL-STD-981.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 15

METALS, CORROSION RESISTANCE

1. Purpose. This guideline establishes criteria for the selection and treatment of metals as related to their ability to resist corrosion.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-STD-889 Dissimilar Metals

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Corrosion resistant. Metals should be corrosion resistant or should be coated or metallurgically processed to resist corrosion.

4.2 Metallic parts. Materials and processes for metallic parts should conform to applicable requirements in MIL-STD-889.

5. Detail guidelines.

5.1 Selection of metals. The environmental severity to which the equipment will be exposed should be considered in selection of metals.

5.2 Noncorrosion resistant. The use of noncorrosion resistant steel alloys, except where specifically required for electronic purposes, should be kept to a minimum.

GUIDELINE 16

DISSIMILAR METALS

1. Purpose. This guideline establishes criteria for the selection and protection of dissimilar metal combinations and other significant corrosion behavior factors.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-STD-889	Dissimilar Metals

3. Definitions. This section not applicable to this guideline.

4. General Guidelines.

4.1 Selection of metals. Selection of metals for use in electronic equipment should be made in accordance with the requirements of MIL-STD-889.

5. Detail Guidelines.

5.1 Incompatible Metal. Where electronic design requirements preclude the insulation of incompatible metal combinations as identified in MIL-STD-889 from one another, specific attention should be paid to isolating the combination from exterior environments.

GUIDELINE 17

PRINTED WIRING

1. Purpose. This guideline established criteria for the design and treatment of printed wiring assemblies.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-HDBK-1861	Selection and Use of Electrical and Electronic Assemblies, Boards, Cards, and Associated Hardware.
ANSI/IPC-D-322	Guidelines for Selecting Printed Wiring Board Sizes Using Standard Panel Sizes.

3. Definitions. This section not applicable to this guideline.

4. General Guidelines.

4.1 Rigid printed wiring and printed wiring boards. Rigid printed wiring and printed wiring boards for single-sided, double-sided, and multilayer printed wiring should conform to MIL-HDBK-1861. The materials used for single-sided, double-sided, and multilayer printed wiring boards should conform to MIL-HDBK-1861.

4.2 Rigid printed wiring assemblies. Rigid printed wiring assemblies consisting of rigid printed wiring boards, on which separately manufactured parts have been added, should conform to MIL-HDBK-1861.

4.3 Conformal coating. When conformal coating is required, rigid printing wiring assemblies should be conformally coated with a coating material which conforms to MIL-HDBK-1861.

4.4 Flexible and rigid-flex printed wiring. Flexible and rigid-flex printed wiring should conform to MIL-HDBK-1861 and should be designed in accordance with MIL-HDBK-1861.

4.5 Discrete wiring boards. Discrete wiring boards with plated-through holes should be in accordance with MIL-HDBK-1861.

4.6 Backplane assemblies, printed wiring. Electrical backplane printed wiring assemblies should conform to MIL-STD-1861 and should be designed in accordance with MIL-STD-1861.

5. Detail guidelines.

5.1 Printed wiring board size. Guidelines for the selection of printed wiring board sizes are delineated in ANSI/IPC-D-322.

GUIDELINE 18

DERATING OF ELECTRONIC PARTS AND MATERIALS

1. Purpose. This guideline establishes criteria for derating of electronic parts and materials.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-HDBK-1547	Electronic Parts, Materials, and Processes for Space and Launch Vehicles

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Derating. In the application of electronic parts and materials, the parts and materials selected should be used within their electrical ratings and environmental capabilities; (e.g., any ambient or hot spot temperatures, voltage, current, or power dissipation). Derating should be accomplished as necessary to ensure the required equipment reliability within the specified operating conditions.

4.2 Derating for launch vehicles and space systems. Electronic parts and materials used in launch vehicles or space systems should be derated in accordance with the guidelines of MIL-HDBK-1547.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 19

TERMINATIONS

1. Purpose. This guideline establishes criteria for the selection and application of terminations.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-DTL-15659	Terminal, Lug; Solder, Copper and Phosphor Bronze.
MIL-T-55156	Terminals, Lug, Splices, Conductor; Screw Type, General Specification for.
MIL-HDBK-1277	Splices, Chips, Terminals, Terminal Boards, Binding Posts, Electrical.
A-A-59125	Terminal Boards, Molded, Barrier Screw and Stud Types and Associated Accessories.
SAE AS 7928	Terminals, Lug: Splices, Conductor: Crimp Style, Copper, General Specification for.
SAE AS 27212	Terminal Board Assembly, Molded-In- Stud, Electric.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Terminals. Lug terminals, stud terminals, feed-through terminals, and binding posts should be selected from MIL-HDBK-1277.

4.1.1 Lug terminals. Lug terminals should conform to one of the following specifications:

MIL-DTL-15659	Solder
MIL-T-55156	Screw

4.1.2 Number of wires per terminal or lug. The number of wires terminated in an individual terminal or lug should not be greater than three. Multisection turret, bifurcated, or multi-hole lug terminals should have not more than three wires per section, tong, or hole. In no case should the total cross sectional area of the terminated wires exceed the cross sectional area capacity of the terminal or lug. If a greater number of wires are required than those specified herein, approval of the procuring activity should be obtained.

4.2 Terminal boards. Terminal boards should be selected from MIL-HDBK-1277.

4.2.1 Number of lugs per terminal. The maximum number of lugs to be connected to any one terminal on a terminal board should be two for screw-type terminal boards covered by A-A-59125 and as specified in the specification sheets for stud-type terminal boards. Not more than four lugs should be connected to any one terminal of a board covered by SAE AS27212. Accessories such as stud connectors, straddle plates, jumpers, and terminal board lugs should be counted as lugs for this purpose.

4.3 Terminal junction systems. Terminal junction systems should be selected from MIL-HDBK-1277.

5. Detail guidelines.

5.1 Crimping. Crimping of terminal lugs should be so accomplished that the connections will meet the resistance (voltage drop), and tensile strength requirements, and tests of SAE AS 7928.

GUIDELINE 20

WIRE, HOOKUP, INTERNAL

1. Purpose. This guideline establishes criteria for the selection and application of electrical internal hookup wire.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-DTL-16878	Wire, Electrical, Insulated, General Specification for.
MIL-DTL-81381	Wire, Electric, Polyimide-Insulated, Copper or Copper Alloy.
A-A-59551	Wire, Electrical, Copper (Uninsulated).
MIL-STD-681	Identification Coding and Application of Hook-Up and Lead Wire.
ASTM B 298	Standard Specification for Silver-Coated Soft or Annealed Copper Wire.
SAE AS 22759	Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy.
SAE AS 50861	Wire, Electric, Polyvinyl Chloride Insulated, Copper or Copper Alloy.
SAE AS 81044	Wire, Electric, Crosslinked Polyalkene, Crosslinked Alkane-Imide Polymer, or Polyarylene Insulated, Copper or Copper Alloy.
SAE AS81822	Wire, Electrical, Solderless Wrap, Insulated and Uninsulated.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Selection. Internal hookup wire should be selected from the types and classes specified by the documents listed in table 20-I. For solderless wrap applications, wires should be selected which are in accordance with MIL-W-81822.

4.1.1 MIL-DTL-16878 usage. MIL-DTL-16878 should not be used for Air Force or Navy aerospace applications.

4.1.2 SAE AS 22759 usage. SAE AS 22759 wire with only single polytetrafluoroethylene insulation used in Air Force space and missile applications should require the approval of the procuring activity.

4.1.3 Insulation restriction. Wires with polyvinyl chloride insulation should not be used in aerospace applications. Use of these wires in any other application requires prior approval of the procuring activity.

4.1.4 Silver plated copper wire. Silver plated copper wire should not be used in applications involving Army missile systems without certification by the wire manufacturer that it passes the sodium polysulfide test in accordance with ASTM B 298. Silver plated copper wire should not be used in conjunction with water-soluble solder fluxes. Wire should be stored and handled in such a way so as to minimize exposure to moisture.

4.2 Identification. Hookup wires in the equipment should be, insofar as practicable, distinctly coded in color or numbered. Short hookup wire, 150 mm or less between termination points, need not be marked if the path of the short wire can be easily and visually traced. The unmarked wire must be specified on the drawing. Codes, when used, should be in accordance with MIL-STD-681 or as otherwise agreed upon with the procuring activity. Numbers should not be used where they would be difficult to read or trace, such as in compact assemblies.

4.3 Bare wire. Bare hookup wire should be type H, class S, soft or drawn and annealed, and coated, and should conform to A-A-59551. Bare hookup wire should not be used unless insulated wire is impractical because of circuit characteristics or shortness of wire run.

5. Detail guidelines.

5.1 Solid or stranded. Stranded wire should be used for conductors and cables which are normally flexed in use and servicing of the equipment, such as cables attached to the movable half of detachable connectors and hanging cables attached to removable or movable doors and shields. Leads 150 mm or less in length may be run as solid wires unless they form interconnections between shock isolation mounted parts and non-shock isolation mounted parts. There are some other instances, such as wire wrapping, where a solid conductor may be required regardless of length.

5.2 Cold flow. Certain insulating materials exhibit a cold flow characteristic. Caution should be used in the selection of these materials in applications requiring restrictive clamping or tying, etc., where this feature may result in exposed or shorted conductors.

5.3 Stranded copper conductor test. The following test procedure should be used for stranded conductors since the ASTM B 298 procedure covers only a single, round conductor.

5.3.1 Sodium polysulfide test. Stranded samples of annealed copper or copper alloy conductors should be tested in accordance with ASTM B 298. When this test is performed, one factor which should be taken in to consideration is that the ASTM test applies to single end wires taken before stranding. Thus, the applicability of the polysulfide test is restricted by the ASTM in recognition of the abrasion to the wire inherent in the stranding process. As a result, the following exceptions and criteria apply when testing stranded product:

a. Examination of the samples to occur immediately after the solution cycle.

b. Samples to be immersed into the solution in the as-stranded condition.

(1) Unilay constructions to be tested as the whole conductor.

(2) Concentric constructions to be tested as whole conductor.

(3) Two members from each layer of rope constructions to be tested after they have been carefully removed from the finished rope.

GUIDELINE 20

TABLE 20-I. Wire, electrical

Spec no	Title	Construction: Spec type or class	Material	Conductor Coating 1/	Type	Primary	Insulation Primary Cover 2/	Jacket topcoat	Max Cond temp °C	Max rms volts
MIL-W-5086	Wire, Electric, Polyvinyl Chloride Insulated, Copper or Copper Alloy	SAE AS 50861						8	105	600
		SAE AS 50861	Cu/A	Sn				8, 11		
		SAE AS 50861			Str	1		8	110	3000
		SAE AS 50861	HSA	Ag				9A		
		SAE AS 50861								600
		SAE AS 50861	Cu/A	Sn				8	105	
MIL-DTL-16878 See Note 4	Wire, Electrical, Insulated	M16878/1								600
		M16878/2	Cu/A, HSA, CCW	Ag, Sn		1	8,10,11	1,8,10, 11	105	1000
		M16878/3								3000
		M16878/4						3/ 3A, 3B, 4A, 13B		600
		M16878/5				3A				1000
		M16878/6		Ag					200	250
		M16878/7	Cu/A			6	4A,8,10, 11			600
		M16878/8						4A,8,10, 11		1000
		M16878/10		Sn		2A	8,10,11		75	600
		M16878/11	Cu/A, CCW	Ag						
		M16878/12				4A		4A	200	1000
		M16878/13								250
		M16878/14		Ag,Sn	S,Str					600
		M16878/15	Cu/A	Sn		2C			125	1000
		M16878/16								600
		M16878/17								3000
		M16878/18		Ag, Sn		1		8	105	1000
		M16878/19								3000
		M16878/20								250
		M16878/21		Ag		3B			200	600
		M16878/22	Cu/A HSA CCW							1000
		M16878/23				3A		3/ 3A, 3B, 4A 13B		250
		M16878/24				3B				
		M16878/25		Ni		3A			260	600
		M16878/26				3B				
		M16878/27				3A				1000

Spec no	Title	Construction							Max Cond temp °C	Max rms volts
		Spec type or class	Material	Conductor Coating 1/	Type	Primary	Insulation Primary Cover 2/	Jacket topcoat		
		M16878/28				3B				
		M16878/29								600
		M16878/30	Cu/A	Sn	Str	6			150	
		M16878/31								1000
		M16878/32		Ag					200	
		M16878/33	Cu/A CCW	Sn	S, Str	2A			75	600
		M16878/34	Cu	Ag	Str	3B			200	
		M16878/35		Ni					260	1000
SAE-AS22759 See Note 4	Wire, Electrical, Fluoropolymer Insulated, Copper or Copper Alloy	M22759/9		Ag					200	1000
		M22759/10		Ni					260	
		M22759/11	Cu/A	Ag		3A			200	
		M22759/12		Ni					260	
		M22759/14		Sn		4A		9B	135	
		M22759/15	HSA	Ag						
		M22759/16	Cu/A	Sn					150	600
		M22759/17	HSA	Ag						
		M22759/18	Cu/A	Sn		17				
		M22759/19		Ag						
		M22759/21		Ni	Str				260	1000
		M22759/22	HSA	Ag					200	
		M22759/23		Ni		3A			260	
		M22759/31						7		
		M22759/32	Cu/A	Sn					150	
		M22759/33	HSA	Ag					200	600
		M22759/34	Cu/A	Sn					150	
		M22759/35	HSA	Ag		21				
		M22759/41	Cu/A	Ni						
		M22759/42	HSA					21	200	
		M22759/43	Cu/A	Ag						
SAE-AS81044 See Note 5	Wire, Electric, Crosslinked Poly- alkene, etc.	AS81044/12	Cu/A	Sn	Str	2B		9B	150	600
		AS81044/13	HSA	Ag						

GUIDELINE 20

Spec no	Title	Construction							Max Cond temp °C	Max rms volts
		Spec type or class	Material	Conductor Coating 1/	Type	Primary	Insulation Primary Cover 2/	Jacket topcoat		
	Insulated									
MIL-DTL-81381 See Note 6	Wire, Electric, Polymide-Insulated, Copper or Copper Alloy	M81381/7	Cu/A	Ag	Str	19		20	200	600
		M81381/8		Ni						
		M81381/9	HSA	Ag			4B			
		M81381/10		Ni						
		M81381/11	Cu/A	Ag						
		M81381/12		Ni						
		M81381/13	HSA	Ag						
		M81381/14		Ni						
		M81381/17	Cu/A	Ag						
		M81381/18		Ni						
		M81381/19	HSA	Ag						
		M81381/20		Ni						
		M81381/21	Cu/A	Sn					150	
		M81381/22								

GUIDELINE 20

TABLE 20-I. Wire, electrical - Continued.

1/ Conductor Code		Description
Material	Cu/A	Copper, annealed
	Cu/H	Copper, hard drawn
	CCW	Copper, covered steel
	HAS	High strength copper alloy
	A1	Aluminum
Coating	Sn	Tin
	Ag	Silver
	Ni	Nickel
Type	S	Solid
	Str	Stranded

2/ Insulation Code	Description
1	Polyvinyl chloride/extruded
2A	Polyethylene/extruded
2B	Polyalkene/cross-linked/extruded
2C	Polyethylene/cross-linked/modified/extruded
3A	Polytetrafluoroethylene/extruded (TFE teflon)
3B	Polytetrafluoroethylene/tape
3C	Polytetrafluoroethylene/mineral filled/extruded
4A	Fluorinated ethylene propylene/extruded (FEP teflon)
4B	Fluorinated ethylene propylene/dispersion
6	Silicone rubber/extruded
7	Polyimide lacquer (Pure ML)
8	Polyamide/extruded (Nylon)
9A	Polyvinylidene fluoride/extruded (Kynar)
9B	Polyvinylidene fluoride/extruded/cross-linked
10	Braid/synthetic yarn/lacquer impregnated
11	Braid/nylon/impregnated
13A	Braid/glass fiber/impregnated
13B	Braid/TFE coated glass fiber/TFE finish
17	ETFE fluoropolymer
19	Fluorocarbon/polyimide tape
20	Modified aromatic polyimide resin
21	Ethylene-tetrafluoroethylene/cross-linked/modified/extruded

3/ When specified on purchase order.

4/ Various combinations of primary, primary cover, and jacket insulations, and unshielded, shielded, etc., constructions are available to meet application requirements. See wire specifications.

5/ See application temp limitation on spec sheet.

6/ /11, /12, and /22 have a bright aromatic poly-amide braid with clear finisher coatings on 8 AWG and larger.

GUIDELINE 21

CASTINGS

1. Purpose. This guideline establishes criteria for the design, classification, inspection, and repair of castings.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-STD-276	Impregnation of Porous Metal Castings And Powdered Metal Components.
SAE AMS-STD-2175	Castings, Classification and Inspection of.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Die castings. Die castings should not be used where the casting might be subject to impact. Zinc alloy die castings should not be used where dimensional changes of the casting could affect use of equipment.

4.2 Porous castings. When required, castings should be impregnated in accordance with MIL-STD-276.

4.3 Classification and inspection. Castings should be classified and inspected in accordance with SAE AMS-STD-2175.

4.4 Inserts. Inserts, which are intended to be cast in place, should be knurled, grooved, or otherwise prepared to secure satisfactory keying of the insert to the casting. Inserts should be fabricated from a material which is not adversely affected by exposure to the molten casting alloy. When inserts are located near a casting edge, sufficient edge distance should be allowed in order to develop the required resistance to insert pull-out, and to avoid cracking of the casting. Casting defects resulting from use of inserts, such as partial alloying, poor bonds, porosity, and cracks should not be present.

5. Detail guidelines.

5.1 Selection and application. In any design utilizing metallic castings, consideration should be given to intended application, the availability of molding and casting alloys, the choice of a suitable casting process (see table 21-I), and the use of ribs and fins.

GUIDELINE 21

TABLE 21-I. General comparison of metallic casting processes.

Type of castings	Dimen-sional accuracy	Ability to reproduce fine detail	Tool cost	Suitability for volume production	Surface smooth-ness	Suitability for large sized castings
Sand	3	3	1	3	3	1
Die	1	1	3	1	1	3
Investment	1	1	3	2	1	3
Shell mold	2	2	3	1	2	3
Permanent mold	2	2	3	1	2	2
Plaster mold	2	1	1	3	2	3

NOTE: 1 = Very good; 2 = good; 3 = fair

5.2 Repair of unmachined castings. Repair of minor discontinuities or defects in unmachined or raw castings should be permitted only when specific approval has been granted by the contractor Material Review Board (MRB), or is specified on the engineering documentation. Weld repair should be limited to class 3 and class 4 castings (class 1 and class 2 repair should require procuring activity approval) and to areas where no severe stress will be encountered. Heat treatable alloys should be fully reheat treated after welding to meet drawing guidelines.

5.3 Repair of machined castings. Repair of defects in machined castings should be permitted for class 3 and class 4 castings based on the contractor's MRB decision. Class 1 and class 2 casting repair should require procuring activity approval. Reheat treatment should be required unless engineering analysis during MRB action can demonstrate it is unnecessary.

GUIDELINE 22

PARTS MANAGEMENT

1. Purpose. This guideline offers guidance as to parts management and selection which may be considered when preparing contractual documents. Parts management and selection should be directly specified in the contract or the system/equipment specification, as appropriate.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-STD-3018	Parts Management.
SD-19	Life Cycle Cost Savings Through Parts Management.
AIAA R-100	Recommended Practice for Parts Management.

3. Definitions. This section not applicable to this guideline.

4. General guidelines. This section not applicable to this guideline.

5. Detail guidelines.

5.1 Parts management program. SD-19 provides Government and industry managers a pragmatic approach toward parts management to keep weapon system acquisition cost, total ownership cost, and supportability cost at a manageable level. When used in conjunction with MIL-STD-3018, “Parts Management”, the guidance herein will help achieve successful parts management support to acquisition strategy. This document offers guidance to individuals who are defining parts management needs in contracts; establishing a parts management process for prime contractors, suppliers, and subcontractors; and looking for an efficient and a manageable part selection process. MIL-STD-3018 establishes procedures covering the submission, review, and approval of Program Parts Selection Lists, and changes thereto. The objective is to achieve life cycle cost savings and cost avoidances by:

a. Assisting equipment or system managers and their contractors in the selection of parts commensurate with contractual requirements.
b. Minimizing the variety of parts used in new design.
c. Enhancing interchangeability, reliability, and maintainability of military equipment and supplies.
d. Conserving resources.
e. Assuring long term availability of parts. MIL-STD-3018should be tailored when applied; application guidance is offered in the document.

5.2 Parts management program for spacecraft and launch vehicles. (Not applicable to NASA programs.) AIAA-R-100 establishes the criteria and guidelines for the preparation and implementation of a Parts, Materials, and Processes Standardization Control and Management Program for use during the design, development, fabrication, and test of spacecraft and launch vehicles. The implementation of this handbook is intended to:

a. Ensure total, integrated, and coordinated management of the selection, application, procurement, and standardization of parts, materials and processes.
b. Reduce program costs.
c. Improve the standardization and reliability of program parts, materials, and processes.
d. Assure long term availability of parts.

GUIDELINE 23

ADHESIVES

1. Purpose. This guideline establishes guidance for the selection and application of adhesives.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MMM-A-121	Adhesive, Bonding, Vulcanized Synthetic Rubber to Steel.
MMM-A-132	Adhesives, Heat Resistant, Airframe Structural, Metal to Metal.
MMM-A-134	Adhesive, Epoxy Resin, Metal to Metal Structural Bonding.
MMM-A-138	Adhesive, Metal to Wood, Structural.
MMM-A-181	Adhesives, Phenol, Resorcinol, or Melamine Base.
MMM-A-189	Adhesive, Synthetic-Rubber, Thermoplastic, General Purpose.
MIL-A-3920	Adhesive, Optical, Thermosetting.
MIL-A-22397	Adhesive, Phenol and Resorcinol Resin Base (for Marine Service Use).
MIL-A-24179	Adhesive, Flexible Unicellular-Plastic Thermal Insulation.
MIL-A-46146	Adhesive-Sealants, Silicone, RTV, Non Corrosive (For Use With Sensitive Metals and Equipment).
MIL-HDBK-691	Adhesive Bonding.
29 CFR 1910	Code of Federal Regulations, Title 29, Chapter XVII, Part 1910.
A-A-1936	Adhesives, Contact, Neoprene Rubber.
A-A-3097	Adhesives, Cyanoacrylate, Rapid Room Temperature-Curing, Solventless.
SAE AMS-A-8576	Adhesive, Acrylic Base, for Acrylic Plastic.
SAE AMS-A-25463	Adhesive, Film Form, Metallic Structural Sandwich Construction.

3. Definitions. This section not applicable to this guideline.

3.1 Adhesives. Adhesives are substances capable of holding materials together by surface attachment. Adhesive is a general term and includes, among others, cement, glue, mucilage, and paste. All of these terms are loosely used interchangeably.

4. General guidelines. This section not applicable to this guideline.

5. Detail guidelines.

5.1 Design of joint. The joint should be designed to minimize concentrations of stress. The basic stress should be in shear. The weakest design is where the basic stress is in cleavage or peel and nonaxial loading in tension produces cleavage.

5.2 Deleterious effects. The user should ascertain that the formulation of the adhesive selected will have no deleterious effects on the bonded assembly or nearby items when the bonded assembly is in storage, transit, or use under the environmental conditions for which it was designed. Deleterious effects may be caused by the slow release of trapped solvents which can damage many types of rubber and plastic, or cause other harmful results degrading operation of the equipment.

5.3 Application. Care should be taken to avoid starved joints which are the result of either absorption of adhesive by a porous material, poor application, inadequate coverage, or excessive pressure. Where one or both of the adherents are porous, successive thin coats of adhesive should be applied to completely seal the surface, and each coat should be dry before the next coat is applied. This procedure should be used instead of the application of one thick adhesive coat to the porous surface, except in the case of silicone adhesives. In general, the thicker the adhesive layer, the lower the shear resistance, but the higher the strength to impact and peeling.

5.4 Structural compatibility. Adhesives which are not compatible structurally should be avoided. For example, a brittle adhesive should not be used for glass bonding because excessive shrinkage during setting or curing will load the glass in tension. For assemblies which may be flexed or subject to impact, a brittle adhesive should not be used.

GUIDELINE 23

5.5 Carcinogens. Certain chemicals have been identified in the Occupational Safety and Health Act (OSHA) as cancer producing substances (carcinogens). Before using any materials which might contain carcinogens, they should be evaluated in accordance with 29 CFR 1910. Consideration of the toxicity of a substance should be given prior to material selection.

5.6 Thermoplastic. All thermoplastic adhesives have a tendency to creep under load, especially at elevated temperature, and should not be used in critical structural applications. Many thermoplastic adhesives have limited or poor resistance to certain solvents.

5.7 Materials to be bonded. The materials to be bonded assume critical importance as there are some materials, such as fluorocarbon, polyethylene, and nylon that cannot be bonded satisfactorily without prior treatment, special adhesives, or both.

5.8 Guide for selection and application. The following, although not a complete list, may be used as a guide in selecting adhesives and bonding procedures to meet design guidelines in electronic equipment.

MMM-A-121	MIL-A-3920	A-A-1936
MMM-A-132	MIL-A-22397	A-A-3097
MMM-A-134	MIL-A-24179	SAE AMS-A-8576
MMM-A-138	MIL-A-46146	SAE AMS-A-25463
MMM-A-181	MIL-HDBK-691	
MMM-A-189		

Many of these specifications have no requirements pertaining to electrical properties. Where electrical properties are important, the suitability of the material for the application should be established.

GUIDELINE 24

WELDS, RESISTANCE, ELECTRICAL INTERCONNECTIONS

1. Purpose. This guideline establishes criteria for resistance welds of electrical and electronic interconnections and part leads. This guideline does not include structural welds.

2. Applicable documents. This section not applicable to this guideline.

3. Definitions. This section not applicable to this guideline.

4. General guidelines. This section not applicable to this guideline.

5. Detail guidelines.

5.1 Contaminants. All surfaces of leads, or parts, to be welded should be free of contaminants which would adversely affect forming of the welded joint.

5.2 Electrical connections. Except where needed to meet electromagnetic interference or system compatibility guidelines, welded electrical connections should not be used where it may be necessary to disconnect, replace, or reconnect a part or module during servicing.

5.3 Excess conductor wire. Excess conductor wire should be trimmed sufficiently close to provide adequate clearance to prevent possible electrical shorting but not so close as to cause damage to the welded joint.

5.4 Strain relief. Each part lead terminating at a connection point should have allowance for strain relief to minimize tensile or shear stress.

GUIDELINE 25

ELECTRICAL POWER

1. Purpose. This guideline establishes criteria for electrical power.

2. Applicable documents.

MIL-STD-704	Aircraft Electric Power Characteristics.
MIL-STD-1275	Characteristics of 28 Volt DC Electrical Systems in Military Vehicles.
MIL-STD-1399	Interface Standard for Shipboard Systems.
MIL-HDBK-411	Power and The Environment for Sensitive DoD Electronic Equipment.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Airborne. The electrical power guidelines for airborne and associated equipment should be in accordance with MIL-STD-704.

4.2 Shipboard. The electrical power guidelines for shipboard and associated equipment should be in accordance with type I or type II of section 300 of MIL-STD-1399.

4.3 Ground vehicles. The electrical power guidelines for military ground vehicles should be in accordance with MIL-STD-1275.

5. Detail guidelines.

5.1 Critical fixed communications and related automatic data processing facilities. MIL-HDBK-411 provides the electrical power guidelines for critical communications and related automatic data processing equipment and should be for a nominal -48 V dc uninterruptible power supply.

GUIDELINE 26

ARC-RESISTANT MATERIALS

1. Purpose. This guideline establishes criteria for the selection and application of arc-resistant materials used for insulation of electrical power circuits.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

L-P-516	Plastic Sheet and Plastic Rod, Thermosetting, Cast.
MIL-I-24768	Insulation, Plastics, Laminated, Thermosetting, General Specification for.
A-A-59588	Rubber, Silicone.
ASTM D 495	Standard Test Method for High-Voltage, Low-Current, Dry Arc Resistance of Solid Electrical Insulation.
ASTM D 5213	Standard Specification for Polymeric Resin Film for Electrical Insulation and Dielectric Applications.
ASTM D 5948	Standard Specification for Molding Compounds, Thermosetting.
29 CFR 1910	Code of Federal Regulations, Title 29, Chapter XVII, Part 1910.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Materials. Materials should conform to table 26-I. The materials listed have passed the minimum guidelines of 115 seconds when subjected to the arc-resistance test of ASTM D 495 and are listed in approximate order of arc resistance.

5. Detail guidelines.

5.1 Applications. Materials may be masked, if necessary, during any treatment of the equipment in which they are used which might result in degradation of the arc-resistant properties of the material. For parts which may be exposed to other than high-voltage, low-current arcing, the materials should be evaluated for overall thermal and electrical characteristics. Suitability for the specific application and the potential for satisfactory performance in elevated humidity, as defined in the detail equipment specification, should also be considered.

5.2 Carcinogens. Certain chemicals have been identified in the Occupational Safety and Health Act (OSHA) as cancer-producing substances (carcinogens). Before using any materials which might contain these chemicals, they should be evaluated in accordance with 29 CFR 1910. Consideration of the toxicity of a substance should be given prior to material selection.

GUIDELINE 26

TABLE 26-I. Arc-resistant materials.

Materials	Specification	Types
Plastic(s), thermosetting, molding		CMI-5, GDI-30, GDI-30F, MAG, MAI-30, MAI-60, MAI-100, MAT-30, MDG, MME, MMI-5, MMI-30, MSG MSI-30, SDG, SDG-F, SDI-30
Molding, epoxy compounds	ASTM D 5948	MEE
Laminated rods and tubes, Laminated sheets	MIL-I-24768	GMG
Glass cloth, silicone resin	MIL-I-24768	GSG
Sheet and rod, cast	L-P-516	E-2
Sheet and strip, polyimide	ASTM D 5213	All
Silicone rubber	A-A-59588	All

GUIDELINE 27

BATTERIES

1. Purpose. This guideline establishes the criteria for the selection and application of batteries, including installation and marking criteria.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

W-B-133	Battery, Storage, Lead-Acid (Industrial Motive Power Service).
MIL-PRF-8565	Batteries, Storage, Aircraft, General Specification for.
MIL-B-18013	Battery, Storage, Support Equipment, General Specification for.
DOD-B-24541	Battery Cells and Elements, Lead-Acid, Main Storage, Submarine; General Specification for.
MIL-B-29595	Batteries and Cells, Lithium, Aircraft, General Specification for.
MIL-PRF-49450	Battery, Rechargeable, Nickel-Cadmium, Vented, Aircraft.
MIL-PRF-49471	Batteries, Non-Rechargeable, High Performance.
MIL-PRF-81757	Batteries and Cells, Storage, Nickel-Cadmium, Aircraft, General Specification for.
DOD-STD-1578	Nickel-Cadmium Battery Usage Practices for Space Vehicles.
ANSI C18.1M	Dry Cells and Batteries-Specifications.
SAE J537	Storage Batteries.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Use. Batteries should not be used unless approved by the procuring activity.

4.1.1 Army applications. Battery power for Army equipment (development and nondevelopment type) and other service developed equipment adopted by the Army should be selected in accordance with guidance available from the Army Communications-Electronics Command, Ft. Monmouth, NJ. The point of contact is:

Headquarters, Communications-Electronics Command
Attn: AMSEL-LC-P-AMC
Ft. Monmouth, NJ 07703
DSN 992-2411 or commercial (732) 532-2411

4.1.2 Space applications. Batteries for space applications should be selected and applied in accordance with DOD-STD-1578.

4.1.3 Lithium batteries. When lithium batteries are to be used in an equipment, direction on their use, transportation, storage, and disposal should be requested through the procuring activity from the following sources:

For Army:	US Army Communications-Electronics Command AMSEL-LC-P-AMC Ft Monmouth NJ 07703
For Navy:	Naval Surface Warfare Center Crane Division 300 Highway 361 Crane, IN 47522-3235
For Air Force:	AFMC/LGYE 4375 Chidlaw Road Post 119C Wright Patterson OH 45433−5006

GUIDELINE 27

4.2 Rechargeable batteries. Rechargeable batteries should conform to MIL-PRF-8565, DOD-B-24541, MIL-PRF-49450, DOD-STD-1578, W-B-133, or SAE J537.

4.3 Nonrechargeable batteries. Nonrechargeable batteries should conform to MIL-B-29595, MIL-PRF-49471, or ANSI C18.1M.

4.4 Installation marking. Connections, polarity, minimum acceptable voltage for equipment operation, nominal voltage, and type(s) of batteries required should be marked as applicable in a prominent place on, or adjacent to, the battery compartment.

4.5 Warning label. Battery-powered equipment, with the exception of equipment requiring permanent battery installation, should be labeled externally as follows:

WARNING
REMOVE BATTERIES BEFORE
SHIPMENT OR INACTIVE STORAGE
OF 30 DAYS OR MORE

Examples of equipment requiring permanent battery installation are sonobuoys, missiles, and fuses.

5. Detail guidelines.

5.1 Battery compartment. The battery compartment should be provided with devices to firmly secure the batteries. Adequate room should be provided for battery installation, maintenance, testing, and removal without disassembly of the equipment. The battery compartment should prevent pressure build-up from heat, gases, liquids, or chemicals released during battery operation, charging, deterioration, or rupture, and should also prevent such materials from entering the electronic compartment.

5.2 Magnesium dry batteries. When magnesium dry batteries are used, extra precautions should be observed since these batteries give off heat at high rates of discharge (less than 10 hours) and evolve hydrogen.

GUIDELINE 28

CONTROLS

1. Purpose. This guideline establishes criteria for the selection and application of controls.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

NASM28728 Dial, Control, Multi-Turn Counters, General Specification for

3. Definitions.

3.1 Operating control. Operating controls are controls that may be required for use during the normal operation of the equipment.

3.2 Adjustment controls. Adjustment controls are controls that are used for alignment and calibration of the equipment and are not used during normal operation of the equipment.

4. General Guidelines.

4.1 General. All controls should be marked, indexed, sized, and located so that the control position can be readily identified. Controls should have fixed guide marks if pre-setting of the controls is required. Controls located adjacent to their associated displays should be so positioned that operation of the control will not obscure the display. Controls should be so connected in the circuit that the controlled characteristics; (e.g., sensitivity, volume, or voltage) increase with clockwise rotation of the control as seen from the operating position. In general, movement of a control forward, clockwise, to the right, or up, should turn the equipment on, cause the quantity to increase, or cause the equipment to move forward, clockwise, to the right, or up.

4.2 Accessibility.

4.2.1 Operating controls. Controls necessary for the operation of the equipment should be readily accessible, and unless otherwise specified, should be located on the front panel of the unit.

4.2.2 Adjustment controls. Adjustment controls that are required for periodic alignment or calibration should be mounted behind covered openings, such as access doors, on the surfaces of the equipment accessible when installed. When not adjustable by hand, controls should be designed to accept a common screwdriver blade tip. Controls which infrequently require adjustment need not be accessible from the operating panel, but should be readily accessible for servicing when the equipment is opened for maintenance purposes.

4.3 Mechanical characteristics.

4.3.1 Stops. Mechanical stops should be provided for all adjustable controls, except controls designed for unlimited rotation. Where flexible control shafts are employed, or where stops integral to the adjustable control or the mechanism could be damaged by excessive torque, stops should be provided on the driving end of the shaft.

4.3.2 Locking devices. Control locking devices should be capable of retaining the controls in any given setting within the range of control. The locking and unlocking action should be easily and quickly accomplished, and should not affect the setting of the control. When in the unlocked position, the locking devices should not interfere with the normal operation of the control. Where vernier controls are used, the locking devices should operate on both main and vernier controls, if necessary, to prevent damage.

4.3.3 Nonturn devices. All nonturning controls and bodies, or cases of turning controls, should be equipped with a positive device to prevent their turning in the panel or assembly on which they are mounted.

4.3.4 Shafts and couplings. Coupling between, or to, shafts should be accomplished by means of metallic or insulated couplings rigidly secured.

GUIDELINE 28

4.3.5 Control knobs and handles. Control knobs and handles should have high impact strength and should be firmly secured to the control shafts by use of setscrews wherever that type of fastener is applicable. Plastic knobs and handles should have metal inserts for setscrews and should not warp or crack.

4.3.6 Multiturn counters control dials. Manually operated multiturn counters control dials should conform to NASM28728.

4.3.7 Stability. All controls should be so designed that the setting, position, or adjustment of any control should not be altered when the equipment is subjected to the service conditions specified in the detail equipment specification.

4.3.8 Factory adjustment controls. The design of equipment should not include factory or sealed adjustment controls, unless specifically approved by the detail equipment specification.

5. Detail guidelines.

5.1 Arrangement and location. Controls should be arranged to facilitate smooth and rapid operation. All controls which have sequential relations, which are related to a particular function or operation or which are operated together, should be grouped together along with their associated displays. Controls should be conveniently located with respect to associated visual displays. Controls should be of such size and so spaced that the manipulation of a given control does not interfere with the setting of an adjacent control. Adjustment controls, with required test points, should be grouped and so marked as to provide for simplicity and ease of maintenance.

5.2 Mechanical operation. Infrequently required controls should be screwdriver adjusted. Play and backlash in controls should be held to a minimum commensurate with intended operational functions and should not cause poor contact or inaccurate setting. Controls should operate freely and smoothly without binding, scraping, or cutting. Controls may be lubricated when lubrication does not interfere with operation and is specified in the detail equipment specification.

5.3 Shafts and couplings. Shafts subject to removal may have their couplings secured by two setscrews 90° to 120° apart. Flexible couplings may be used for controls where the use of rigid couplings would interfere with the satisfactory operation or mounting of such controls.

GUIDELINE 29

ELECTRON TUBES

1. Purpose. This guideline establishes criteria to support the design and testing of electron tube devices and their application equipment.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-PRF-1	Electron Tubes, General Specification for.
MIL-STD-1311	Test Methods for Electron Tubes.
QPL-1	Qualified Products List of Products Qualified Under Performance Specification MIL-PRF-1 Electron Tubes, General Specification for.

3. Definitions. Terms, definitions, methods, abbreviations, and symbols used in conjunction with electron tubes are found in appendices of MIL-PRF-1.

4. General guidelines.

4.1 General requirements and classification. General requirements and ratings for electron tubes used by the military are found in MIL-PRF-1. The main category into which each tube is classified is indicated in the title of the tube specification sheet (TSS).

4.2 Production, test and reliability. Manufacture of electron tubes will use production and test facilities and a quality and reliability assurance program adequate to ensure compliance with MIL-PRF-1 and its corresponding TSS.

4.3 Qualification. Adequacy of electron tube manufacturer to meet the acceptance requirements of MIL-PRF-1 and the TSS is determined by the qualifying activity. Uniform methods for testing environmental, physical, and electrical characteristics of electron tubes as required by MIL-PRF-1 and the TSS are provided by MIL-STD-1311.

4.3.1 Delivery. Only electron tubes inspected for and meeting all requirements of MIL-PRF-1 and the TSS are to be marked as compliant and delivered. Tubes furnished under MIL-PRF-1 are either tubes authorized by the qualifying activity for listing on the qualified products list (QPL) or tubes passing first article inspection (determined by TSS and Contracting Officer). The QPL cross references tube designation numbers with TSS numbers and qualified manufacturers and is updated annually. The Contracting Officer can waive first article acceptance for manufacturers who pass first article testing on previous, recent contracts.

4.4 Critical interfaces. Critical interfaces of an electron tube are specified in appendices of MIL-PRF-1 and in the TSS.

5. Detailed guidelines. Equipment using tubes manufactured in accordance with MIL-PRF-1 should be designed so that the tubes perform satisfactorily in the normal service for which the equipment is designed. The use of characteristics not controlled by MIL-PRF-1 is not permitted without specific military command or service approval.

GUIDELINE 30

SEMICONDUCTOR DEVICES

1. Purpose. This guideline establishes criteria for the selection and application of semiconductor devices. These criteria are based on the objectives of achieving technological superiority, quality, reliability, and maintainability in military systems.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-PRF-19500	Semiconductor Devices, General Specification for
QML-19500	Qualified Manufacturers List of Products Qualified Under Performance Specification MIL-PRF-19500 Semiconductor Devices, General Specification for.
TEOOO-AB-GTP-010	Parts Requirements and Application Manual for Navy

3. Definitions.

3.1 Qualified device (semiconductors): Any device or semiconductor which has met the requirements of MIL-PRF-19500 and is listed on the associated Qualified Manufacturers Listing (QML).

3.2 Reliability. The probability of a part performing its specified purpose for the period intended under the operating conditions encountered.

3.3 Derating. The method of reducing stress or making quantitative allowances for a part's functional degradation. Consequently, derating is a means to reduce failures and extending part life. In addition, derating helps protect parts from unforeseen application anomalies and overstresses. See guideline 18.

4. General Guidelines.

4.1 Application. The use of semiconductor devices should be qualified and monitored to the application and environment they are used in. The "Parts Requirements and Application Manual for the Navy", TEOOO-AB-GTP-010, is recommended to be used as guidance.

4.2 Parts standardization. Parts standardization is encouraged. Standardization positively affects logistic supportability, the overall life cycle costs, obsolete part issues, as well as the quality and reliability of the devices. Standard semiconductor devices are manufactured in accordance with MIL-PRF-19500 and are listed in QML-19500, and in electronic format on the DSCC web site.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 31

MOISTURE POCKETS

1. Purpose. This guideline establishes criteria for the treatment and drainage of moisture pockets.

2. Applicable documents. This section not applicable to this guideline.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Moisture pockets. Where moisture pockets are unavoidable in unsealed equipment, provision should be made for drainage of such pockets. Desiccants or moisture-absorbent materials should not be used within moisture pockets.

5. Detail guidelines.

5.1 Pockets, wells, and traps. Pockets, wells, traps, and the like, in which water or condensate could collect when the equipment is in normal position, should be avoided.

5.2 Sealed equipment. In sealed equipment or assemblies such as waveguides, the use of desiccants or other methods, such as gas purging, is not restricted.

GUIDELINE 32

TEST PROVISIONS

1. Purpose. This guideline establishes criteria for test provisions.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-HDBK-2165 Testability Program for Systems and Equipments

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Built-in test devices. Built-in test devices should maintain their accuracy under all operating conditions required by the equipment under test. These devices should be provided with connections or access for their operational check-out or calibration.

4.2 External test points. Protection should be provided in the test point circuitry to prevent equipment damage caused by the external grounding of test points.

4.3 Failure effect. Unless otherwise specified, provisions for testing should be so designed that any failure of built-in test devices will not degrade equipment operation or cause equipment shut down.

5. Detail guidelines.

5.1 Testability program. When specified by the procuring activity, a testability program should be implemented in accordance with MIL-HDBK-2165.

GUIDELINE 33

RESISTORS

1. Purpose. This guideline establishes criteria for the selection and application of resistors.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-HDBK-199 Resistors, Selection and Use of

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Selection. Resistors should be selected and applied in accordance with MIL-HDBK-199.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 34

NOMENCLATURE

1. Purpose. This guideline establishes criteria for nomenclature (item name and type designation).

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-STD-196 Joint Electronics Type Designation System.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Nomenclature. Item names and type designations for electronic equipment should be established in accordance with MIL-STD-196.

5. Detail guidelines.

5.1 Type designations. The assignment of type designations does not constitute approval of equipment or the use of a particular item in a specific set, and does not waive any requirements of the contract involved, nor does the approval of the equipment constitute approval of the type designation assignment.

GUIDELINE 35

RELIABILITY

1. Purpose. This reliability guideline should be considered when preparing contractual documents. Reliability program tasks, quantitative requirements, and verification or demonstration requirements may be directly specified in the contract or the system/equipment specification, as appropriate.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-HDBK-781	Reliability Test Methods, Plans, and Environments for Engineering Development, Qualification, and Production.
MIL-HDBK-217	Reliability Prediction of Electronic Equipment.

3. Definitions. This section not applicable to this guideline.

4. General guidelines. This section not applicable to this guideline.

5. Detail guidelines.

5.1 Reliability program. Reliability engineering and accounting tasks aimed at preventing, detecting, and correcting reliability design deficiencies, weak parts, and workmanship defects and providing reliability related information essential to acquisition, operation, and support management should be included in contract requirements with the objective of establishing and maintaining an efficient reliability program according to life cycle phase. MIL-HDBK-781 and MIL-HDBK-217 provide additional guidance.

5.2 Quantitative requirements. Quantitative reliability requirements and verification or demonstration requirements should be established appropriate to program phase.

GUIDELINE 36

ACCESSIBILITY

1. Purpose. This guideline establishes criteria for accessibility.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-STD-1472	Human Engineering.
MIL-HDBK-505	Definition of Item Levels, Item Exchangeability, Models, and Related Terms.

3. Definitions.

3.1 Part, subassembly, and assembly. Part, subassembly, and assembly are as defined in MIL-HDBK-505.

4. General guidelines.

4.1 Access. Each article of equipment, and each major subassembly forming a part thereof, should provide for the necessary access to its interior parts, terminals, and wiring for adjustments, required circuit checking, and the removal and replacement of maintenance parts. Accessibility for testing and replacement does not apply to parts located in nonrepairable subassemblies or assemblies. For routine servicing and maintenance, unsoldering of wires, wire harnesses, parts, or subassemblies should not be required in order to gain access to terminals, soldered connections, mounting screws, and the like. Inspection windows should be provided where necessary. Sizes of openings, maximum reach guidelines, and allowable sizes and weights of replaceable assemblies should conform to limits established in MIL-STD-1472.

4.2 Connections. Connections to parts inside a removable container should be arranged to permit removal of the container without threading connection leads through the container.

4.3 Parts. Parts which are identified as replaceable parts should not be mounted by means of rivets, spot welding, or hard curing compounds. No unsoldering or soldering of connections should be necessary when the front panel, or any subchassis, is removed for maintenance purposes. Design should be such that where plug-in modules or assemblies are used, they can be easily inserted in the proper location when correctly oriented without damage to equipment or parts being engaged.

4.4 Enclosures. Accessibility to chassis, assemblies, or parts contained within cabinets, consoles, or other enclosures should be provided from outside the basic equipment through the use of access doors, by mounting such items on withdrawal slides, swinging doors, through cable extenders and cable retractors, provisions for circuit card extenders which will allow part or module operation in the open position, or other arrangements to permit adequate access for properly servicing the equipment. Automatic or manually operated locks should be provided to lock the chassis in the servicing position. When withdrawal slides are used they should be of guided sectional construction with tracks and rollers. Complete removal and access for servicing of electronic equipment contained within cabinets, consoles, or other enclosures should be provided from either the front or rear of the equipment. Guide pins, or locating pins, or the equivalent, should be provided for mechanical alignment during mounting. Shipboard equipment should have complete access for maintenance and servicing from the front of the equipment.

4.5 Bolt-together racks and enclosures. For Navy ship and shore applications, when bolt-together racks are required, fastening should be provided to bolt adjacent racks together at the top with external brackets and through the bottom of the rack to a base or foundation. Bottom mounting should be accessible from the front with minimum disassembly of internal parts or subassemblies.

5. Detail guidelines.

5.1 Compatibility. Equipment should be designed for optimum accessibility compatible with operating, maintenance, electromagnetic compatibility, and enclosure requirements.

GUIDELINE 36

5.2 Parts. If, in order to check or remove a part, it is necessary to displace some other part, the latter part should be so wired and mounted that it can be moved without being disconnected and without causing circuit detuning or instability.

GUIDELINE 37

CIRCUIT BREAKERS

1. Purpose. This guideline establishes criteria for the selection and application of circuit breakers.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-PRF-39019	Circuit Breakers, Magnetic, Low-Power Sealed, Trip-Free, General Specification for.
MIL-PRF-55629	Circuit Breakers, Magnetic, Unsealed or Panel Seal, Trip-Free, General Specification for.
MIL-PRF-83383	Circuit Breakers, Remote Control, Thermal, Trip Free, General Specification for.
MIL-HDBK-217	Reliability Prediction of Electronic Equipment.

3. Definitions.

3.1 Overcurrent protection. There are two main purposes for overcurrent protective devices: (1) The protection of components and equipment from overcurrent damage; and (2) To isolate sub-systems from a main system when a fault occurs.

3.2 Circuit breaker. A circuit breaker is a device that opens a circuit automatically, without damaging itself, when the current exceeds a predetermined value.

4. General guidelines.

4.1 Selection and application. Trip-free circuit breakers should be used. Nontrip-free circuit breakers should be used only when the application requires overriding of the tripping mechanism for emergency use.

4.2 Manual operation. Circuit breakers should be capable of being manually operated to the ON and OFF positions. Circuit breakers should not be used as ON-OFF switches unless such breakers have been specifically designed and tested for that type of service.

4.3 Position identification. Circuit breakers should have easily identified ON, OFF, and TRIPPED positions except that the TRIPPED position may be the same as the OFF position with no differentiation between OFF and TRIPPED being required.

4.4 Orientation. Circuit breakers should operate when permanently inclined in any direction up to 30 from the normal vertical or normal horizontal position. The trip point of an inclined unit should not vary more than +5 percent of the current specified for normal position mounting. Circuit breakers used on flight equipment and portable test equipment should operate within the limits of the detail specification when the equipment is in any position or rotation about its three principal axes.

4.5 Reliability. MIL-HDBK-217 provides reliability prediction models for circuit breakers.

5. Detail guidelines.

5.1 Type and configuration. Circuit breakers are available in various sizes and configurations including thermal, magnetic, thermal-magnetic, and solid state types. The size and configuration of the package are dependent on the electrical characteristics, power dissipation, and the environmental requirements. There are many types available. To obtain further information on configuration, interface requirements, and testing, consult an individual military specification listed in section 2 of this guideline.

GUIDELINE 38

QUARTZ CRYSTALS AND OSCILLATOR UNITS

1. Purpose. This guideline establishes criteria for the selection of quartz crystal units and crystal oscillators.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-PRF-3098	Crystal Units, Quartz, General Specification for.
MIL-PRF-55310	Oscillators, Crystal Controlled, General Specification for.
MIL-HDBK-217	Reliability Prediction of Electronic Equipment.

3. Definitions.

3.1 Crystal. A solid in which the constituent atoms or molecules are arranged with a degree of geometric regularity.

3.2. Crystal oscillator. An oscillator in which a piezoelectric crystal controls the frequency of oscillation.

3.3. Piezoelectric. A property of some crystals that produce a voltage when subjected to a mechanical stress; or, that when voltage is applied, undergo a mechanical stress.

4. General guidelines.

4.1 Crystal units and crystal oscillators units. Crystal units and crystal oscillators units should conform to MIL-PRF-3098 and MIL-PRF-55310 respectively.

4.2 Reliability. MIL-HDBK-217 provides reliability prediction models for quartz crystal units.

5. Detail guidelines:

5.1 Type and configuration. Crystal-controlled oscillators have many applications in electronic equipment. Oscillator types are designated as crystal oscillators (XO), voltage-controlled crystal oscillators (VCXO), temperature-compensated crystal oscillators (TCXO), oven-controlled crystal oscillators (OCXO), temperature-compensated/voltage-controlled crystal oscillators (TCVCXO), oven-controlled/voltage-controlled crystal oscillators (OCVCXO), microcomputer-compensated crystal oscillators (MCXO), and rubidium-crystal oscillators (RbXO). Definitions of the various oscillator types along with information on configuration, interface requirements and testing, can be found in MIL-PRF-55310. Details on quartz crystal units can be found in MIL-PRF-3098.

GUIDELINE 39

FUSES AND FUSE HOLDERS

1. Purpose. This guideline establishes criteria for the selection and application of fuses, fuseholders, and associated hardware.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-PRF-15160	Fuses, Instrument, Power, and Telephone, General Specification for.
MIL-PRF-19207	Fuseholders, Extractor Post Type, Blown Fuse, Indicating and Nonindicating, General Specification for.
MIL-PRF-23419	Fuse, Cartridge, Instrument Type, General Specification for.
MIL-HDBK-217	Reliability Prediction of Electronic Equipment.
SAE-ARP 1199	Selection, Application, and Inspection of Electric Overcurrent Protective Devices.

3. Definitions.

3.1 Overcurrent protection. There are two main purposes for overcurrent protective devices: (1) The protection of components and equipment from overcurrent damage; and (2) To isolate sub-systems from a main system when a fault occurs.

3.2 Fuse. A fuse is a protective device with a fusable link, or link, that will break the current when the current exceeds the capacity of the fuse. When potentially harmful overcurrents occur the link will melt rapidly to protect circuit components.

4. General guidelines.

4.1 Selection and application. Fuses, fuseholders, and associated hardware should be selected from SAE-ARP 1199.

4.2 Extractor post type fuseholders. The load should be connected to the fuseholder terminal that terminates in the removable cap assembly.

4.3 Reliability. MIL-HDBK-217 provides reliability prediction models for fuses.

5. Detail guidelines.

5.1 Branch circuits. Fusing should be so applied that fuses in branch circuits will open before the fuses in the main circuit.

5.2 Thermal considerations. Fuses are thermally activated devices. In general, time delay fuses are most susceptible to ambient temperature extremes; current limiters the least.

5.3 Load current considerations. Fuse ratings are in terms of RMS, not average, line currents measured using true RMS reading instruments. Direct current lines having a pulsating component should be measured using a true RMS reading instrument.

5.4 Type and configuration. Fuses are available in a variety of configurations and sizes (e.g., surface mount, wire leads, blade type, fuse clips, and large cartridges). The size and configuration of the package are dependent on the electrical characteristics, power dissipation and the environmental requirements. There are many military types available. To obtain further information on configuration, interface requirements, and testing, consult an individual military specification listed i section 2 of this guideline.

GUIDELINE 40

SHUNTS

1. Purpose. This guideline establishes criteria for the selection of external meter shunts.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-I-1361	Instrument Auxiliaries, Electrical Measuring: Shunts, Resistors, and Transformers.
A-A-55524	Shunt, Instrument (External, 50 millivolt, Lightweight Type).

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 External meter shunts. External meter shunts should conform to A-A-55524 or MIL-I-1361, as applicable.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 41

SPRINGS

1. Purpose. This guideline establishes criteria for the design, selection, and application of springs.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-S-46049	Strip, Metal, Carbon Steel, Cold Rolled, Hardened and Tempered, Spring Quality.
ASTM A29/A29M	General Specification for, Steel Bars, Carbon and Alloy, Hot Wrought.
ASTM A228/A228M	General Specification for, Steel Wire, Music Spring Quality.
ASTM A313/A313M	General Specification for, Stainless Steel Spring Wire.
ASTM A682/A682M	General Specification for, Steel, Strip, High-Carbon, Cold Rolled.
ASTM A684/A684M	General Specification for, Steel, Strip, High-Carbon, Cold Rolled.
ASTM B122/B122M	General Specification for, Copper-Nickel-Tin Alloy, Copper-Nickel-Zinc Alloy (Nickel Silver),and Copper-Nickel Alloy Plate, Sheet, Strip, and Rolled Bar.
ASTM B139/B139M	General Specification for, Phosphor Bronze Rod, Bar, and Shapes.
ASTM B151/B151M	General Specification for, Copper-Nickel-Zinc Alloy (Nickel Silver) and Copper-Nickel Rod and Bar.
ASTM B194	General Specification for, Copper-Beryllium Alloy Plate, Sheet, Strip, and Rolled Bar.
ASTM B196/B196M	General Specification for, Copper-Beryllium Alloy Rod and Bar.
ASTM B197/B197M	General Specification fo,r Copper-Beryllium Alloy Wire.
ASTM B206/B206M	General Specification for, Copper-Nickel-Zinc Nickel Silver Wire and Copper-Nickel Alloy Wire.
ASTM B522	General Specification for, Gold-Silver-Platinum Electrical Contact Alloy.
SAE/AMS 5121	Sheet and Strip, Steel (0.90-1.04) (SAE1095).
SAE/AMS 5122	Steel Strip (0.90-1.04) (SAE1095) Hard Temper.
SAE AS 13572	Springs, Helical, Compression and Extension.
SAE AS 81021	Copper-Beryllium Alloy (Copper Alloy Numbers C17500 and C17510), Strip.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Helical springs. Helical springs should conform to SAE AS 13572.

4.2 Electrical contact springs. Electrical contact springs should use materials selected from table 41-I.

4.3 Carbon steel springs. Carbon steel springs should be suitably plated or finished to resist corrosion.

5. Detail guidelines.

5.1 Corrosion resisting steel. Corrosion resisting steel springs are preferred where electrical conductivity is not a consideration and where they are adequate for the purpose intended.

5.2 Fatigue limits. Fatigue limits of the springs should not be adversely affected by corrosion, operating temperature, and other environmental conditions in service. Fatigue limits should be consistent with the maximum specified operating cycles for the respective part or equipment or, if such is not specified, with the maximum duty cycle to be expected during the equipment service life.

5.3 Electrical conductivity. Electrical conductivity of contact springs should not be adversely affected by corrosion, operating temperature, and other environmental conditions in service.

5.4 Enclosure. Where practicable, springs should be enclosed in housings, or otherwise captivated, in order to prevent broken pieces from entering and adversely affecting the equipment.

GUIDELINE 41

5.5 Heat treatment. Springs made of materials that achieve their desired properties by heat treatment, such as copper-beryllium alloys, annealed carbon steels, CRES steels, or heat resisting alloys, should be heat treated to the specified temper after forming.

5.6 Grain orientation. Flexure and forming of springs should be designed to occur perpendicular to the grain of the material. Deviation from the perpendicular should not exceed 45°.

5.7 Documents for specifying materials. When the materials listed in tables 41-I, 41-II, and 41-III are used, they should conform to the specifications listed for each material.

GUIDELINE 41

TABLE 41-I. Materials for electrical spring application.

Material	Form	Material specification
Copper-nickel-zinc alloy	Plate, sheet, strip, and rolled bar	ASTM B122/B122M
	Rod, shapes, and flat products with finished edges (flat wire, strip, and bar)	ASTM B122/B122M ASTM B151/B151M ASTM B206/B206M
Copper-beryllium alloy	Bars and rod	ASTM B196/B196M
	Wire	ASTM B197/B197M
	Strip	ASTM B194
Copper-cobalt-beryllium alloy	Strip	SAE AS 81021
Phosphor bronze	Bar, rod, plate, sheet, strip, and flat wire	ASTM B139/B139M
Platinum-iridium alloy	Strip	ASTM B522
Palladium-copper alloy		Metals Handbook,Vol I

TABLE 41-II. Corrosion resisting steel for springs.

Material	Form	Material Specification
Steel, CRES	Wire	ASTM A313/A313M

GUIDELINE 41

TABLE 41-III. Carbon steel for springs.

Material	Form	Material specification
Steel, high carbon	Wire, spring, music	ASTM 228/A228M
Steel, carbon and alloy (for springs)	Strip, cold rolled untempered spring	ASTM 682/A682M ASTM 684/A684M
Steel, carbon and alloy (for springs)	Bars, round, square and flat	ASTM A29/A29M
Steel, carbon, strip and tempered spring	Cold rolled, hardened	MIL-S-46049
Steel, carbon (1095)	Sheet and strip A-annealed (condition 1) H-hard temper (condition 3) cold finished	SAE AMS 5121 SAE AMS 5122

GUIDELINE 42

TUNING DIAL MECHANISMS

1. Purpose. This guideline establishes criteria for the design of tuning dial mechanisms.

2. Applicable documents. This section not applicable to this guideline.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Dial. The division marking and lettering on tuning dials should be suitably etched. Dial markings should be legible at a distance of 0.6 meter from any point within a solid angle of 60° defined by a surface of revolution about a line through the center of the dial and perpendicular to the panel. Minimum space between characters should be one stroke width. The width of the lubber line or pointer tip should not exceed the width of the graduation marks. Except for digital tuning indicators, for which only one calibration number will be seen, dials should be marked so that at least two calibration numbers on each band can be seen at any dial setting.

4.2 Balance and friction. Weighted tuning knobs should be counterbalanced. Friction in tuning dial mechanism should allow smooth and easy adjustment of the operating knob over the entire operating range of the mechanism, but should have sufficient resistance, or should incorporate a positive locking device to maintain the setting under all specified service conditions. Friction should be achieved through dry or elastic resistance rather than by fluid resistance.

4.3 Flexible control shafts. Flexible shaft assemblies should be used when a flexible mechanical connection is required between the tuning knob and the tuned device.

5. Detail guidelines.

5.1 Tuning ratio. The tuning ratio used should be the optimum which will permit both rapid and precise setting.

GUIDELINE 43

LUBRICANTS

1. Purposes. This guideline establishes criteria for the selection and application of lubricants.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-L-3918	Lubricating Oil, Instrument, Jewel Bearings.
MIL-PRF-3150	Lubricating Oil, Preservative, Medium.
MIL-PRF-6085	Lubricating Oil, Instrument, Aircraft, Low Volatility.
MIL-PRF-6086	Lubricating Oil, Gear, Petroleum Base.
MIL-L-15719	Lubricating Grease, (High-Temperature, Electric Motor, Ball and Roller Bearings).
MIL-PRF-17331	Lubricating Oil, Steam Turbine, and Gear, Moderate Service.
MIL-PRF-17672	Hydraulic Fluid, Petroleum, Inhibited.
MIL-L-23398	Lubricant, Solid Film, Air-Cured, Corrosion Inhibiting, NATO Code Number S-749.
MIL-PRF-23827	Grease, Aircraft and Instrument, Gear and Actuator Screw.
MIL-PRF-24139	Grease, Multi Purpose, Water Resistant.
DOD-G-24508	Grease, High Performance, Multi-Purpose (Metric).
MIL-PRF-46010	Lubricant, Solid Film, Heat Cured, Corrosion Inhibiting.
MIL-PRF-81322	Grease, Aircraft, General Purpose, Wide Temperature Range, NATO Code Number G-395.
MIL-PRF-81329	Lubricant, Solid Film, Extreme Environment, NATO Code Number S-1737.
29 CFR 1910	Code of Federal Regulations, Title 29, Chapter XVII, Part 1910.
SAE J2360	Lubricating Oil, Gear Multipurpose (Metric) Military Use.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 General. Lubricants should conform to one of the following:

MIL-PRF-3150	MIL-PRF-17331	DOD-G-24508
MIL-L-3918	MIL-PRF-17672	MIL-PRF-46010
MIL-PRF-6085	MIL-L-23398	MIL-PRF-81322
MIL-PRF-6086	MIL-PRF-23827	MIL-PRF-81329
MIL-L-15719	MIL-PRF-24139	SAE J2360

4.2 Silicones. Silicone compounds should not be used as lubricants.

4.3 Graphite base lubricants. Graphite base lubricants should not be used.

5. Detail guidelines

5.1 Variety. The number of different lubricants should be held to a minimum.

5.2 Volatility. Low volatility lubricants should be used where practical.

5.3 Compatibility. The lubricant should be chemically inert with regard to the materials it contacts.

5.4 Carcinogens. Certain chemicals have been identified in the occupational Safety and Health Act (OSHA) as cancer-producing substances (carcinogens). Before using any materials which might contain these chemicals, they should be evaluated in accordance with 29 CFR 1910. Consideration of the toxicity of a substance should be given prior to material selection.

GUIDELINE 44

FIBROUS MATERIALS, ORGANIC

1. Purpose. This guideline establishes criteria for the selection and application of organic fibrous materials.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-DTL-32072	Thread, Polyester.
V-T-295	Thread, Nylon.
MIL-W-530	Webbing, Textile, Cotton, General Purpose, Natural or in Colors.
MIL-C-572	Cords, Yarns, and Monofilaments, Organic Synthetic Fiber.
MIL-T-3530	Thread and Twine, Mildew Resistant or Water Repellent Treated.
MIL-W-4088	Webbing, Textile, Woven Nylon.
MIL-C-9074	Cloth, Laminated, Sateen, Rubberized.
MIL-W-27265	Webbing, Textile, Woven Nylon Impregnated.
A-A-50197	Thread, Linen .
A-A-52094	Thread, Cotton.
29 CFR 1910	Code of Federal Regulations, Title 29, Chapter XVII, Part 1910.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Webbing.

4.1.1 Cotton. Cotton webbing should conform to MIL-W-530, class 4 or 7. Class 7 should be used when webbing will come in contact with natural or synthetic rubber or class 4 when prolonged contact with the skin may occur.

4.1.2 Nylon. Nylon webbing should conform to MIL-W-4088 or class R of MIL-W-27265.

4.2 Cotton duck. Medium texture number 4 should be used for heavy-duty service and hard texture number 12 should be used for services requiring light weight.

4.3 Thread. Thread should conform to A-A-52094, MIL-DTL-32072, A-A-50197, or V-T-295.

4.3.1 Treatment. Cotton and linen thread should be treated in accordance with MIL-T-3530. Type I, class 2 mildew inhibiting agent should be used when thread will come in contact with natural or synthetic rubber or type I, class 1 when prolong contact with the skin may occur.

4.4 Sateen. Laminated, two-ply rubberized cotton sateen should conform to MIL-C-9074. This sateen should not be used when prolonged contact with the skin may occur.

4.5 Cords, yarn, and monofilaments. Cords, yarns, and monofilaments should conform to MIL-C-572. Types PVCA, AR, VCR, and CTA should not be used where they may be exposed to fungus attack.

5. Detail guidelines

5.1 Shrinkage. Fabric and thread should be preshrunk or allowance should be made for shrinkage in order to provide for satisfactory fit of finished items, both before and after they are immersed in water and then dried.

5.2 Carcinogens. Certain chemicals have been identified in the Occupational Safety and Health Act (OSHA) as cancer producing substances (carcinogens). Before using any materials which might contain these chemicals, they should be evaluated in accordance with 29 CFR 1910. Consideration of the toxicity of a substance should be given prior to material selection.

GUIDELINE 45

CORONA AND ELECTRICAL BREAKDOWN PREVENTION

1. Purpose. This guideline establishes criteria for the prevention of corona and electrical breakdown.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

ASTM D 149	Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies
ASTM D 1868	Standard Test Method for Detection and Measurement of Partial Discharge (Corona) Pulses in Evaluation of Insulation Systems

3. Definitions.

3.1 Corona (air). A luminous discharge due to ionization of the air surrounding a conductor caused by a voltage gradient exceeding a certain critical value, called the partial discharge (Corona) Inception Voltage (CIV).

3.2 Partial discharge (corona) inception voltage (CIV). The lowest rms voltage at which continuous partial discharges above some stated magnitude (which may define the limit of permissible background noise) occur as the applied voltage is gradually increased.

3.3 Partial discharge (corona) extinction voltage (CEV). The highest rms voltage at which partial discharges above some stated magnitude no longer occur as the applied voltage is gradually decreased from above the inception voltage.

3.4 Breakdown. A disruptive discharge through insulation, involving a sudden and large increase in current through the insulation because of complete failure under electrostatic stress, also called puncture.

4. General guidelines.

4.1 Corona prevention. The CEV should be at least 150 percent of the peak circuit voltage, corresponding to the maximum specified steady-state rms supply voltage. This guideline applies:

a. When the equipment is terminated with the cabling, or other accessory equipment, with which it is intended to be used and;

b. When the equipment is operated under the specified environmental service conditions and;

c. When the equipment is supplied with the specified power source frequencies and voltages including commonly recurring transients.

4.2 Electrical breakdown prevention. The equipment should be designed and manufactured with electrical clearance spacing, leakage (creepage) distances, and insulation characteristics adequate to prevent electrical breakdown. This guideline applies under all specified environmental service conditions including service life and using the specified operating voltages (including transients). Liquid dielectrics, gases other than air, or pressurization to prevent electrical breakdown should not be used unless approved by the procuring activity.

5. Detail guidelines.

5.1 Effects of corona. Corona occurring at the interface of an insulator and a metal can damage or reduce the life of an insulating system. In general, inorganic insulating materials are more resistant to the damaging effects of corona than organic insulating materials. Corona also generates electromagnetic interference and liberates ozone, a toxic, oxidant gas.

GUIDELINE 45

5.2 Insulation systems. Corona can occur within cavities between an insulating material and a metal surface which are in contact. Therefore, care should be exercised to avoid cavities at such interfaces where high voltages are encountered.

5.3 Metal parts. Sharp edges and points should be avoided on metal parts which are included in high intensity electric fields.

5.4 Corona testing. There are many factors which determine whether or not corona will occur, including temperature, humidity, ambient pressure, test specimen shape, rate of voltage change, and the previous history of the applied voltage. Test methods such as ASTM D 1868 may be used but the test results lack accuracy and repeatability and require great care due to the personnel hazards involved.

5.5 Electrical breakdown testing. The breakdown voltage of a given insulating material is dependent upon electrode size and shape, insulator thickness, temperature, humidity, rate of voltage application, voltage waveform, and voltage frequency. When testing, care must be exercised to ensure that the insulating material is evaluated under the actual environmental conditions which apply to the equipment and that the occurrence of corona, or localized heating, does not mask the true breakdown voltage. Provides a test usable at power frequencies, 25 to 800 Hz in accordance with ASTM D 149.

GUIDELINE 46

MOTORS AND ROTARY POWER CONVERTERS

1. Purpose. This guideline establishes criteria for the selection and application of motors and rotary power converters.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-M-17059	Motor, 60 Cycle, Alternating Current, Fractional H.P. (Shipboard Use).
MIL-M-17060	Motors, 60 Hertz, Alternating Current, Integral-Horsepower, Shipboard Use.
MIL-B-23071	Blowers, Miniature, for Cooling Electronic Equipment, General Specification for.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Motors - alternating current. Alternating current motors should conform to MIL-M-17059 or MIL-M-17060, except that any motor used with a miniature blower for cooling electronic equipment should be in accordance with MIL-B-23071.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 47

ENCAPSULATION AND EMBEDMENT (POTTING)

1. Purpose. This guideline establishes criteria for encapsulating and embedding (potting) a part or an assembly of discrete parts. Conformal coating of printed circuit assemblies is excluded from this guideline.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-PRF-8516	Sealing Compound, Synthetic Rubber, Electric Connectors and Electric Systems, Chemically Cured.
A-A-59877	Insulating Compound, Electrical, Embedding.
MIL-PRF-23586	Sealing Compound, (with Accelerator), Silicone Rubber, Electrical.
MIL-M-24041	Molding and Potting Compound, Chemically Cured Polyurethane.
SAE AS81822	Insulating Compound, Electrical, Embedding, Reversion Resistant Silicone.
29 CFR 1910	Code of Federal Regulations, Title 29, Chapter XVII, Part 1910.

3. Definitions.

3.1 Encapsulation. A process for encasing a part or an assembly of discrete parts within a protective material which is generally not over 2.5 mm thick and does not require a mold or container.

3.2 Embedment (potting). A process for encasing a part or an assembly of discrete parts within a protective material which is generally over 2.5 mm thick, varies in thickness, fills the connecting areas within an assembly, and requires a mold or container to confine the material while it is hardening. Potting is an embedding process where the protective material bonds to the mold or container so that it becomes integral with the item.

4. General guidelines.

4.1 Encapsulation and embedment materials. Encapsulation and embedment materials should be of a non-reversion type and should be selected from the following specifications: MIL-S-8516, A-A-59877, SAE AS81822. The materials selected should be capable of filling all voids and air spaces in and around the items being encased. For Air Force applications, approval for use of any material other than transparent silicone, in accordance with SAE AS81822, should be requested through the procuring activity.

5. Detail guidelines.

5.1 Selection. The following points should be considered when selecting an encapsulation or embedment material:

a. Need for precautions due to hazardous characteristics of the material.

b. Electrical, mechanical, and thermal properties, including tear resistance, resistance to flame, chemicals, moisture, water, humidity, fungus, and temperature extremes.

c. Color or transparency.

d. Dissipation factor.

e. Specific gravity.

f. Shrinkage.

g. Heat distortion parameters.

h. Stresses on parts.

GUIDELINE 47

i. Durometer hardness.

j. Adhesion to substrates (and priming).

k. Temperatures of application and curing.

l. Repairability.

m. Dielectric constant.

n. Volume resistivity.

o. Reversion resistance, including hydrolytic stability.

p. Viscosity.

q. Solvent affects.

r. Compatibility with parts or assemblies to which applied.

5.2 Application. The encapsulation or embedment of microelectronic modules and equipment modules should be avoided, except where specifically indicated by the requirements of a particular application. In such instances, the module design should be completely verified for the particular encapsulation or embedment materials and processes to be employed. Any changes in module design, materials, and processes may require re-evaluation of the modules. In particular, extreme temperature aging and temperature cycling tests, combined with random vibration screening, should be performed to verify adequacy of the design. Design considerations should address thermal coefficent of expansion mismatches between potting material and components and stress relief techniques. Wherever economically feasible, the module to be encapsulated or embedded should be designed as a throw-away unit.

5.3 Carcinogens. Certain chemicals have been identified in the Occupational Safety and Health Act (OSHA) as cancer-producing substances (carcinogens). Before using any materials which might contain these chemicals, they should be evaluated in accordance with 29 CFR 1910. Consideration of the toxicity of a substance should be given prior to material selection. Consideration of hazards should address all stages of the equipment lifecycle from fabrication to assembly, to installation, use maintenance, and decomposition during failure analysis and troubleshooting.

GUIDELINE 48

GEARS

1. Purpose. This guideline establishes criteria for the selection and application of gears.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

American Gear Manufacturers Association (AGMA), Standards & Information Sheets

3. Definitions. Not applicable.

4. General guidelines.

4.1 Gears. Gears not operating in a lubricant bath should be made of corrosion resistant materials. Gears operating in a lubricant bath containing a corrosion inhibiting additive may be made of noncorrosion resistant materials.

5. Detail guidelines.

5.1 Designation. Gears should be designated, dimensioned, toleranced, and inspected in accordance with the applicable AGMA specifications.

5.2 Planetary or epicyclic gearing. Planetary or epicyclic gearing is preferred to worm gearing.

5.3 Nonmetallic gears. Nonmetallic gears may be used when they meet load, life, and environmental requirements of the applicable specification.

GUIDELINE 49

HYDRAULICS

1. Purpose. This guideline establishes criteria for the design and installation of a hydraulic system when it functions as an integral part of an electronic system.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

NFPA B93.3	Fluid Power Systems and Products - Cylinder Bores and Piston Rod Diameters - Inch Series.
NFPA B93.8	Bore and Rod Size Combinations and Rod End Configurations for. Cataloged Square Head Industrial Fluid Power Cylinders.
NFPA B93.9M	Symbols for Marking Electrical Leads and Ports on Fluid Power Valves.
NFPA B93.10	Static Pressure Rating Methods of Square Head Fluid Power Cylinders.
SAE J514	Hydraulic Tube Fittings.
SAE J518	Hydraulic Flanged Tube, Pipe, and Hose Connections, Four-Bolt, Split Flanged Type.
ISO 3019-2	Hydraulic fluid power Dimensions and identification code for mounting flanges and shaft ends of displacement pumps and motors.
ISO 5598	Fluid Power Systems and Components – Vocabulaty.
ISO 6099	Fluid Power Systems and Components - Cylinders - Indentification Code for Mounting Dimensions and Mounting Types.
ISO 10763	Hydraulic Fluid Power - Plain-End, Seamless and Welded Precision Steel Tubes - Dimensions and Nominal Working Pressures.
NFPA T2.13.1	Recommended Practice - Hydraulic Fluid Power - Use of Fire-Resistant Fluids in Industrial Systems.
NFPA T3.5.1	Hydraulic Fluid Power - Valves - Mounting Surfaces.
SAE AS 5440	Hydraulic Systems, Aircraft, Design and Installation, Requirements for.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Aircraft or manned flight vehicles. The design and installation of hydraulic systems for aircraft or manned flight vehicles should conform to the applicable type and class or system described in SAE AS 5440.

5. Detail guidelines. The following documents contain additional information on hydraulic design:

NFPA B93.3	ISO 3019-2
NFPA B93.8	ISO 5598
NFPA B93.9	ISO 6099
NFPA B93.10	ISO 10763
SAE J514	NFPA T2.13.1
SAE J518	NFPA T3.5.1

GUIDELINE 50

INDICATOR LIGHTS

1. Purpose. This guideline establishes criteria for selection and application of indicator lights and associated items.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-DTL -3661	Lampholders, Indicator Lights, Indicator Light Housings, and Indicator Light Lenses, General Specification for.
MIL-DTL-6363	Lamps, Incandescent, Aircraft Service, General Specification for.
MIL-DTL -7961	Lights, Indicators, Press to Test.
MIL-L-15098	Lamp, Glow, General Specification for.
MIL-PRF-19500	Semiconductor Devices, General Specification for.
MIL-STD-1472	Human Engineering.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Lights and accessories. Indicator lights, indicator light housings, lampholders, lenses, and lamps should be selected in accordance with table 50-I.

4.2 Visual display and legend lights. Visual display and legend lights should comply with the requirements in MIL-STD-1472.

4.3 Light emitting diodes (LEDs). LEDs when used as indicator lights should conform to the applicable specification sheets of MIL-PRF-19500.

4.4 Night vision goggles. Night vision goggle compatibility considerations for cockpit indicator lights should be considered where use of night vision goggles by cockpit crews is possible.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 50

TABLE 50-I. Indicator lights and associated items.

	MIL-DTL-3661	MIL-DTL-6363	MIL-DTL-7961	MIL-L-15098	MIL-PRF-19500
Indicator lights	X		X		X
Indicator light housings	X				
Lamp holders	X				
Lenses	X				
Incandescent lamps, general purpose		X			
Incandescent lamps, severe environment		X			
Neon lamps				X	

GUIDELINE 51

METERS, ELECTRICAL INDICATING

1. Purpose. This guideline establishes criteria for the selection and application of electrical meters.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-M-7793	Meter, Time Totalizing.
MIL-PRF-10304	Meters, Electrical Indicating, Panel Type, Ruggedized, General Specification for.
MIL-M-16034	Meters, Electrical-Indicating (Switchboard and Portable Types).
MIL-M-16125	Meters, Electrical, Frequency.

3. Definitions. This section not applicable to this guideline.

4. General Guidelines.

4.1 Meters. Meters should conform to one of the following specifications: MIL-M-7793, MIL-M-16034, MIL-M-16125, or MIL-PRF-10304.

5. Detail guidelines.

5.1 Analog meters. For analog meters, the normal operating value of the quantity to be indicated should be between 0.3 and 0.8 of full-scale deflection, wherever practicable.

GUIDELINE 52

THERMAL DESIGN

1. Purpose. This guideline establishes criteria for thermal design.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-PRF-16552	Filter, Air Environmental Control System, Cleanable, Impingement (High Velocity Type).
MIL-B-23071	Blowers, Miniature, for Cooling Electronic Equipment, General Specification for.
MIL-HDBK-251	Reliability/Design, Thermal Applications.
ASTM F 1040	Filter Units, Air Conditioning: Viscous-Impingement Types, and Dry Types, Replaceable.

3. Definitions.

3.1 Auxiliary heating or cooling. External heating or cooling devices not normally part of the equipment configuration.

3.2 Cold plate. A heat transfer surface cooled by forced air or other heat transfer fluid to which heat dissipating parts are mounted.

3.3 Contaminant. Any foreign substance contained in air or other heat transfer fluid which adversely affects cooling performance, such as dust particles, lint, oil, sludge, etc.

3.4 Direct impingement. Passing cooling air over parts without the use of cold plates or heat exchangers.

3.5 Entrained water. Water condensed from the cooling air and carried along with the cooling air.

3.6 External source supplied cooling air. Forced air supplied from a conditioning source such as an air conditioner or aircraft environmental control system which is not normally a part of the electronic equipment.

3.7 Forced air cooling. The dissipation of heat to cooling air, including ram air, supplied by a source with sufficient pressure to flow through the unit.

3.8 Heat exchanger. An air-to-air or liquid-to-air finned duct arrangement which is used to transfer dissipated heat from a hot recirculating fluid to the cooling fluid by conduction through the finned surfaces.

3.9 Natural cooling. The dissipation of heat to surroundings by conduction, convection, radiation, or any combination thereof without the benefit of external cooling devices.

3.10 Part. An element or component used in the production of electronic equipment or subsystem, such as a microcircuit, diode, transistor, capacitor, resistor, relay switch, or transformer.

3.11 Pressure drop (differential pressure). Resistance to flow usually measured as the static pressure difference across the electronic equipment from inlet to coolant outlet.

4. General guidelines.

4.1 Forced air cooling. Forced air cooling should be used only when natural cooling is not adequate. Exhaust and recirculating fans and blowers should be driven by ac brushless motors or by properly shielded dc motors. Miniature blowers should conform to MIL-B-23071. Air filters should be provided for air intakes for fan and blower cooled units when required to protect internal parts. Filters, when used, should conform to ASTM F 1040 or MIL-PRF-16552, and should be removable for cleaning without disassembly of the equipment. All ventilation openings should be designed and located to comply with electromagnetic interference, undesired radiation and enclosure guidelines. Air exhaust should be directed away from operating personnel.

GUIDELINE 52

4.1.1 External source. For equipment designed for use with external source supplied cooling air, which may contain entrained water or other contaminants detrimental to the equipment, precautionary measures should be taken to avoid direct impingement on internal parts and circuitry by channeling or use of heat exchangers.

4.1.2 Aircraft application. Equipment that is intended for use in aircraft, and requires forced air cooling, should be designed using cold plates or heat exchangers so that none of the cooling air will come into contact with internal parts, circuitry, or connectors.

4.2 Other cooling methods. Prior approval of the procuring activity should be obtained when heat densities, or other design requirements, make the use of air for cooling impractical and alternate methods, such as liquid, evaporative, change of phase material, or heat pipes are required.

5. Detail guidelines.

5.1 Fan and blower characteristics. The design factors which should be considered in determining the required fan or blower characteristics include such factors as amount of heat to be dissipated, the quantity of air to be delivered at the pressure drop of the enclosed equipment, the allowable noise level, the permissible level of heat that may be exhausted into the surrounding environment, and other pertinent factors affecting the cooling requirements of the equipment. Induced drafts and ventilation by means of baffles and internal vents should be used to the greatest practicable extent. When practicable, ventilation and air exhaust openings should not be located in the top of enclosures or in front panels. When it is impractical to avoid direct impingement on internal parts and circuitry by channeling or use of heat exchangers, the water and contaminants should be removed from the cooling air by suitable water and contaminant removal devices.

5.2 External source. For equipment designed for use with external source supplied cooling air, minimum differential pressure (pressure drop) of the cooling air through the equipment heat exchanger or cold plate should be maintained, consistent with adequate cooling.

5.3 Design guidance. MIL-HDBK-251 may be used as a guide for detail information on thermal design of electronic equipment.

GUIDELINE 53

WAVEGUIDES AND RELATED DEVICES

1. Purpose. This guideline establishes criteria for the selection and application of waveguides and related devices.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

EIA-979	RF Transmission Line and Connector Selection Guide
MIL-DTL-85	Waveguides, Rigid, Rectangular, General Specification for.
MIL-DTL-287	Waveguide, Assemblies, Flexible, Twistable and Non-Twistable, General Specification for.
MIL-DTL-3922	Flanges, Waveguide, General Purpose, General Specification for.
MIL-DTL-3928	Switches, Radio-Frequency Transmission Line (Coaxial and miicrostrip), General Specification for.
MIL-DTL-3933	Attenuators, Fixed, General Specification for.
MIL-D-3954	Dummy Loads, Electrical, Waveguide, General Specification for.
MIL-DTL-3970	Waveguide Assemblies, Rigid, General Specification for.
MIL-DTL-15370	Couplers, Directional, General Specification for.
MIL-DTL-22641	Adapters, Coaxial to Waveguide, General Specification for.
MIL-DTL-23971	Power Dividers, Power Combiners, and Power Divider/Combiners, General Specification for.
MIL-DTL-24044	Flange, Coaxial Line, Rigid, Air Dielectric, General Specification for.
MIL-DTL-24211	Gasket, Waveguide Flange, General Specification for.
MIL-DTL-25879	Switch, Radio Frequency Transmission Line, Coaxial Type SA-521 A/A.
MIL-DTL-28791	Isolators and Circulators, Radio Frequency, General Specification for.
MIL-DTL-28837	Mixer Stages, Radio-Frequency, General Specification for.
MIL-DTL-28875	Amplifiers, Radio Frequency and Microwave, Solid-State, General Specification for.
MIL-DTL-39030	Dummy Loads, Electrical, Coaxial and Stripeline, General Specification for.
MIL-DTL-55041	Switches, Waveguide, General Specification for.
MIL-HDBK-660	Fabrication of Rigid Waveguide Assemblies (Sweep Bends and Twists).

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Waveguides and related devices. Waveguides and related devices should be selected in accordance with the standards appearing in table 53-I and should conform to a specification listed in the table or to a specification imposed by the listed standard.

5. Detail guidelines.

5.1 RF transmission lines and fittings. EIA-979 should be used as a technical information guide for RF transmission lines and fittings.

5.2 Rigid waveguide assemblies. MIL-HDBK-660 should be used as a guide to the fabrication of rigid waveguide assemblies where bends and twists are required to satisfy a particular application.

GUIDELINE 53

TABLE 53-I. Waveguides and related devices.

Item description		Applicable document
Amplifier, RF and microwave	DIP, coaxial, TO, and flatpack	MIL-DTL-28875
Attenuators	Fixed and variable coaxial and waveguide	MIL-DTL-3933
Circulators	RF-SMA and waveguide	MIL-DTL-28791
Couplers	Directional coaxial waveguide and t printed circuit	MIL-C-15370
Coupling assemblies	Quick-disconnect for subminiature waveguide flanges	MIL-D-3954
Dummy loads	Waveguide, coaxial and stripline	MIL-DTL-39030
Flanges	Waveguide and coaxial	MIL-DTL-3922 MIL-DTL-24044
Gaskets	Pressure sealing for use with cover flanges and flat face	MIL-DTL-24211
Isolators	RF-SMA and stripline	MIL-DTL-28791
Mixer stages	RF-DIP, flatpack, TO and connector	MIL-DTL-28837
Power dividers, combiners and divider/combiners	Solder terminals, plug-in, flatpack, TO and connector	MIL-DTL-23971
Switches	Waveguide to waveguide manual and electro mechanically operated RF coaxial	MIL-DTL-55041 MIL-DTL-25879 MIL-DTL-3928
Waveguide assemblies	Flexible and rigid	MIL-DTL-287 MIL-DTL-3970 MIL-HDBK-660
Waveguides	Rigid rectangular, rigid circular, single, and double ridge	MIL-DTL-85 MIL-DTL-22641

GUIDELINE 54

MAINTAINABILITY

1. Purpose. This guideline offers guidance as to maintainability which may be considered when preparing contractual documents. Maintainability program tasks, quantitative requirements, and verification or demonstration requirements may be directly specified in the contract or the system/equipment specification, as appropriate.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-HDBK -470	Designing and Developing Maintainable Products and Systems.
MIL-HDBK-472	Maintainability Prediction.

3. Definitions. This section not applicable to this guideline.

4. General Guidelines. This section not applicable to this guideline.

5. Detail Guidelines.

5.1 Maintainability program. Maintainability engineering and accounting tasks aimed at preventing, detecting, and correcting maintainability design deficiencies and providing maintainability related information essential to acquisition, operation, and support management should be included in contract requirements with the objective of establishing and maintaining an efficient maintainability program according to life cycle phase. MIL-HDBK-470 is the overall program document for the area. MIL-HDBK-472 provides additional guidance.

5.2 Quantitative requirements. Quantitative maintainability requirements and verification or demonstration requirements should be established as appropriate to program phase.

GUIDELINE 55

ENCLOSURES

1. Purpose. This guideline establishes criteria for the design and construction of enclosures.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-F-85731	Fastener, Positive Locking, Electronic Equipment, General Specification for.
MIL-STD-108	Definitions of and Basic Requirements for Enclosures for Electric and Electronic Equipment.
EIA/ECA-310	Cabinets, Racks, Panels, and Associated Equipment.

3. Definitions.

3.1. Enclosures. Enclosures are housings such as consoles, cabinets, and cases, which are designed to provide protection and support to mechanisms, parts, and assemblies.

4. General Guidelines.

4.1. Cases and mounting bases for airborne equipment. Materials, bonding, shielding, and performance requirements of MIL-F-85731 should apply to all cases. Mounting bases should conform to MIL-F-85731, as applicable.

4.2. Degree of enclosure. Enclosures should be designed in accordance with MIL-STD-108, table I for the degree of enclosure best suited to the application. Moisture absorbent materials such as open-celled foam should not be used to fill moisture pockets.

4.3. Materials. Materials used should be corrosion and deterioration resistant, or coated to resist corrosion and deterioration.

4.4. Racks and panels. The internal clearance and the equipment mounting holes of racks and panels should be in accordance with EIA/ECA-310.

4.5. Test guidelines. Enclosures should be tested as specified in MIL-STD-108.

5. Detail Guidelines.

5.1. Cases for aerospace ground support equipment. The equipment specification or contract for the particular equipment will specify the type of case to be supplied by the contractor. Transit cases and combination type cases may not be required for ship, depot, or field shops wherever the area of use is protected or controlled for human occupancy.

5.2. Desiccants. Where moisture build up in sealed equipment cannot be tolerated, the use of desiccants or dehydrating agents should be considered.

5.3. Materials. Materials for the enclosure should be the lightest practical consistent with the strength required for sturdiness, serviceability, and safety.

GUIDELINE 56

ROTARY SERVO DEVICES

1. Purpose. This guideline establishes criteria for the selection and application of rotary servo devices such as servomotors, synchros, electrical resolvers, tachometer generators, encoders, and transolvers.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-S-22432	Servomotor, General Specification.
MIL-S-22820	Servomotor-Tachometer Generator, AC; General Specification for.
MIL-T-22821	Tachometer Generator AC; General Specification for.
MIL-S-81746	Servtorq, General Specification for.
MIL-DTL-81963	Servocomponents, Precision Instrument, Rotating, Common Requirements and Tests, General Specification for.
MIL-E-85082	Encoders, Shaft Angle to Digital, General Specification for.
MIL-STD-710	Synchros, 60 and 400 Hz, Selection and Application of.
MIL-HDBK-225	Synchros Description and Operation.
MIL-HDBK-231	Encoders Shaft Angle to Digital.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Rotary servo devices. Rotary servo devices should conform to MIL-DTL-81963 as applicable.

4.2 Servomotors. Servomotors should conform to MIL-S-22432.

4.3 Synchros. Synchros should be selected and applied in accordance with MIL-STD-710.

4.4 Tachometer generators. Tachometer generators should conform to MIL-T-22821.

4.5 Encoders. Encoders should conform to MIL-E-85082 for general application.

4.6 Servomotor-tachometer generators. Servomotor-tachometer generators should conform to MIL-S-22820.

4.7 Servtorqs. Servtorqs should conform to MIL-S-81746.

4.8 Application Information. The following documents contain additional information for application: MIL-HDBK-225 and MIL-HDBK-231.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 57

RELAYS

1. Purpose. This document is intended to be a general guide to aid the designer in the appropriate selection of a relay for the intended application.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-R-5757	Relays, Electromagnetic, General Specification for
MIL-PRF-6106	Relays, Electromagnetic, General Specification for.
MIL-PRF-28750	Relays, Solid State, General Specification for.
MIL-PRF-28776	Relays, Hybrid, Established Reliability, General Specification for.
MIL-PRF-32085	Relays, Electromagnetic, 270 V DC, Established Reliability, General Specification for
MIL-PRF-32140	Relays, Electromagnetic, Radio Frequency, Established Reliability, General Specification for
MIL-PRF-39016	Relays, Electromagnetic, Established Reliability, General Specification for.
MIL-PRF-83536	Relays, Electromagnetic, Established Reliability 25 amperes and below, General Specification for.
MIL-PRF-83726	Relays, Hybrid and Solid State, Time Delay, General Specification for.

3. Definitions.

3.1 Relay. A relay is defined as an electrically controlled device that opens and closes electrical contacts or activates and deactivates operation of other devices in the same or another electrical circuit. Two types of relay technology are available, mechanical and solid state. A mechanical relay is essentially a combination of an inductor and a switch, where the electromagnetic force of the inductor causes a switch to change position. A solid state relay accomplishes the same function with semiconductor devices changing impedance to effectively activate or deactivate a circuit open or closure

3.2 Type. Relays are classified into four general application categories, dependent on the load levels they are designed to switch. A definition of each follows:

3.2.1 Low level. Relays intended for switching low currents, typically in the milliampere range. In these circuits, only the mechanical force between the contacts affects the physical condition of the contact interface. There are no thermal or electrical effects, such as arcing.

3.2.2 Intermediate level. Relays used in load applications where there is insufficient contact arcing to effectively remove surface residue from the organic vapor deposits on the contact surface. However, there may be sufficient energy to cause melting of the contact material.

3.2.3 Power. Relays intended for switching high current loads, typically in excess of 25 A. Significant arcing occurs and the relay is designed with sufficient design margin to withstand the continuous arcing for a given number of cycles.

3.2.4 Special purpose. Sensor, hybrid, and time delay relays are classified as special purpose relays intended for specific applications. A sensor relay is designed to detect specific functions, such as frequency drift, out of phase conditions, voltage level, etc., and produce the appropriate switching response. A hybrid relay has an isolated input and output. This is accomplished through a solid state device, which controls the electromagnetic output. A mechanical time delay relay incorporates a conductive slug, or sleeve, on the core, which produces a counter-magnetomotive force and results in a switching delay. For solid state time delay relays, a separate circuit is incorporated within the device to produce the time delay.

4. General guidelines. Standardized military relays are segregated by the specifications listed on Table 57-1. Relays can further be segregated by sensitivity, or how much current is necessary to switch the relay. Increased sensitivity in non-solid state relays is accomplished by increasing the number of inductive windings inside the relay, which increases resistance.

Table 57-1 Military relay specifications

Military specification	Description
MIL-R-5757	Relays, Electromagnetic, General Specification for
MIL-PRF-6106	Relays, Electromagnetic, General Specification for
MIL-PRF-28776	Relays, Hybrid, Established Reliability, General Specification for
MIL-PRF-32085	Relays, Electromagnetic, 270 V DC, Established Reliability, General Specification for
MIL-PRF-32140	Relays, Electromagnetic, Radio Frequency, Established Reliability, General Specification for
MIL-PRF-39016	Relays, Electromagnetic, Established Reliability, General Specification for
MIL-PRF-28750	Relays, Solid State, General Specification for
MIL-PRF-83726	Relays, Hybrid and Solid State, Time Delay, General Specification for
MIL-PRF-83536	Relays, Electromagnetic, Established Reliability 5 amperes and below

4.1 Selection. Quality and reliability levels of relays may be expressed as the number of switch cycles before wear-out rather than the more traditional failure rate. Vendors consider rated number of switch cycles to be the guaranteed minimum number of cycles the relay can withstand under normal operating conditions before failure (intermittent or constant). Quality is further dependent on the ruggedness of the package and how well the internal switching elements are sealed against influences of the outside environment. Commercial grade relays and relays found in COTS equipment are not routinely acceptable for use in Military environments. Some relay vendors will advertise ISO 9000 quality systems or state they are ISO 9000 certified. Many manufacturers will then give a higher vendor rating (or increased preference) to the ISO 9000 certified vendor. While acceptable, care should be taken to also account for the fundamental design aspects of the relay. For example, a commercial-grade relay designed to withstand a sufficient number of switch cycles to operate 3 to 5 years in a particular application, should not be used in a system with an anticipated life of 15 years, even if the vendor for the commercial relay is ISO 9000 certified.

5. Detail guidelines.

5.1 Interface and physical dimensions. Relays are available in a variety of unique package styles. The size and mass of the package are dependent on the electrical characteristics, power dissipation, and the environmental requirements. Relays are generally the larger size components of a system, where increased attention should be paid to clearances and mounting, especially in high vibration level environments. Many package styles initially developed for unique applications have since gained wide acceptance.

5.2 Failure mechanisms and anomalies.

5.2.1 Failure modes. Table 57-II shows the relative probability of the three principal failure modes for relays. Relays most commonly fail in the "stuck open" position where the mechanical switching element fails to close and the relay fails to carry a current. Relays are less likely to unintentionally close or remain closed after the switching current is released. For this reason, the reliability of relay circuits can be improved by using parallel redundancy. Unlike most of the other electrical parts, relays (with the exception of solid state relays) contain a switching element that physically moves to make electrical contact. This makes them less likely to follow a constant failure rate or traditional "bathtub" curve profile. Instead, they are more prone to follow the failure rate curve for a mechanical part, with an increasing failure rate with age. Except for special high voltage and high temperature applications, solid-state relays are inherently more reliable and predictable for long life applications.

Table 57-II Normalized failure mode distribution for relays

Failure Mode	Relative Probability
Failure to Trip	55%
Spurious Trip	26%
Short	19%

5.2.2 Failure mechanisms. The two most common failure mechanisms of relays are contamination and mechanical wear of the internal switching elements discussed as follows:

a. Contamination. Contamination is a major cause of early life failures. Sources of contamination are numerous, but they are often from the various chemicals used in the manufacturing operation (e.g., soldering fluxes and cleaning agents). Types of contamination can be divided into two categories: Metallic and non-metallic. Metallic contamination causes shorted conditions or blocks the physical movement of mechanical elements. Non-metallic, or gaseous, contamination creates open circuits when it periodically deposits itself on contacts.

b. Mechanical wear. A second major cause of early life failures in relays is mechanical wear of internal switching elements. In fact, the life of a relay is essentially determined by the life of its contacts. Degradation of contacts is caused from high inrush currents, high-sustained currents, and from high voltage spikes. The source of high currents and voltages, in turn, are determined by the type of load. Inductive loads create the highest voltage and current spikes because they have lowest starting resistance compared to operating resistance. This is especially true for lamp filaments and motors, which is why derating is more severe for these types of loads. The life of a contact can be further degraded if contamination or pitting is present on the contact. Physical wear can also occur to other elements within the relay. Some relays contain springs to provide a mechanical resistance against electrical contact when a switching current is not applied. Springs will lose resiliency with time. Relays can also fail due to poor contact alignment and open coils.

5.3 Design and reliability. Selection of the proper relay type for a given application is the most significant factor affecting relay reliability. Many poor design practices are used when designing them into circuits. This is because relays are a relatively uncommon circuit element and often receive little attention during the design process. Whereas most designs will use hundreds each of microcircuits, resistors, etc.; relays typically number in the single digits. Therefore, designers are often less familiar with the intricacies of selecting the proper relay type and rating for a particular application. Some of the more common poor design practices are listed as follows:

a. Paralleling contacts. Paralleling contacting is when two relays are placed in parallel to handle the current that one of them cannot handle alone. The problem with this type of design is that mechanical switching occurs at relatively slow switching speeds. Therefore, for a brief instant, only one relay carries the full current load. Further, switching speeds tend to slow with age, amplifying the affect over time. The preferred method is to use a single relay of sufficient current handling capability. If dual relays are used in parallel in increase reliability, each relay should be capable of handling the full current load.

b. Circuit transient surges. Surge currents are often difficult to measure and predict, especially when switching inductive loads. It is not uncommon for surge current to reach ten times steady state current. Protective devices should be used to limit surge current. The simplest solution is to use a relay with a substantially higher rated surge current than anticipated.

c. High lamp currents. A cold filament lamp draws between 3 and 10 times the steady-state current until warmed up. Relay contacts used for switching lamps should be able to withstand such current surges without the possibility of welded contacts.

d. Load Transferring. Relays are sometimes used in applications where they switch a redundant circuit element, or an additional power supply current, into a circuit. High surges occur in ac applications when the redundant current is not in synchronization with the original current.

e. Polyphase Circuits. A typical misapplication is the use of small multipole relays in 112/200 volt 3-phase ac applications. Phase-to-phase shorting at rated loads is a strong possibility, with potentially catastrophic results.

f. Using relays without motor ratings to switch motor loads. Caution must be applied when using relays to reverse motors, particularly where the motor can be reversed while running (commonly called "plugging"). This results in a condition where both voltage and current can greatly exceed nominal. Only power relays rated for "plugging" and reversing service should be utilized in these applications.

g. Relay race. A relay race condition occurs when one relay must operate prior to another from a separate drive circuit, but fails to do so. The problem usually occurs after the equipment ages or temperatures rise. Potential race circuits should be avoided. Where they must be used, extra consideration must be given to wear considerations, coil suppression circuitry, ambient temperature, drive power, and operate and release times.

h. Slow rate of rise currents. A slowly rising triggering current has an increased likelihood of causing chattering conditions. A problem occurs because back electromotive forces (EMFs) are produced when the armature closes to the pole face. This voltage is opposite in polarity to the driving voltage and can cause the relay to release immediately after initial contact. This process repeats and causes a chatter condition until a sufficient amount of drive current is available to overcome the back EMF.

5.4 Derating.

5.4.1 Continuous current. Derating of continuous current is dependent upon the load type and is shown on Table 57-III. Derating is more severe for inductive and filament loads, due to high current demands upon initial startup and increased propensity of voltage spikes. If a relay is used to switch a combination of loads, the most dominant load should be used for derating purposes. Some relay specifications will contain individual current limitations for capacitive, inductive, motor, and filament loads. For such specifications, limit current to either the current derived through Table 57-I or the maximum current rating for the particular load type given in the specification, whichever is less.

5.4.2 Coil energizing voltage. The voltage to energize or trigger the relay should be at least 110% of the minimum rated energizing voltage. Coil energizing voltage is not derated in the traditional sense of the term because operation of a relay at less than nominal ratings can result in switching failures or increased switching times. The latter condition introduces contact damage and can reduce relay reliability.

5.4.3 Coil dropout voltage. The voltage to dropout or un-trigger a relay should be less than 90% of the maximum rated coil dropout voltage.

5.4.4 Temperature. Limit ambient temperature to maximum rated ambient temperature as shown in Table 57-III.

Note: Relay ratings may be given under the assumption that the relay case will be grounded. If such relays are used in applications where the case is not grounded, additional derating should be considered because the relay may lack arc barriers and contain smaller internal spacings.

Table 57-III Derating factors for relays

Part Type	Derating Parameter	% of Resistive Load Rated Value in Environment		
		Category 1 Protected	Category 2 Normal	Category 3 Severe
Relay	Continuous Current	70 -- Resistive Load 70 -- Capacitive Load 50 -- Inductive Load 30 -- Motor 20 -- Filament (Lamp)	60 -- Resistive Load 60 -- Capacitive Load 40 -- Inductive Load 20 -- Motor 10 -- Filament (Lamp)	50 -- Resistive Load 50 -- Capacitive Load 30 -- Inductive Load 20 -- Motor 10 -- Filament (Lamp)
	Coil Energize Voltage	110, Maximum	110, Maximum	110, Maximum
	Coil Dropout Voltage	90, Minimum	90, Minimum	90, Minimum
	Ambient Temperature	10°C of Max Rated	20°C of Max Rated	30°C of Max Rated

5.5 Technology and design. The construction methods and materials of each type of relay differ. Considerable differences exist between the materials and processes used to manufacture relays. A relay, in its most basic form, is a combination of a switch and an inductive element. In solid state relays, the inductor is replaced by a semiconductor element. The following lists the major categories available:

a. Reed (or dry reed). A reed relay is operated by an electromagnetic coil or solenoid which, when energized, causes two flat magnetic strips to move laterally to each other. The magnetic reeds serve both as magnetic circuit paths and as contacts. Because of the critical spacing and the frailty of the arrangement, the reeds are usually sealed in a glass tube.

b. Electromagnetic. A electromagnetic relay's operation depends upon the electromagnetic effects of current flowing in an energizing winding.

c. Electromechanical. An electromagnetic relay is an electrical relay in which the designed response is developed by the relative movement of mechanical elements under the action of a current in the input circuits.

d. Solid state. A solid state relay incorporates semiconductor or passive circuit devices. As the name implies, it contains no moving parts, and therefore has low switching noise and essentially no bounce or chatter. Solid state relays also have long life and fast response times. Their main disadvantage is a limited number of applications for which they can be used. Solid state relays are typically not used in high temperature environments.

e. Latching (or magnetic latching). A bistable polarized relay having contacts that latch in either position. A signal of the correct polarity and magnitude will reset or transfer the contacts from one position to the other.

5.6 Shock-vibration. Special mounting considerations are necessary for mechanical relays in high temperature or vibration environments because relays are typically high mass parts and can switch unintentionally when subjected to shock. Particular care is needed in airborne applications. Relays should not unintentionally switch even during absolute worse case operating conditions. In addition, the designer should take into account the wear of springs in long life applications.

5.7 Arc suppression. Arc suppression techniques should be used to protect relay contacts of intermediate and power level devices to increase long term reliability. Arc suppression usually consists of external circuitry (e.g., diodes) to limit current surge.

5.8 Parallel redundancy. To increase reliability, relays can be designed into circuits with parallel redundancy. The relative probably of a relay failing in the open position is substantially higher than failure in a closed position (see Table 57-II), thereby improving reliability in parallel redundant configurations. However, parallel redundancy should only be used to increase reliability, not to increase the current handling capabilities of a relay circuit.

GUIDELINE 57

5.9 Wide operating temperatures. For relays used over a wide temperature range, account for increased switching current demand at higher temperatures. As a general rule of thumb, coil resistance increases with temperature at a rate of 0.004 Ω/°C.

5.10 Grounded case. If a relay is rated under grounded case conditions, the relay should only be used in applications where the case will be grounded. Use in an ungrounded application may cause a personnel hazard.

5.11 Plugging. When using relays to reverse motor loads while running, use only relays specifically rated to reverse switch motor loads.

GUIDELINE 58

SWITCHES

1. Purpose. This guideline establishes criteria for the selection and application of switches and associated hardware. This guideline is not applicable to RF coaxial switches.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-DTL-15291	Switches, Rotary, Snap Action and Detent/Spring Return Action, General Specification for.
MIL-DTL-15743	Switches, Rotary, Enclosed.
MIL-S-16032	Switches and Detectors, Shipboard Alarm Systems.
MIL-S-18396	Switches, Meter and Control, Naval Shipboard.
MIL-DTL-21604	Switches, Rotary, Mulitpole and Selectors; General Specification for.
MIL-PRF-22710	Switches, Code Indicating Wheel (Printed Circuit), Thumbwheel and Pushbutton General Specification for.
MIL-PRF-22885	Switches, Push Button, Illuminated, General Specification for.
MIL-PRF-24236	Switches, Thermostatic, (Metallic and Bimetallic), General Specification for.
MIL-DTL-3786	Switches, Rotary (Circuit Selector, Low-Current Capacity), General Specification for.
MIL-DTL-3950	Switches, Toggle, Environmentally Sealed, General Specification for.
MIL-DTL-6807	Switches, Rotary, Selector Power, General Specification for.
MIL-PRF-83504	Switches, Dual In-line Package (DIP), General Specification for.
MIL-DTL-83731	Switches, Toggle, Unsealed and Sealed, General Specification for.
MIL-PRF-8805	Switches and Switch Assemblies, Sensitive, Snap Action (Basic, Limit, Push Button and Toggle Switches), General Specification for.
MIL-DTL-9395	Switches, Pressure, (Absolute, Gage, and Differential), General Specification for.
MIL-DTL-9419	Switch, Toggle, Momentary, Four-Position On, Center Off, General Specification for.
W-S-896	Switches, Toggle (Toggle and Lock), Flush Mounted (General Specification) for.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Selection and application. Switches should conform to one of the following specifications.

MIL-DTL-15291	MIL-DTL-15743	MIL-S-16032	MIL-S-18396	MIL-DTL-21604
MIL-PRF-22710	MIL-PRF-22885	MIL-PRF-24236	MIL-DTL-3786	MIL-DTL-3950
MIL-DTL-6807	MIL-PRF-83504	MIL-DTL-83731	MIL-PRF-8805	MIL-DTL-9395
MIL-DTL-9419	W-S-896.			

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 59

BRAZING

1. Purpose. This guideline establishes criteria for brazing.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

AWS C3.4	Specification for Torch Brazing.
AWS C3.5	Specification for Induction Brazing.
AWS C3.6	Specification for Furnace Brazing.
AWS C3.7M/3.7	Specification for Aluminum Brazing.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Torch brazing. Torch brazing of steel, copper, copper alloys, and nickel alloys, should be in accordance with AWS C3.4.

4.2 Induction brazing. Induction brazing of steel, copper, copper alloys, and nickel alloys, should be in accordance with AWS C3.5.

4.3 Furnace brazing. Furnace brazing of steel, copper, copper alloys, and nickel alloys, should be in accordance with AWS C3.6.

4.4 Aluminum and aluminum alloy brazing. Brazing of aluminum and aluminum alloys should be in accordance with AWS C3.7M/C3.7.

5. Detail guidelines.

5.1 Stranded or insulated wire connections. Electrical connections of stranded or insulated wire, or those having construction which may entrap fluxes, should not be brazed.

5.2 Resistance brazing. The current and electrode size for resistance brazing should be selected so that the heat will be distributed over a large enough area to allow the brazing alloy to flow freely, but not large enough to cause overheating.

GUIDELINE 60

SOCKETS AND ACCESSORIES

1. Purpose. This guideline establishes criteria for the selection and application of sockets and accessories for plug-in parts.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-DTL-12883	Sockets and Accessories for Plug-In Electronic Components, General Specification for.
MIL-DTL-24251	Shields, Retainers (Bases), and Adapters, Electron Tube, Heat Dissipating, General Specification for.
MIL-DTL-83502	Sockets, Plug-In Electronic Components, Round Style, General Specification for.
MIL-DTL-83505	Sockets, (Lead, Electronic Components) General Specification for.
MIL-DTL-83734	Sockets, Plug-in Electronic Components, Dual-in-Line (DIPs) and Single-in-Line Packages (SIPs), General Specification for.
A-A-55485	Mounting Pads, Electrical-Electronic Component, General Requirements for.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Sockets. Sockets for plug-in electronic parts should be of the single unit type and should conform to MIL-DTL-12883, MIL-DTL-83502, MIL-DTL-83505 or MIL-DTL-83734. The use of sockets for microcircuits requires approval of the procuring activity.

4.2 Shields. Heat dissipating tube shields should conform to MIL-DTL-24251.

4.3 Mounting pads. Where mounting pads are required for use with small electrical or electronic devices, they should conform to A-A-55485.

5. Detail guidelines.

5.1 Use of sockets. The use of sockets in mission related and ground support equipment should be kept to a minimum, due to the possibility of intermittent connections during shock, vibration, and temperature cycling.

5.2 Shield bases. Shield bases, for use with heat dissipating shields, should be mounted on clean, smooth, metallic mating surfaces, to minimize the contact resistance (thermal and electrical) between the base and the supporting chassis.

GUIDELINE 61

ELECTROMAGNETIC INTERFERENCE CONTROL

1. Purpose. This guideline establishes criteria for electromagnetic interference control.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-STD-464	Electromagnetic Environmental Effects Requirements for Systems.
MIL-STD-469	Radar Engineering Interface Requirements, Electromagnetic Compatibility.
NTIA Manual	National Telecommunications and Information Administration Manual of Regulations and Procedures for Radio Frequency Management.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 General. Electromagnetic interference requirements should be as specified in MIL-STD-464.

4.2 Radar equipment. Radar systems and equipment should also conform to the provisions of section 5.3 of the NTIA Manual as specified in the contract and to MIL-STD-469. MIL-STD-469 should not be used for Air Force applications. In the event of conflict, the following descending order of precedence should prevail: NTIA Manual, MIL-STD-469 then MIL-STD-464.

4.3 Tests. Tests and test methods should be as specified in MIL-STD-464. For other than Air Force applications, MIL-STD-469 should also apply for radar equipment and systems.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 62

HUMAN ENGINEERING

1. Purpose. This guideline establishes human engineering criteria which may be considered when preparing contractual documents. Human engineering, and related test and evaluation guidelines, may be directly specified in the contract or the system/equipment specification, as appropriate.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-STD-1472 Human Engineering.

3. Definitions. This section not applicable to this guideline.

4. General guidelines. This section not applicable to this guideline.

5. Detail guidelines.

5.1 Human engineering. Human engineering applied during development and acquisition of military systems, equipment, and facilities serves to achieve the effective integration of personnel into the design of the system. The objective of a human engineering effort is to develop or improve the crew/equipment/software interface and to achieve required effectiveness of human performance during system operation, maintenance and control, and to make economical demands upon personnel resources, skills, training, and costs. MIL-STD-1472 provides design criteria which may be selectively applied as guidance.

GUIDELINE 63

SPECIAL TOOLS

1. Purpose. This guideline establishes criteria for the selection and application of special tools.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

3. Definitions.

3.1 Special tools. Tools, including jigs, fixtures, stands, and templates, not listed in the Federal Supply Catalog.

4. General Guidelines.

4.1 Approval. The use of any special tool should be subject to the approval of the procuring activity.

4.2 Furnishing and stowing. Special tools needed for operation and organization level maintenance should be furnished by the contractor and should be mounted securely in each equipment in a convenient and accessible place, or in a central accessible location for an equipment array requiring such tools.

5. Detail Guidelines.

5.1 Equipment design. The design of equipment should be such that the need for special tools for tuning, adjustment, maintenance, replacement, and installation is kept to a minimum. Only when the required function cannot be provided by an existing standard tool should special tools be considered and identified as early as possible.

GUIDELINE 64

MICROELECTRONIC DEVICES

1. Purpose. This guideline establishes criteria for the selection and application of microelectronic devices. These criteria are based on the objectives of achieving technological superiority, quality, reliability, and maintainability in military systems.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-PRF-38534	Hybrid Microcircuits, General Specification for.
MIL-PRF-38535	Integrated Circuits (Microcircuits) Manufacturing, General Specification for.
MIL-HDBK-103	List of Standard Microcircuit Drawings.
QML-38534	Qualified Manufacturers List of Hybrid Microcircuits.
QML-38535	Qualified Manufacturers List of Integrated Circuits (Microcircuits) Manufacturing.
SD-18	Program Guide for Parts Requirement and Application.

3. Definitions.

3.1 Microelectronic devices: Monolithic, hybrid, radio frequency, and microwave (hybrid/monolithic) circuits, multichip microcircuits, and microcircuit modules.

3.2 Qualified device (microcircuit): Any device or microcircuit which has met the requirements of MIL-PRF-38535 (monolithic) and MIL-PRF-38534 (hybrid) and is listed on the associated Qualified Manufacturers Listing (QML).

3.3 Reliability. The probability of a part performing its specified purpose for the period intended under the operating conditions encountered.

3.4 Derating. The method of reducing stress and making quantitative allowances for a part's functional degradation. Consequently, derating is a means to reduce failures and extending part life. In addition, derating helps protect parts from unforeseen application anomalies and overstresses. (See guideline 18).

4. General Guidelines.

4.1 General. At each stage in new and re-engineered system designs, (e.g., concept studies, demonstration and validation, and full scale development) the advanced microcircuit technologies which meet reliability, performance, and cost requirements of the application should be evaluated for use in the production phase. Standard parts should be used to the maximum extent possible.

4.2 General guidelines. The use of microelectronic devices should be qualified and monitored to the application and environment they are used in. The "Parts Requirement and Application Guide", SD-18, is recommended to be used as guidance.

4.3 Parts standardization. Parts standardization is encouraged. Standardization positively affects logistic supportability, the overall life cycle costs, obsolete part issues, as well as the quality and reliability of the devices. Standard microcircuit devices are listed in QML-38535 (qualified monolithic parts), QML-38534 (qualified hybrid parts), MIL-HDBK-103 (all standard parts covered on Standard Microcircuit Drawings), and in electronic format on the DSCC web site, https://landandmarititmeapps.dla.mil.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 65

CABLE, COAXIAL (RF)

1. Purpose. This guideline establishes criteria for the selection and application of coaxial Radio Frequency (rf) cable.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

EIA-979	RF Transmission Line and Connector Selection Guide
MIL-DTL-17	Cables, Radio Frequency, Flexible and Semirigid, General Specification for.
MIL-DTL-3890	Lines, Radio Frequency Transmission (Coaxial, Air Dielectric), General Specification for.
MIL-DTL-22931	Cables, Radio Frequency, Semirigid, Coaxial, Semi-Air-Dielectric, General Specification for.
MIL-DTL-23806	Cable, Radio Frequency, Coaxial, Semirigid, Foam Dielectric, General Specification for.
MIL-DTL-28830	Cable, Radio Frequency, Coaxial, Semirigid, Corrugated Outer Conductor, General Specification for.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Cable selection. Selection of coaxial cable should be in accordance with MIL-DTL-17, MIL-DTL-3890, MIL-DTL-22931, MIL-DTL-23806 or MIL-DTL-28830. Other types of cable may be used provided they are selected from specifications acceptable for the specific application and approved by the procuring activity.

4.2 Application restriction. Cables with polyvinyl chloride insulation should not be used in shipboard or aerospace applications. Use of these cables in any other application requires prior approval by the procuring activity.

5. Detail Guidelines.

5.1 Application guidance. EIA-979 may be used as a technical information guide to applications of transmission lines and fittings.

5.2 Critical circuits. For use above 400 MHz and in critical RF circuits, elements such as environmental requirements, short leads, and grounding should be considered in design application, along with critical electrical characteristics such as attenuation, capacitance, and structural return loss.

GUIDELINE 66

CABLE, MULTICONDUCTOR

1. Purpose. This guideline establishes criteria for selection and application of electrical multiconductor cable for use within electronic equipment.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

QQ-W-343	Wire, Electrical, Copper (Uninsulated).
MIL-DTL-17	Cables, Radio Frequency, Flexible and Semirigid, General Specification for.
MIL-DTL 3432	Cables (Power and Special Purpose) and Wire, Electrical (300 and 600 Volts).
MIL-DTL-16878	Wire, Electrical, Insulated, General Specification for.
SAE-AS22759	Wire, Electric, Fluoropolymer-Insulated, Copper or Copper Alloy.
MIL-DTL-24640	Cables, Light-weight, Electric, for Shipboard Use, General Specification for.
MIL-DTL-27072	Cable, Power, Electrical and Cable, Special Purpose Electrical, Multiconductor and Single Shielded, General Specification for.
MIL-DTL-55021	Cable, Electrical, Shielded Singles, Shielded and Jacketed Singles, Twisted Pairs and Triples, Internal Hookup, General Specification for.
MIL-DTL-5846	Chromel and Alumel, Thermocouple Electrical WIre
SAE-AS81044	Wire, Electric, Crosslinked Polyalkene, Crosslinked Alkane-Imide Polymer, or Polyarylene Insulated, Copper or Copper Alloy.
ASTM B 298	Standard Specification for, Silver-Coated Soft or Annealed Copper Wire.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Selection and application. Selection and application of multiconductor cable should be in accordance with table 66-I.

4.2 Solid or stranded. Either solid or stranded conductors may be used (within the restrictions of the particular wire or cable specification) except that: (1) with the exception of thermocouple and flat cable wire, only stranded wire should be used in aerospace applications; and (2) for other applications, stranded wire should be used when so indicated by the equipment application. Specifically, with the exception of flat multi-conductor flexible cable, stranded wire should be used for wires and cables which are normally flexed in use and servicing of the equipment, such as cables attached to the movable half of detachable connectors.

4.3 Application restrictions.

4.3.1 MIL-DTL-16878 usage. Cable containing MIL-DTL-16878 wire should not be used for Air Force or Navy aerospace applications.

4.3.2 Polyvinyl chloride insulation. Cables with polyvinyl chloride insulation should not be used in aerospace applications. Use of these cables in any other application requires prior approval of the procuring activity

4.3.3 Single polytetrafluoroethylene insulation. Wire with only single polytetrafluoroethylene insulation I accordance with SAE-AS22759 used in Air Force space and missile applications requires the approval of the procuring activity.

4.3.4 Silver plated copper wire. Silver plated copper wire should not be used in applications involving Army missile systems without certification by the wire manufacturer that it passes the sodium polysulfide test in accordance with ASTM B 298. Silver plated copper wire should not be used in conjunction with water-soluble solder fluxes. Wire should be stored and handled in such a way so as to minimize exposure to moisture.

GUIDELINE 66

5. Detail Guidelines.

5.1 Solid or stranded. Stranded wire should be used for conductors and cables which are normally flexed in use and servicing of the equipment, such as cables attached to the movable half of detachable connectors and hanging cables attached to removable or movable doors and shields. Leads 150 mm or less in length may be run as solid wires unless they form interconnections between shock isolation mounted parts and non-shock isolation mounted parts. There are some other instances, such as wire wrapping, where a solid conductor may be required regardless of length.

5.2 Stranded copper conductor test. The following test procedure should be used for stranded conductors since the ASTM B 298 test procedure covers only a single, round conductor.

5.2.1 Sodium polysulfide test. The stranded samples of annealed copper, or copper alloy base material, should be tested in accordance with ASTM B 298 with the following exceptions:

NOTE: The ASTM test applies to single-end wires "taken before stranding". The applicability of the polysulfide test is thus restricted by the ASTM in recognition of the abrasion to the wire inherent in the stranding process.
The following exceptions and criteria should be applied when testing stranded product:

a. Examination of the samples to occur immediately after the solution cycle.

b. Samples to be immersed into the solutions in the as-stranded condition.

(1) Unilay constructions to be tested as the whole conductor.

(2) Concentric constructions to be tested as whole conductor.

(3) Two members from each layer of rope construction to be tested after they have been carefully removed from the finished rope.

TABLE 66-I. Cable, multiconductor.

			Conductor			Shield braid 3/			Jacket 3/	
Specification number	Title	Basic wire specifications	Number of conductors	Volts RMS	Temp 2/	Strand material	Strand coating	% Coverage	Material 1/	Type
MIL-DTL-3432	Cable (Power and Special Purpose) and Wire, Electrical (300 & 600V)	QQ-W-343& Insulation	Unlimited and mixed sizes 4/ 5/	300 and 600	-40°C to +65°C or -55°C to +75°C	None or Copper	Tin	85	Styrene butadiene rubber, chloroprene rubber, ethylene-propylene -dinne, rubber, polyurethan thermoplastic elastomer, or natural rubber	Extruded & vulcanized
MIL-DTL-24640	Cable, Electrical, Light-weight, for shipboard use	SAE-AS81044	2-77 pair	600	150°C	Copper tape	Tinned	85	Crosslinked, polyalkene, crosslinked alkaneimid, polymer, or polyarylene	Extruded
MIL-DTL-27072 See NOTE.	Cable Special Purpose, Electrical, Multi-conductor	MIL-DTL-17 MIL-DTL-5846 M16878/1 M16878/2 M16878/3 M16878/4 M16878/5 M16878/6 M16878/10 M16878/13	2-36	Various Various 600 1000 3000 600 1000 250 600 250	Not Spec Not Spec 105°C 105°C 105°C 200°C 200°C 200°C 75°C 200°C	Copper Note: MIL-DTL-27072 applicable detail specification sheets control Materials for each specific cable configuration	Tin, Silver	85	Sheath of PVC, Polyethylene, Polychloroprene, polyamide, TFE-Teflon, or FEP-Teflon	
MIL-DTL-55021	Cable, Twisted Pairs & Triples, Internal Hookup, General Specification for	MIL-W-16878	2-3	600 to 1000°	-40°C to +105°C or -65°C to +200°C	None or Copper	Tin, Silver or Nickel	90	None PVC, Nylon TFE-Teflon	Extruded Extruded or tape

NOTE: Flexible mulit-conductor cable for use in protected areas: tunnels, wire ways, instrument racks, and conduit. Polyethylene jacketed cable suitable for underwater or direct burial applications only. M16878/6 and /13 not for aerospace applications

1/ Polyester - Polyethylene Terephthalate
TFE-Teflon - Polytetrafluoroethylene
PVC - Polyvinly chloride (Not to be used in airborne applications)
KEL-F - Polymonochlorotrifluoroethylene
FEP-Teflon - Fluorinated ethylene propylene
PVF - Polyvinylidene fluoride

2/ See applicable detail specification sheet for temperature limitation.

3/ See applicable detail specification sheet for materials control of specific cable configurations

4/ Although the specification does not limit the number of conductors in a cable, the size, weight, and flexibility are determining factors.

5/ Available in three classifications:

Class L - Light Duty - to withstand severe flexing and frequent manipulation

Class M - Medium Duty - to withstand severe flexing and mechanical abuse

Class H - Heavy Duty - to withstand sever flexing and mechanical abuse and ability withstand severe service impacts such as to be run over by tanks or trucks .

6/ See applicable detail specification sheet for mechanical test requirements for cold bend, cold bend torque, impact bend, and twist.

7/ For use under abusive mechanical conditions and resistance to weather, oil and ozone are requirements.

GUIDELINE 67

MARKING

1. Purpose. This guideline establishes criteria for external and internal markings on equipment, assemblies and component parts. Marking for safety, shipping and handling is not within the scope of this guideline.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-DTL-15024	Plates, Tags, and Bands for Identification of Equipment.
MIL-DTL-18307	Nomenclature and Identification for, Aeronautical Systems Including Joint Electronics .Type Designated Systems and Associated Support Systems.
MIL-DTL-81963	Servocomponents, Precision Instrument, Rotating, Common Requirements and Tests, General Specification for.
MIL-STD-130	Identification Marking of U.S. Military Property.
MIL-STD-196	Joint Electronics Type Designation System.
MIL-STD-411	Aircrew Station Alerting Systems.
JSSG-2010	Crew Systems.
MIL-STD-1285	Marking of Electrical and Electronic Parts.
MIL-STD-13231	Marking of Electronic Items.
MIL-HDBK-505	Definitions of Item Levels, Item Exchangeability, Models, and Related Terms.
AIM BC1	Uniform Symbology Specification - Code 39.
ASME Y14.38	Abbreviations and Acronyms.
ASTM D 4956	Standard Specification for Retro reflective Sheeting for Traffic Control.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Patent information. At the manufacturer's option, patent information may be included on equipment, subject to the following restrictions:

a. The identification plate may contain patent information when approved by the procuring activity.

b. The location of, and method used to mark, patent information should not conflict with any specified equipment guidelines, such as marking, enclosure integrity, control, and indicator locations, etc.

c. Patent information should not be located on, or in, equipment having a security classification of confidential or higher, with the exception that patented items used in security classified equipment, when marked, should be marked in such a manner that patent information should be visible only when the item is removed or disassembled for repair or replacement.

4.2 Symbology.

421 Reference designations. Except for external connectors and cables, reference designations should be employed to identify the location of each item for its particular circuit application. The identification and marking of reference designators for parts and equipment should be in accordance with IEEE 200. On subminiaturized assemblies, such as printed or etched boards or other forms of assembly where space is at a premium, the reference designations need not be marked. In lieu thereof, reference designation marking should be shown by means of pictorial diagrams, line drawings, photographs, or other media to provide for circuit identification (by means of reference designations) in the appropriate handbooks for the equipment. It should not be mandatory to mark the reference designations of parts in nonrepairable subassemblies. Connectors may be further identified on that side of the panel to which the mating connector attaches, by a name denoting the function of the cable attached thereto. External cables should be assigned reference designations W1, W2, etc., for identification. The numerical portions of the reference designations should be consecutive, where practicable.

GUIDELINE 67

4.2.2 Abbreviations and legends. Abbreviations and legends should conform to MIL-STD-411, or JSSG-2010 as applicable.

4.3 Marking methods. Equipment, parts and assemblies should be permanently marked or identified. Permanency and legibility should be as required in MIL-STD-130.

4.3.1 Direct marking. Markings may be applied directly to a part, or an assembly, by die or rubber stamping, etching, engraving, molding, casting, forging, decalcomania transfer, stenciling, or silk screening.

4.3.2 Plates. Information and identification plates should conform to, and should be marked, in accordance with MIL-DTL-15024.

4.3.2.1 Identification (ID) plates. The ID plate should be fastened in such a manner as to remain firmly affixed throughout the normal life expectancy of the item to which it is attached. Type G, adhesive-backed metal, ID plates should be used on hermetically sealed items, magnesium cases, or other items where mounting of a plate by mechanical fasteners is impractical.

4.3.2.2 ID plate location. Plates should be located so that they are not obscured by other parts.

4.3.3 Marking cables, cords, and wires. The following methods should be used to mark cables, cords, and wires:

a. Molded on the cable or cord.

b. Stamped on the cable, cord, or wire.

c. Bands in accordance with MIL-P-15024, securely attached or captivated.

d. Adhesive tag or tape that should withstand the applicable environmental guidelines.

NOTE: Hot stamp marking has been determined to damage the wire insulation. Therefore hot stamp marking should not be used for direct marking on wire and cable intended for aerospace vehicle equipment.

4.4 Bar codes. Bar codes should conform to AIM-BC1.

4.5 Type designated items. Each item which is type designated in accordance with MIL-STD-196 should contain an identification marking in accordance with MIL-DTL-18307 for Navy and Air Force or MIL-STD-13231 for Army. These items are systems (electrical-electronic), sets, groups, and some units and assemblies, as defined in MIL-HDBK-505.

4.6 Fuse holders. The current rating of fuses should be marked adjacent to the fuse holder. In addition, "SPARE" should be marked adjacent to each spare fuse holder.

4.7 Connections. Marking adjacent to plugs, jacks, and other electrical connectors should identify the connected circuits to preclude cross connections. The connections to electrical parts such as motors, generators, and transformers should be marked.

4.8 Servo-component connections and markings. Servo-component marking and connection identification should conform to MIL-DTL-81963.

4.9 Controls and indicating devices. Markings should be provided on the front of each exterior and interior panel and panel door, also on control mounting surfaces of each chassis, subpanel, etc., to clearly (though necessarily briefly) designate the functions and operations of all controls, fuses, and indicating devices mounted thereon, protruding through, or available through, access holes therein. All markings should be located on the panel or chassis in correct relationship to the respective designated items.

GUIDELINE 67

4.10 Sockets. The chassis should be marked to identify both sockets and parts, modules, or assemblies to be plugged into the sockets. The side of the chassis upon which items are plugged into sockets should be marked, adjacent to each socket, with the reference designation for the item. The reverse side of the chassis should be marked, adjacent to each socket, with the reference designation used in the circuit diagram and table of parts to identify the socket itself. If space does not permit marking of reference designations for sockets and parts, modules, or assemblies mounted in sockets, a location diagram should be placed where it is visible when viewing the chassis, and should display the markings described herein.

4.11 Cables, cords, and wires. All cables, cords, and wires which require disconnection to remove units for servicing and maintenance should be uniquely identified.

4.12 Printed wiring boards. Markings on printed wiring boards should not interfere with electrical operation. When ink is used, it should be nonconductive. Markings should be considered when leakage (creepage) distances are determined.

4.13 Replaceable parts and assemblies. Replaceable parts and assemblies should be marked for identification in accordance with MIL-STD-1285 or MIL-STD-130, as applicable.

4.14 Programmable items. Equipments which are software programmable should indicate the identifying number and revision of the software program which has been loaded into memory. The preferred method is to provide either a local or a remote display which is under the control of the software program. However, when the use of a display is not practical, the equipment enclosure should be marked with the information asfollows.

4.14.1 Preproduction and production equipment. Preproduction and production equipment should be marked with the identifying number and revision of the software program. The identifying number should be preceded by the words "software program".

4.14.2 Development equipment. Development equipment should be marked in a manner similar to preproduction and production equipment, except that means should be provided to easily change the revision letter by the use of a matte surface for hand marking or by using self-adhesive labels. The use of the revision letter, or number, and a patch letter, or number, is permissible.

4.14.3 Certain hardware changes. The marking guideline does not apply when changes to the software program are accomplished by making a hardware change (for example, when the software program resides in fusible link devices such as PROMs). In such cases, the marking guidelines applicable to a hardware change should apply.

5. Detail Guidelines.

5.1 Reflective markers. Where reflective markers are required, reflective polyester tape in accordance with ASTM D 4956 may be used.

GUIDELINE 68

READOUTS AND DISPLAYS

1. Purpose. This guideline establishes criteria for the selection of readouts and displays.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-DTL-28803	Display, Optoelectronic, Readouts, Back Lighted Segmented, General Specification for.
MIL-PRF-19500/708	Displays, Diode, Light Emitting, Solid State, Red, Numeric and Hexadecimal, with On Board Decoder/Driver Types 4N51, 4N52, 4N53 and 4N54 JAN and JANTX.

3. Definitions.

3.1 Readouts and displays. Readouts and displays are devices which are designed primarily to convert electrical information into alphanumeric or symbolic presentations. These devices may contain integrated circuitry to function as decoders or drivers.

4. General guidelines.

4.1 Optoelectronic type readouts. Optoelectronic type readouts should conform to MIL-DTL-28803.

4.2 Light emitting diode displays. Visible light emitting diode displays should conform to MIL-PRF-19500/708.

4.3 Night vision goggles. Night Vision Goggle compatibility considerations for cockpit readouts and displays should be considered where use of night vision goggles by cockpit crews is possible.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 69

INTERNAL WIRING PRACTICES

1. Purpose. This guideline establishes criteria for internal wiring practices.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-T-152	Treatment, Moisture and Fungus Resistant, of Communications, Electronic and Associated Electrical Equipment.
MIL-I-631	Insulation, Electrical, Synthetic-Resin Composition, Non rigid.
MIL-T-713	Twine, Fibrous: Impregnated, Lacing and Tying.
MIL-I-3158	Insulation Tape, Electrical Glass-Fiber (Resin Filled): and Cord, Fibrous-Glass.
MIL-I-3190	Insulation Sleeving, Electrical, Flexible, Coated, General Specification for.
MIL-I-22076	Insulation Tubing, Electrical, Non rigid, Vinyl, Very Low Temperature Grade.
MIL-STD-108	Definitions of and Basic Requirements for Enclosure for Electric and Electronic Equipment.
SAE AS 7928	Terminals, Lug: Splices, Conductor: Crimp Style, Copper, General Specification for.
SAE AS 23190	Straps, Clamps, and Mounting Hardware, Plastic and Metal for Cable Harness Tying and Support.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Clearance and leakage (creepage) distances. Clearance between solder connections or bare conductors, such as on terminal strips, standoffs, or similar connections, should be such that no accidental contact can occur between adjacent connections when subjected to service conditions specified in the equipment specification. For electrical clearance and leakage distances, see Table 69-I.

4.2 Through hole protection. Whenever wires are run through holes in metal partitions, shields, and the like, less than 3 mm in thickness, the holes should be equipped with suitable mechanical protection (grommet) of insulation. Panels 3 mm or more in thickness either should have grommets or should have the hole edges rounded to a minimum radius of 1.5 mm.

a. Condition A. For use where the effect of a short circuit is limited to the unit and where normal operating power does not exceed 50 watts.

b. Condition B. For use where short circuit protection in the form of fuses, circuit breakers, etc., is provided and where normal operating power does not exceed 2000 watts.

c. Condition C. For use where short circuit protection in the form of fuses, circuit breakers, etc., is provided and where normal operating power exceeds 2000 watts.

d. Enclosure I. Enclosure I is an equipment enclosure which has no openings, or in which the openings are so constructed that drops of liquid or solid particles striking the enclosure at any angle from 0° to 15° from the downward vertical cannot enter the enclosure, either directly or by striking and running along a horizontal or inwardly inclined surface. (Drip-proof enclosure for other than motors, generators, and similar machines of MIL-STD-108 meets the description).

e. Enclosure II. Enclosure II is any equipment enclosure which affords less protection than enclosure I.

GUIDELINE 69

TABLE 69-I. Electrical clearance and leakage (creepage) distances.

Voltage ac (rms) or dc	Condition	Clearance (mm)	Leakage distances (mm)	
			Enclosure I	Enclosure II
Up to 150	A	1.5	1.5	1.5
	B	3	3	6
	C	6	9.5	19
150 to 300	A	1.5	1.5	1.5
	B	3	3	6
	C	6	12.5	19
300 to 600	A	1.5	3	3
	B	3	6	6
	C	6	12.5	19
600 to 1000	A	3	9.5	12.5
	B	6	19	25
	C	12.5	38	50

4.3 Wiring arrangement. Wiring should be arranged to permit bundling by one or more of the following methods or permanently mounted in cable ducts.

4.3.1 Lacing. Twine should be in accordance with Type P of MIL-T-713. Cordage should be in accordance with type SR-4.5 of MIL-I-3158.

4.3.2 Sleeving insulation. Sleeving insulation should conform to MIL-I-631, MIL-I-3190, or MIL-I-22076.

4.3.3 Wrapping and tying. Plastic devices for wrapping and tying of wires should conform to SAE AS 23190.

4.4 Clamped connections. In no case should electrical connections depend upon wires, lugs, terminals, and the like, clamped between a metallic member and an insulating material of other than a ceramic or vitric nature. Such connections should be clamped between metal members, preferably, such as an assembly of two nuts, two washers and a machine screw.

4.5 Connectors, insulation sleeving. Unpotted connectors furnished as integral wired in parts of articles of equipment should have a piece of insulating tubing placed over each wire in the connector. The tubing should be long enough to cover the contact and at least 12.5 mm of insulation of the wire attached to it; but in no case should the length of the tubing exceed 50 mm. The minimum length of 12.5 mm may be reduced to 4.5 mm where restricted volume does not permit longer tubing (such as in miniaturized electronic subassemblies). The tubing should fit tightly over the contact or be tied securely enough so that it will not slide off. If bare wire is used, the tubing should be long enough to extend at least 6 mm beyond the contact, metal shell or clamp, whichever projects the farthest. This section does not apply to connectors with body insulated crimp-on contacts, to insulation displacement connectors, or mass soldered flat cable connectors.

5. Detail guidelines.

5.1 Wiring arrangement. All wiring should be arranged in a neat and workmanlike manner. The use of preformed cables and wiring harness is preferred to the point-to-point method of wiring. Wires should be bundled and routed to minimize electrical coupling. Unless suitably protected, wire or cable attached to sensitive circuits should not be placed adjacent to a disturbing circuit.

5.2 Internal wiring. Stranded wire is preferred; however, solid wire may be used in the equipment, provided such wire is so insulated, or held in place, that it does not fail or show excessive motion likely to result in failure when the equipment is subjected to vibration and shock encountered under the specified service conditions. An uninterrupted wire is preferable to a junction. The following descending order of preference exists when junctions are used, and the choice of the listed junctions should be determined by consideration of reliability factors, maintenance factors, and manufacturing procedures.

a. Permanent splices.

b. Bolted connections.

c. Connectors.

5.3 Wiring protection. The wiring should be secured and protected against chafing due to vibration or movement (such as slide out racks or drawers). For securing of wiring, polyamide clamps, or wrapping and tying devices with integral mounting facilities, or adhesive bonding are preferred. Metal clamps, if used, should be cushioned. Individual conductors thus secured should lie essentially parallel.

5.4 Cable ducts. Where cable ducts are employed, provisions should be made for the removal of any wire that may become faulty. For example, covers may be employed at intervals to aid in the removal of a faulty wire.

5.5 Bend radius. The bend radius of polyethylene cable should not be less than five times the cable diameter to avoid establishing a permanent set in the cable.

5.6 Sleeving. Flexible plastic sleeving, either nonflammable, self-extinguishing, or flame retardant, should be used on cables subject to flexing, such as panel door cables. The sleeving should be secured under cable clamps at each end, and the cable should be formed and secured so that the cable will not be subject to abrasion in its normal flexing motion. In cases where abrasion cannot be avoided, additional protection should be provided.

5.7 Panel door cables. Wiring to parts on a hinged door should be in a single cable if possible, arranged to flex without being damaged when the door is opened and closed.

5.8 Slack. Wires and cable should be as short as practicable, except that sufficient slack should be provided to:

a. Prevent undue stress on cable forms, wires, and connections, including connections to resiliently supported parts.

b. Enable parts to be removed and replaced during servicing without disconnecting other parts.

c. Facilitate field repair of broken or cut wires.

d. Permit units in drawers and slide out racks to be pulled out to the limit of the slide or support travel without breaking connections. Units which are difficult to connect when mounted, should be capable of movement to a more convenient position for connecting and disconnecting cables. When drawers or racks are fully extended and rotated, if rotatable, the cable bend radius should not be less than three times the cable assembly diameter. When flat molded cable assemblies are used, the bend radius should not be less than ten times the cable assembly thickness.

e. Permit replacement of the connected part at least twice. Exceptions to this provision are cases where RF leads must be as short as possible for electrical reasons, when fixed path rotating is specified, or the amount of slack is limited by space available; ensure freedom of motion of lugs or terminals normally intended to have some degree of movement.

5.9 Support. Wire and cable should be properly supported and secured to prevent undue stress on the conductors and terminals and undue change in position of the wire or cable during and after subjection of the equipment to specified service conditions, or after service or repair of the equipment in a normal manner. When shielding on wire or cable is unprotected by an outer insulation, adequate support is necessary to prevent the shielding from coming in contact with exposed terminals or conductors. Twine or tape should not be used for securing wire and cable.

GUIDELINE 69

5.10 Cable and harness design. Cables and separable harnesses should be of the two-connector type. The two connectors should be of the same number of contacts and all contacts should be wired point-to-point; (e.g., pin 1 to pin 1, pin A to pin A, or pin 1 to pin A and up in sequence). A minimum number of connector types and contact configurations within a type should be used consistent with noncrossmating guidelines, and circuit and spare considerations.

5.11 Solderless crimp connections. Solderless crimp connections should meet the following guidelines:

a. Insulated, solderless lugs are preferred and should conform to SAE AS 7928.

b. Where thermal or other considerations prevent the use of insulated lugs, noninsulated solderless lugs conforming to SAE AS 7928 should be used, provided they are covered with an insulating sleeve.

5.12 Fungus protection. Prior to attachment of terminals to prepared lengths of cables which contain materials that will support fungus, the ends should be protected against entrance of moisture and fungus by treatment with a fungicidal varnish in accordance with MIL-T-152.

GUIDELINE 70

ELECTRICAL FILTERS

1. Purpose. This guideline establishes criteria for the selection and application of electrical filters.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-PRF-15733	Filters and Capacitors, Radio Frequency Interference, General Specification for.
MIL-PRF-28861	Filters and Capacitors, Radio Frequency/Electromagnetic Interference Suppression, General Specification for.

3. Definitions. This section not applicable to this guideline.

4. General Guidelines. Electrical filters should be selected and applied in accordance with MIL-PRF-15733 and MIL-PRF-28861.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 71

CABLE AND WIRE, INTERCONNECTION

1. Purpose. This guideline establishes criteria for the selection and application of electric cable and wire used for interconnection between units.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

A-A-59551	Wire, Electrical, Copper (Uninsulated)
MIL-DTL-17	Cables, Radio Frequency, Flexible and Semi rigid, General Specification for
MIL-DTL-3432	Cables (Power and Special Purpose) and Wire, Electrical (300 and 600 Volts)
MIL-DTL-8777	Wire, Electrical, Silicone-Insulated, Copper, 600 Volt, 200 C
MIL-C-13777	Cable, Special Purpose, Electrical, General Specification for
MIL-DTL-16878	Wire, Electrical, Insulated, General Specification for
SAE-AS22759	Wire, Electric, Fluoropolymer-Insulated, Copper or Copper Alloy
MIL-DTL-24640	Cables, Light-weight, Electric, for Shipboard Use, General Specification for
MIL-DTL-24643	Cables and Cords, Electric, Low Smoke, for Shipboard Use, General Specification for
MIL-DTL-25038	Wire, Electrical, High Temp, Fire Resistant and Flight Critical
MIL-DTL-27072	Standard for Aerospace and Industrial Electrical Cable
NEMA WC 27500	Cable, Power, Electrical, and Cable Special Purpose, Electrical Shielded and Unshielded, General Specification for
MIL-DTL-55021	Cable, Electrical, Shielded Singles, Shielded and Jacketed Singles, Twisted Pairs and Triples, Internal Hookup, General Specification for
SAE-AS81044	Wire, Electric, Crosslinked Polyalkene, Crosslinked Alkane-Imide Polymer, or Polyarylene Insulated, Copper or Copper Alloy
MIL-DTL-81381	Wire, Electric, Polyimide-Insulated, Copper or Copper Alloy
MS25471	Wire, Electrical, Silicone-Insulated, Copper, 600 Volt, 200 C, Polyester Jacket
MS27110	Wire, Electrical Silicone Insulated, Copper, 600 Volt, 200 C, FEP Jacket
ASTM A 580/A 580M	Standard Specification for Stainless Steel Wire
ASTM B33	Standard Specification for Wire, Tinned Soft or Annealed Copper Wire for Electrical Purposes
ASTM B298	Standard Specification for Silver-Coated Soft or Annealed Copper Wire
ASTM A 580	Standard Specification for Stainless Steel Wire
SAE AS 50861	Wire, Electric, Polyvinyl Chloride Insulated, Copper or Copper Alloy

3. Definitions.

3.1 Interconnecting wire. Insulated, single-conductor wire used to carry electric current between units.

3.2 Interconnecting cable. Two or more insulated conductors contained in a common covering, or one or more insulated conductors with a gross metallic shield outer conductor used to carry electrical current between units.

4. General guidelines.

4.1 Wire selection. Selection of wire for interconnection between units should be in accordance with table 71-I.

4.2 Multiconductor cable selection. Selection of multiconductor cable for interconnection between units should be in accordance with table 71-II.

4.3 Application restrictions.

4.3.1 MIL-DTL-16878 usage. MIL-DTL-16878 should not be used for Air Force or Navy aerospace applications.

4.3.2 Insulation restriction. Cable or wire with polyvinyl chloride insulation should not be used in aerospace applications. Use of these wires or cables in any other application requires prior approval of the procuring activity.

GUIDELINE 71

4.3.3 SAE-AS 22759 usage. SAE-AS 22759 wire with only single polytetra-fluoroethylene insulation used in Air Force space and missile applications will require the approval of the procuring activity.

4.3.4 Aluminum wire. Use of aluminum wire may need specific approval by the procuring activity.

4.3.5 Silver plated copper wire. Silver plated copper wire should not be used in applications involving Army missile systems without certification by the wire manufacturer that it passes the sodium polysulfide test in accordance with ASTM B 298. Silver-plated copper wire should not be used in conjunction with water-soluble solder fluxes. Wire should be stored and handled in such a way so as to minimize exposure to moisture.

5. Detail Guidelines.

5.1 Pulsed or RF signals. All interconnecting cables carrying pulsed or RF signals should be coaxial cables or waveguides and should be terminated, when possible, in the characteristic impedance of the transmitting media.

5.2 Stranded copper conductor test. The following test procedure should be used for stranded conductors since the ASTM B 298 procedure covers only a single, round conductor.

5.2.1 Sodium polysulfide test. The stranded samples of annealed copper or copper alloy base material should be tested in accordance with the ASTM B 298, with the following exceptions:

NOTE: The ASTM test applies to single-end wires "taken before stranding". The applicability of the polysulfide test is thus restricted by the ASTM in recognition of the abrasion to the wire inherent in the stranding process. The following exceptions and criteria should be applied when testing stranded product.

a. Examination of the samples to occur immediately after the solution cycle.

b. Samples to be immersed into the solutions in the as-stranded condition.

(1) Unilay constructions to be tested as the whole conductor.

(2) Concentric constructions to be tested as whole conductor.

(3) Two members from each layer of rope constructions to be tested after they have been carefully removed from the finished rope.

5.3 Solid or stranded. Stranded wire should be used for conductors and cables which are normally flexed in use and servicing of the equipment, such as cables attached to the movable half of detachable connectors and hanging cables attached to removable or movable doors and shields. Leads 150 mm or less in length may be run as solid wires unless they form interconnections between shock isolation mounted parts and non-shock isolation mounted parts. There are some other instances, such as wire wrapping, where a solid conductor may be required regardless of length.

5.4 Cold flow. Certain insulating materials exhibit a cold flow characteristic. Caution should be used in the selection of these materials in applications requiring restrictive clamping or tying, etc., where this feature may result in exposed or shorted conductors.

5.5 Stranded copper conductor test. The following test procedure should be used for stranded conductors since the ASTM B 298 procedure covers only a single, round conductor.

5.5.1 Sodium polysulfide test. Stranded samples of annealed copper or copper alloy conductors should be tested in accordance with ASTM B 298. When this test is performed, one factor which should be taken in to consideration is that the ASTM test applies to single end wires taken before stranding. Thus, the applicability of the polysulfide test is restricted by the ASTM in recognition of the abrasion to the wire inherent in the stranding process. As a result, the following exceptions and criteria apply when testing stranded product.

GUIDELINE 71

a. Examination of the samples to occur immediately after the solution cycle.

b. Samples to be immersed into the solution in the as-stranded condition.

(1) Unilay constructions to be tested as the whole conductor.

(2) Concentric constructions to be tested as whole conductor.

(3) Two members from each layer of rope constructions to be tested after they have been carefully removed from the finished rope.

Specification Number.	Title	Spec Type or class	Construction						Max Cond Temp ^{0}C	Max rms volts	Remarks
			Conductor 1/			Insulation 2/					
			Material	Coating	Type	Primary	Primary Cover	Jacket/ topcoat			
SAE AS 50861	Wire, Electric, PVC Insulated, Copper or Copper Alloy	M5086/1						8			
		M5086/2					13A	8, 11	105	600	
		M5086/3	Cu/A	Sn	Str	1					
		M5086/4						8		3000	Medium weight
		M5086/5						9A	110		
		M5086/6	HSA	Ag						600	See Note 4
		M5086/7	Cu/A	Sn				8	105		
MIL-DTL-8777	Wire, Electrical, Silicone Insulated, Copper, 600 V 200^{0}C'	MS25471	Cu/A	Ag	Str	6	13A	12	200	600	
		M27110						4A			
MIL-W-16878	Wire, electrical Insulated, High Temperature	M6878/1								600	
		M16878/2		Ag, Sn		1	8, 10, 11	1, 8, 10, 11	105	1000	
		M16878/3	Cu/A, HSA, CCW							3000	
		M16878/4								600	See Note 4
		M16878/5				3A		3/, 3A, 3B, 4A 13B		1000	
		M16878/6		Ag					200	250	
		M16878/7				6	4A, 8, 10, 11			600	
		M16878/8	Cu/A					4A, 8, 10 11		1000	
		M16878/10		Sn	S, Str	2A	8, 10, 11		75	600	
		M16878/11	Cu/A, CCW								
		M16878/12		Ag		4A		4A	200	1000	
		M16878/13								250	
		M16878/14		Ag, Sn						600	
		M16878/15	Cu/A	Sn		2C			125	1000	
		M16878/16								600	
		M16878/17	Cu/A HSA CCW							3000	
		M16878/18		Ag,Sn		1		8	105	1000	
		M16878/19								3000	
		M16878/20		Ag		3B		3/, 3A,3B,4A 13B	200	250	
		M16878/21								600	
		M16878/22								1000	
		M16878/23				3A				250	
		M16878/24				3B					
		M16878/25		Ni		3A			260	600	
		M16878/26				3B					
		M16878/27				3A				1000	
		M16878/28				3B					
		M16878/29								600	

Table 71-I Wire, electrical, interconnection.

Specification Number.	Title	Spec Type or class	Construction						Max Cond Temp °C	Max rms volts	Remarks
			Conductor 1/			Insulation 2/					
			Material	Coating	Type	Primary	Primary Cover	Jacket/ topcoat			
		M16878/30	Cu/A	Sn	Str	6			150		
		M16878/31								1000	
		M16878/32		Ag					200		
		M16878/33	Cu/A,CCW	Sn	S,Str	2A			75	600	
		M16878/34	Cu/A	Ag	Str	3B			200	1000	
		M16878/35		Ni					260		
SAE AS 22759	Wire, Electric, Fluoropoly mer - insulated, Copper or Copper Alloy	M22759/1		Ag		3A,3B, 3D		13B	200		
		M22759/2		Ni					260		
		M22759/3				3B,3D	13B	3B		600	
		M22759/4		Ag				4A	200		
		M22759/5				3C					
		M22759/6		Ni					260		
		M22759/7	CuA	Ag					200		Medium weight
		M22759/8		Ni					260		Medium weight
		M22759/9		Ag					200	1000	
		M22759/10		Ni		3A			260	1000	
		M22759/11		Ag					200		
		M22759/12		Ni					260		
		M22759/13		Sn							Medium weight
		M22759/14				4A		9A	135		Light weight
		M22759/15	HSA	Ag						600	Light weight
		M22759/16	Cu/A	Sn							Medium weight
		M22759/17	HSA	Ag	Str	18			150		Medium weight
		M22759/18	Cu/A	Sn							Light weight
		M22759/19		Ag							Light weight
		M22759/20							200	1000	
		M22759/21	HSA	Ni				3A	260		
		M22759/22		Ag					200		
		M22759/23		Ni		3A			260		
		M22759/28	Cu/A	Ag					200		
		M22759/29		Ni				7B	260		
		M22759/30	HSA	Ag					200		
		M22759/31		Ni							
		M22759/32	Cu/A	Sn					150	600	
		M22759/33	HSA	Ag					200		
		M22759/34	Cu/A	Sn					150		
		M22759/35	HSA	Ag		20		20			
		M22759/41	Cu/A	Ni							
		M22759/42	HSA						200		

Specification Number.	Title	Spec Type or class	Construction: Conductor 1/ Material	Coating	Type	Insulation 2/ Primary	Primary Cover	Jacket/ topcoat	Max Cond Temp ^{0}C	Max rms volts	Remarks
		M22759/43	Cu/A	Ag							
MIL-DTL-25038	Wire, Electrical High Temperature and Fire Resistant	M25038/1	Cu/A	Ni clad	Str	15	3B	13B	288	600	Critical circuits where electrical integrity must be maintained during fire (1093 C flame/5 min)
SAE-AS81044	Wire, Electric, Crosslinked Polyalkene Cross-linked Alkaneimide Polymer, etc Insulated, Copper or Copper Alloy	AS81044/6	Cu/A	Sn							Sheets /12 & /13 light weight - See Note 4 Sheets /9 & /10 medium weight. See application temp limitation stipulated on detail specification sheet
		AS81044/7	HSA	Ag							
		AS81044/9	Cu/A	Sn	Str	2B		9B	150	600	
		AS81044/10	HSA	Ag							
		AS81044/12	Cu/A	Sn							
		AS81044/13	HSA	Ag							
MIL-DTL-81381	Wire, Electric Polyimide Insulated Copper or Copper Alloy	M81381/7	Cu/A	Ag				17			Sheets /7 through /10 light weight Sheets /11 through /14 medium weight Sheets /17 through /20 light weight, single wrap primary Interconnect wiring where weight, space, and high temperature capability are critical Sheets /7 through /10 & 17/ through /20 - See Note 4 3B jackets in sheets are in sized 8 and larger
		M81381/8		Ni							
		M81381/9	HSA	Ag							
		M81381/10		Ni							
		M81381/11	Cu/A	Ag				15 or 17			
		M81381/12		Ni							
		M81381/13	HSA	Ag	Str	7A			200	600	
		M81381/14		Ni							
		M81381/17	Cu/A	Ag							
		M81381/18		Ni				17			
		M81381/19	HSA	Ag							
		M81381/20		Ni							
		M81381/21	Cu/A	Sn					105		
		M81381/22						15 or 17			

Table 71-I Wire, electrical, interconnection.

1/ Conductor code		Description
Material	Cu/A	Copper, annealed
	Cu/H	Copper, hard-drawn
	CCW	Copper covered steel
	HSA	High strength copper alloy
	Al	Aluminum
Coating	Sn	Tin
	Ag	Silver
	Ni	Nickel
Type	S	Solid
	Str	Stranded

2/ Insulation code	Description
1	Polyvinyl chloride/extruded
2A	Polyethylene/extruded
2B	Polyalkene/cross-linked extruded
2C	Polyethylene/cross-linked/modified/extruded
3A	Polytetrafluoroethylene/extruded (TFE Teflon)
3B	Polytetrafluoroethylene/tape
3C	Polytetrafluoroethylene/mineral filled/extruded
3D	Polytetrafluoroethylene impregnated glass type
4A	Fluorinated-ethylene propylene/extruded (FEP Teflon)
4B	Fluorinated-ethylene propylene/dispersion
5	Monochlorotrifluoroethylene/extruded (Kel-F)
6	Silicone rubber/extruded
7A	FEP/polyimide film (Kapton)
7B	Polymide lacquer (Pure ML)
8	Polymide/extruder (Nylon)
9A	Polyvinylidene fluoride/extruded (Kynar)
9B	Polyvinylidene fluoride/extruded/cross-linked
10	Braid/synthetic yarn/lacquer impregnated
11	Braid/nylon/impregnated
12	Braid/polyester/impregnated
13A	Braid/glass fiber/impregnated
13B	Braid/TFE coated glass fiber/TFE finish
14	Braid/asbestos/TFE impregnated
15	Braid, weave or wrap/inorganic fiber
16	Alkane-imide polymer/extruded/cross-linked
17	Modified aromatic polyimide
18	Ethylene-tetrafluoroethylene/extruded (Tefzel)
19	Polyarylene/extruded
20	Cross-linked, extruded, modified ethylene-tetrafluoroethylene

3/ When specified on purchase order.

4/ Wire intended for use in electronic equipment hook-up applications. It may also be used as an interconnecting wire when an additional jacket or other mechanical protection is provided

5/ Various combinations of primary, primary cover, and jacket insulations and unshielded, shielded, etc, constructions are available to meet application requirements. See detail wire specification.

Specification number.	Basic Title	Basic Wire Specifications	Conductor Number of conductors	Volts RMS	Temp 2/	Shield braid 3/ Strand material	Strand coating	% Coverage	Jacket 3/ Material 1/	Type	Remarks
MIL-DTL-3432	Cable (Power and Special (Purpose)and Wire, Elec-trical (300& 600V)	A-A-59551 & Insulation	Unlimited and mixed sizes 4/ 5/	300 & 600	-40°C to +65°C or -55°C to +75°C	None or Copper	Tin	85	Styrene butadiene Rubber, chloroprene rubber, ethylene-propylene rubber, ethylene-propylene-diene rubber, polyurethane thermoplastic elestomer or natural rubber	Extruded & Vulcanized	
NEMA WC 27500	Cable, Electric Aero Space Vehicle	M5086/1 M5086/2 M5086/3	2-7 1-7 1-7	600	105°C	 Copper Copper	 Tin Tin		None Polyamide (Nylon)	 Extruded or Impregbaird	(a) Fluorinated ethylene propylene (b) Polytetra-fluoroethylene
		M22759/12 M22759-23	1-7 1-7		260°C 260°C	Copper Copper	Nickel Nickel	85 85	(a) (b)	Extruded extruded or tape	
		AS81044/9	1-7		100°C	Copper	Tin	85	Polyvinylidene fluoride	Extruded	
		M81381/8 /10 and /14	2-7 1-7		200°C 200°C	Copper	Nickel	85	FEP/polyimide	Film Tape	
		M81381/11	2-7		200°C						
		M81381/12 M81381/13	1-7 1-7		150°C 200°C	Copper Copper	Tin Nickel	85 85	FEP/polyimide	Film Tape	
MIL-C-13777	Cable Special Purpose Electrical	MIL-C-17 A-A-59551 ASTM A580 &Insulation	2-78 6/	600	-53°C to +71°C	Copper	Tin	80	Sheath Poly-Chloroprene Primary Insulation Polyethylene	Extruded & vulcanized Extruded	See Note 7
MIL-C-24640	Cable, Electrical, Light weight for ship board use	SAE-AS81044	2-77 pair	600	150°C	Copper Tape Tinned	85	Crosslinked Polyalkene, Crosslinked Alkaneimide polymer, or Polyarylene	Extruded		
MIL-DTL-	Cable Special	MIL-DTL-17	2-36	Various	Not spec	Copper	Tin,	85	Sheath of		Flexible

Table 71-II Wire, electrical, interconnection.

Specification number.	Basic Title	Basic Wire Specifications	Conductor			Shield braid 3/			Jacket 3/		Remarks
			Number of conductors	Volts RMS	Temp 2/	Strand material	Strand coating	% Coverage	Material 1/	Type	
							Silver				
27072	Purpose, Electrical, Multi-conductor	M16878/1 M16878/2 M16878/3 M16878/4 M16878/5 M16878/6 M16878/10 M16878/13		600 1000 3000 600 1000 250 600 250	105°C 105°C 105°C 200°C 200°C 200°C 75°C 200°C	Note: MIL-DTL-27072 applicable detail specification sheets control materials for each specific cable configuration.			PVC, polyethylene, polychloroprene, polyamide,TFE - Teflon, or FEP- Teflon		multiconductor cable for use in protected, wire ways, instru-ment racks, and conduit, Poly-ethylene jack- eted cable suitable for underwater or direct burial applications only. M16878 /6 and /13 not for aerospace applications
NEMA WC	Cable,	MIL-DTL-8777	1-7	600	200°C	Various	Various	85	Various	Braided	For general aerospace flight vehicle applications
27500	Electrical, Shielded and	SAE AS 22759	1-7	Various	Various	Various	Various	85	Various	Extruded or Braided	

Specification number.	Basic Title	Basic Wire Specifications	Conductor			Shield braid 3/			Jacket 3/		Remarks
			Number of conductors	Volts RMS	Temp 2/	Strand material	Strand coating	% Coverage	Material 1/	Type	
	Unshielded, Aerospace										
		MIL-DTL-25038	1-7	600	260°C	Various	Various	85	TFE coated glass fiber	Braided	
		SAE-AS81044 MIL-DTL-81381	1-7 1-7	600 600	150°C Various	Various Various	Various Various	85 85	Various Various	Extruded Tape	
MIL-DTL-55021	Cable, Twisted Pairs & Triples, Internal Hookup, General Specification for	MIL-DTL-16878	2-3	600 to 1000	-40°C to +105°C or -65°C to +200°C	None or Copper	Tin, Silver or Nickel	90	None PVC, Nylon TFE-Teflon	Extruded Extruded or Tape	

Table 71-II Wire, electrical, interconnection.

1/ Polyester - Polyethylene Terephthalate
TFE-Teflon - Polytetrafluoroethylene
PVC - Polyvinyl chloride (Not to be used in airborne applications)
KEL-F - Polymonochlorotribluoroethylene
FEP-Teflon - Fluorinated ethylene propylene
PVF - Polyvinylidene fluoride

2/ See applicable detail specification sheet for temperature limitations.

3/ See applicable detail specification sheet for materials control of specific cable configurations impact bend, and twist.

4/ Although the specification does not limit the number of conductors in a cable, the size, weight, and flexibility are determining factors.

5/ Available in three classifications:

Class L - Light Duty - to withstand severe flexing and frequent manipulation

Class M - Medium Duty - to withstand severe flexing and mechanical abuse

Class H - Heavy Duty - to withstand severe flexing and mechanical abuse and ability to withstand severe service impacts such as to be run over by tanks or trucks

6/ See applicable detail specification sheet for mechanical test requirements for cold bend torque,

7/ For use under abusive mechanical conditions and where resistance to weather, oil and ozone are requirements.

GUIDELINE 72

SUBSTITUTABILITY

1. Purpose. This guideline establishes criteria for the selection and application of substitute parts.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-HDBK-61	Configuration Management Guidance
EIA-649	Configuration Management

3. Definitions. This section not applicable to this guideline.

4. General Guidelines.

4.1 Military parts. Substitution of parts covered by defense specifications and standards that include substitutability or supersession information is acceptable. This type substitution does not require submission of engineering change proposals, deviations, or waivers in accordance with MIL-HDBK-61.

4.2 Commercial parts. When the equipment design specifies a commercial part, a defense specification part may be substituted when the form, fit, and functional characteristics of the standard part are equal to, or better than, those of the specified commercial part under equivalent environmental conditions. Substitutions are subject to applicable configuration control procedures of MIL-HDBK-61.

4.3 Unavailable parts. When the equipment design specifies a part that is unavailable, a substitute part which meets the form, fit, and functional characteristics of the specified part may be substituted after approval is obtained from the applicable procuring activity. Substitutions are subject to the applicable configuration control procedures of MIL-HDBK-61.

4.4 Initial qualification/reliability demonstration. Substitute parts with quality/reliability characteristics superior to those specified in the parts list should not be used in equipment to be subjected to initial qualification or demonstration tests.

4.5 Other Guidance. Additional information can be found in EIA-649.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 73

STANDARD ELECTRONIC MODULES

1. Purpose. This guideline establishes criteria for the selection and application of Standard Electronic Modules (SEM).

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-STD-1389	Design Requirements for Standard Electronic Modules.
MIL-HDBK-246	Program Managers Guide for the Standard Electronic Modules Program.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Application. Requirements for the design and application of SEMs should be in accordance with MIL-STD-1389.

5. Detail guidelines.

5.1 Program and acquisition managers. Guidance for program and acquisition managers, as to the applicability of SEMs for specific system/equipment acquisitions, is provided in MIL-HDBK-246.

GUIDELINE 74

GROUNDING, BONDING, AND SHIELDING

1. Purpose. This guideline establishes grounding, bonding, and shielding interface criteria for installation of electronic equipment.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-STD-188-124	Grounding, Bonding, and Shielding for Common Long Haul/Tactical Communication Systems Including Ground Based Communications-Electronics Facilities and Equipments.
MIL-STD-464	Interface Standard for Electromagnetic Environmental Effects Requirements for Systems.
MIL-STD-1310	Shipboard Bonding, Grounding, and Other Techniques for Electromagnetic Compatibility and Safety.
MIL-STD-1542	Electromagnetic Compatibility (EMC) and Grounding Requirements for Space System Facilities.
MIL-HDBK-419	Ground, Bonding, and Shielding for Electronic Equipments and Facilities.
MIL-HDBK-1857	Grounding, Bonding, and Shielding Design Practices.

3. Definitions. This section not applicable to this guideline.

4. General guidelines.

4.1 Provisions. Grounding, bonding, and shielding provisions should be incorporated into equipment design, as necessary, to enable installation of equipment into the applicable platform or facility. The grounding, bonding, and shielding installation and interface requirements are specified in the following documents:

Aerospace ground support facilities	MIL-STD-464
Aircraft and space vehicles	MIL-STD-464
Ground telecommunications C-E equipment	MIL-STD-188-124
Shipboard equipment	MIL-STD-1310
Ground space systems facilities	MIL-STD-1542
Other Army ground equipment	MIL-HDBK-1857

4.2 Other Guidance. Guidance for grounding, bonding, and shielding may be found in MIL-HDBK-419.

5. Detail guidelines. This section not applicable to this guideline.

GUIDELINE 75

ELECTROSTATIC DISCHARGE CONTROL

1. Purpose. This guideline offers guidance regarding the handling and control of electronic parts and assemblies that are susceptible to damage or degradation from electrostatic discharge. Guidelines for the establishment and implementation of an Electrostatic Discharge (ESD) control program in accordance with MIL-STD-1686 may be directly specified in the contract or equipment specification.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-STD-883	Microcircuits.
MIL-STD-1686	Electrostatic Discharge Control Program for Protection of electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Explosive Devices), Standard Practice for.
ESD TR20.20	Handbook for the Development of an Electrostatic Discharge Control Program for the Protection of Electronic Parts, Assemblies and Equipment.

3. Definitions. Definitions of applicable terminology may be found in MIL-STD-883, MIL-STD-1686, and ESD TR20.20.

4. General guidelines. This section not applicable to this guideline.

5. Detail guidelines.

5.1 ESD control program. MIL-STD-1686 provides the guidelines for the establishment, implementation, and monitoring of an ESD control program, including identification of Electrostatic Discharge Sensitive (ESDS) items, classification of ESD sensitivity levels, control program elements, extent of program element applicability to each acquisition, protective measures to be employed in equipment design, handling, storage, and packaging of ESDS items, protected work areas, personnel training, ESD audits and program reviews, and tailoring. Appendix A of MIL-STD-1686 provides the criteria and procedure for classifying ESDS parts by test. Appendix B of MIL-STD-1686 identifies and classifies ESDS items. ESD TR20.20 provides guidance for the establishment and implementation of an ESD control program in accordance with MIL-STD-1686.

5.2 General guidelines for an ESD control program. Any program designed for the prevention of ESD damage to ESDS parts and assemblies should be based on the following considerations.

a. Identification of ESDS parts and assemblies and determination of sensitivity.

b. Minimization of static charge generation.

c. Reduction of stored charges (grounding).

d. Isolation of ESDS parts (Faraday shielding and line transient protection).

e. Proper handling, storage, and transportation of ESDS parts and assemblies.

f. Personnel training and certification.

g. Protected work areas.

GUIDELINE 76

FIBER OPTICS

1. Purpose. This guideline establishes the criteria for the selection, application, and testing of fiber optic material, devices and accessories.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

SAE AS22520/10	Crimping Tools, Type 2, Terminal, Hand, Wire Termination, for Coaxial, Twinaxial, Triaxial, Shielded Contacts and Ferrules, Terminal Lugs, Splices, and End Caps..
MIL-PRF-24623	Splice, Fiber Optic Cable, General Specification for (Metric).
MIL-DTL-24728	Interconnection Box, Fiber Optic, Metric, General Specification for.
MIL-M-24791	Module, Fiber Optic, Transmitter or Receiver, Digital, General Specification for.
MIL-PRF-24792	Adhesive, Epoxy, Two Part, Fiber Optics.
MIL-PRF-24793	Adhesive, UV Curable, One Part, Fiber Optics.
MIL-PRF-24794	Material, Index Matching, Fiber Optics.
MIL-PRF-28876	Connectors, Fiber Optic, Circular, Plug and Receptacle Style, Multiple Removeable Termini, General Specification for.
MIL-PRF-29504	Termini, Fiber Optic Connector, Removable, General Specification for.
MIL-PRF-49291	Fiber, Optical, (Metric), General Specification for.
MIL-DTL-49292	Cable Assemblies, Nonpressure Proof, Fiber Optic, Metric, General Specification for.
MIL-DTL-83522	Connectors, Fiber Optic, Single Ferrule, General Specification for.
MIL-DTL-83526	Connectors, Fiber Optic, Circular, Environmental Resistant, Hermaphroditic, General Specification for.
MIL-PRF-85045	Cables, Fiber Optics, (Metric), General Specification for.
MIL-STD-188-200	System Design and Engineering Standards for Tactical Communications.
MIL-STD-790	Established Reliability and High Reliability Qualified Products List (QPL) Systems for Electrical, Electronic, and Fiber Optic Parts Specifications.
DOD-STD-1678	Fiber Optics Test Methods and Instrumentation.
MIL-STD-2163	Insert Arrangements for MIL-C-28876 Connectors, Fiber Optic, Circular, Plug and Receptacle Style, Multiple Removable Termini.
MIL-HDBK-415	Design Handbook for Fiber Optic Communications Systems.
TIA-440	Fiber Optic Terminology.
TIA-587	Fiber Optic Graphic Symbols.

3. Definitions.

3.1 Terminology. Definitions of terminology used in fiber optics technology should be as specified in TIA-440.

4. General guidelines.

4.1 Symbology. Graphic symbols for fiber optic parts for use on engineering drawings, specifications, etc, should be as specified in TIA -587.

4.2 Fiber dimensions. Dimensions for optical fibers should be as specified in MIL-DTL-49291.

4.3 System and subsystem design. Fiber optic system and subsystem designs should be in accordance with the criteria specified in MIL-STD-188-200 (see 5.1 of this guideline).

4.4 Test procedures. Standardized test procedures for fiber optic components should be as specified in DOD-STD-1678.

4.5 Splices. Fiber optic splices should conform to MIL-PRF-24623.

4.6 Cable assemblies. Cable assemblies should conform to MIL-PRF-49292.

GUIDELINE 76

4.7 Connectors. Fiber optic connectors should conform to MIL-PRF-28876, MIL-DTL-83522,and MIL-DTL-83526. Insert arrangements for MIL-PRF-28876 connectors should conform to MIL-STD-2163. Removable terminals for fiber optic connectors should conform to MIL-PRF-29504.

4.8 Interconnection boxes. Fiber optic interconnection boxes should conform to MIL-DTL-24728.

4.9 Tools and inspection equipment. Fiber optic tools, inspection equipment, and related kits should conform to SAE AS22520/10.

4.10 Transmitters and receivers. Fiber optic transmitters and receivers should conform to MIL-M-24791.

4.11 Adhesives.

4.11.1 Two part epoxy adhesives should conform to MIL-PRF-24792.

4.11.2 UV curable adhesives should conform to MIL-PRF-24793.

4.12 Materials. Index matching materials should conform to MIL-PRF-24794.

4.13 Cables. Fiber optic cables should conform to MIL-PRF-85045.

4.14 Polyvinyl chloride. Polyvinyl chloride insulating materials should not be used in aerospace applications. Their use in other applications requires procuring activity approval.

5. Detail guidelines.

5.1 Design guides. Fiber optic system design guide information is available in MIL-HDBK-415.

5.2 Product assurance program. When a requirement exists for the implementation of a fiber optic product assurance program, refer to MIL-STD-790.

GUIDELINE 77

INTEGRATED DIAGNOSTICS

1. Purpose. This guideline establishes a design process for integrating all elements which constitute a weapon system's diagnostic capability. Engineering analyses, qualitative and quantitative requirements, design analysis, demonstration, and maturation requirements may be specified in the contract or system/equipment specification, as appropriate.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-HDBK-470	Designing and Developing Maintainable Products and Systems
MIL-HDBK-1814	Integrated Diagnostics
MIL-HDBK-2165	Testability Program for Systems and Equipments
AFGS-87256	Integrated Diagnostics
ASTM F 1166	Standard Practices for Human Engineering Design for Marine Systems, Equipment, and Facilities
EIA-632	Processes for Engineering a System

3. Definitions.

3.1 Integrated diagnostics process. Integrated diagnostics is defined as a structured process which maximizes the effectiveness of diagnostics by integrating pertinent elements, such as: testability, automatic and manual testing, training, maintenance aiding, and technical information. Integrated diagnostics provides a cost-effective capability to detect and unambiguously isolate all faults known or expected to occur in weapon systems and equipment, and to satisfy weapon system mission requirements. This emphasis on the design and acquisition of the diagnostic capability is required because this capability tends to become fractionated. MIL-HDBK-2165 is the overall document for testability. However, because it is a multidisciplined process, reference to other portions of military documents that may be invoked or may be cited directly are: MIL-HDBK-470, EIA-IS-632, MIL-HDBK-1814, AFGS-87256, and ASTM F 1166.

4. General guidelines. This section not applicable to this guideline.

5. Detail guidelines.

5.1 Test provisions.

5.1.1 Testability programs. When specified by the procuring activity a testability program should be implemented by guidance found in MIL-HDBK-2165.

5.1.2 Built-in-test devices. Built-in test devices should maintain their accuracy under all operating conditions required by the equipment under test. These devices should be provided with connections or access for their operational check-outs or calibration.

5.1.3 Test provisions. Equipment which is required to be tested by on-line Automatic Test Equipment (ATE) should provide test points.

5.1.4 Test cables. Test cables and extender cards should be provided and fitted with connectors to allow removable subassemblies to be electrically reconnected for maintenance.

5.1.5 External test points. Protection should be provided in the test point circuitry to prevent equipment damage caused by the external grounding of test points.

5.1.6 Failure effect. Provisions for testing should be designed that any failure of built-in test devices will not degrade equipment operation or cause equipment shut down.

GUIDELINE 77

5.1.7 Intermittent fault diagnostics. Intermittent faults are defined in Guideline 79 and should be considered as part of any weapon systems diagnostic process/capability

5.2 Safety criteria. Safety criteria should be applied during equipment hardware design, selection, end construction to eliminate or control hazards that could cause injury to personnel during transportation, storage, installation, operation, maintenance or disposal, or damage to equipment or property.

GUIDELINE 78

PRODUCIBILITY

1. Purpose. This guideline establishes criteria for producibility which should be considered when preparing contractual documents. Producibility program tasks, quantitative requirements, verification, or demonstration requirements may be directly specified in the contract, the system, or equipment specification, as appropriate.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

DoDD 4245.7-M	Transition from Development to Production.
NAVSO P-3679	Producibility Measurement Guidelines.
NAVSO P-6071	Best Practices.
MIL-HDBK-727	Design Guidance for Producibility.

3. Definitions. This section not applicable to this guideline.

4. General guidelines. This section not applicable to this guideline.

5. Detail guidelines.

5.1 Producibility program. Producibility engineering and planning tasks aimed at preventing, detecting, and correcting manufacturability design deficiencies and providing producibility related information essential to acquisition, operation, and support management should be included in contract requirements with the objective of establishing and maintaining an efficient producibility program according to program phase. NAVSO P-3679 is the overall program document for the subject. The successful creation and management of a producibility program is detailed in section 2 of NAVSO P-3679.

5.2 Producibility measurement. Producibility measurement and assessment tools are a critical part of insuring a product is ready for production. Sections 3 and 4 of NAVSO P-3679 give two industry examples of measurement and assessment tools.

5.3 Quantitative producibility. Quantitative producibility requirements and verification, or demonstration requirements, should be established as appropriate to program phase. Producibility measurement is an essential part of the design process which can determine the probability of successful production. Minimal tailoring should be required when NAVSO P-3679 is applied to a program. Other producibility documents which may be cited directly as a basis for contract requirements include DoDD 4245.7M, NAVSO P-6071, and MIL-HDBK-727 for guidance only.

GUIDELINE 79

INTERMITTENT FAULT DIAGNOSIS

1. Purpose. This guideline establishes criteria for diagnosing intermittent faults in Electronic Equipment backplane, chassis and wire harness conductive paths.

2. Applicable documents. The documents listed below are not necessarily all of the documents referenced herein, but are those needed to understand the information provided by this handbook.

MIL-PRF-32516	Electronic Test Equipment, Intermittent Fault Detection and Isolation for Chassis and Backplane Conductive Paths
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests.

2.1 Definitions.

2.2 Intermittent faults. Intermittent faults are short duration discontinuities (opens/shorts) that occur in conductive paths in Electronic Equipment chassis/ backplanes and wire harnesses. Intermittent faults occur as a result of various operational environmental stimuli, including, but not limited to, thermal stress, vibrational stress, gravitational G-force loading, moisture and/or contaminant exposure, as well as changes in the material due to age and use, such as the growth of tin whiskers, metal migration and delamination of materials. These faults can occur individually and /or in rapid succession on any chassis, backplane circuit or wire harness. Fault durations range in time from nanoseconds to milliseconds and have variable random impedances. These conductive path disruptions are frequently caused by: cracked solder joints; intermittent coax lines (e.g., shield corrosion, damaged center conductor, etc.); broken, cracked or frayed wires/wire harnesses; loose clamps; improper crimp connections and unsoldered pins. These conductive path disruptions often cause functional failures/faults in Electronic Equipment chassis, backplanes and wire harnesses whose root cause(s) cannot be detected and isolated using traditional automatic test equipment (ATE) and troubleshooting processes. Lacking the ability to detect and isolate intermittent failures and provide environmental stimuli during test and repair process, such assets are commonly reported as no-fault-found (NFF) or as one of the quasi-NFF repair codes (e.g., cannot duplicate (CND), retest OK (RETOK), beyond capability of maintenance (BCM), disassemble-clean-reassemble (DCR), etc.).

3. General Guidelines.

3.1 General. Each type of Electronic Equipment is different in its function, configuration and operational environment. As a result, no single test method or procedure can adequately replicate an intermittent fault occurrence for all Electronic Equipment. A careful review of the nature of the failure and the operational conditions under which the failure occurred is required. The following steps are recommended when by careful analysis it is determined that the failures occur during ground or flight operating conditions, and the operating temperature does not appear to be contributing to the occurrence of the failures.

3.2 Intermittent faults typical resulting effects.

3.2.1 Vibration-induced. The following is a list of typical effects that may occur as a result of vibration (this list is not intended to be all-inclusive):

a. Chafed wiring.
b. Loose fasteners/components
c. Intermittent electrical contacts
d. Electrical shorts.
e. Deformed seals.
f. Failed components.
g. Optical or mechanical misalignment.
h. Cracked and/or broken structures.
i. Migration of particles and failed components.
j. Particles and failed components lodged in circuitry or mechanisms.
k. Excessive electrical noise.
l. Fretting corrosion in bearings.

3.2.2 Temperature-induced. The following is a list of typical effects as a result of temperature and temperature changes (this list is not intended to be all-inclusive):

a. Binding or slackening of moving parts.
b. Deformation or fracture of components.

c. Cracking of surface coatings.
d. Leaking of sealed compartments.
e. Failure of insulation protection.
f. Differential contraction or expansion rates or induced strain rates of dissimilar materials.
g. Intermittent electrical contacts.
h. Electrical shorts/opens.
i. Failed components.
j. Changes in electrical and electronic components.
k. Electronic or mechanical failures due to rapid water or frost formation.
l. Excessive static electricity.

3.2.3 Combined environmental-induced. Temperature, humidity, vibration, and altitude can combine synergistically to produce the following failures. Although altitude is included in the following discussion typically in regard to Electronic Equipment operating environment it mainly impacts cooling and is a function of temperature. Typically Combined Environmental Test facilities do not include altitude test capability. It should be noted that airborne Electronic Equipment may be operated in environments exceeding -55 °C to +120 °C, 40,000 foot altitude and high vibration due to take-off/landing and carrier catapult launches and arrested landings. The following examples are not intended to be comprehensive:

a. Shattering of optical material. (Temperature/Vibration/Altitude)
b. Binding or loosening of moving parts. (Temperature/Vibration)
c. Separation of constituents. (Temperature/Humidity/Vibration/Altitude)
d. Performance degradation in electronic components due to parameter shifts (Temperature/Humidity)
e. Electronic optical (fogging) or mechanical failures due to rapid water or frost formation. (Temperature/Humidity).
f. Differential contraction or expansion of dissimilar materials. (Temperature/Altitude)
g. Deformation or fracture of components. (Temperature/Vibration/Altitude)
h. Cracking of surface coatings. (Temperature/Humidity/ Vibration/Altitude)
i. Leakage of sealed compartments. (Temperature/Vibration//Altitude)
j. Failure due to inadequate heat dissipation. (Temperature/Vibration /Altitude)

3.3 Operational environment. A review should be conducted of technical manuals, operating manuals and any available operating environment information, prior to development of test procedures using the tailoring process in MIL-STD-810 to determine where forcing functions of temperature, humidity, vibration, and altitude are foreseen in the Electronic Equipment operational environment. Use this method only if the proper engineering has been performed such that the environmental stresses associated with the individual test methods are considered. If appropriate, tailor Electronic Equipment testing to include storage thermal environments and include in environmental testing or, perform them as separate tests, using the individual test methods. It is recommended that where the operational temperature and vibration test levels are not known that the qualification temperature and vibration levels during troubleshooting of the Electronic Equipment be reduced in order to not over stress the Electronic Equipment. The intent is to subject the Electronic Equipment to temperature/vibration level low/high enough to stimulate the intermittent fault, but not reduce the operational life of the Electronic Equipment.

4. Detail guidelines. Testing for intermittent faults should be conducted using diagnostic equipment meeting the performance requirements of MIL-PRF-32516. The diagnostic equipment covered by this specification is intended for use in detecting and isolating intermittent faults in Electronic Equipment, chassis, backplanes and their wire harnesses. The diagnostic equipment is intended to be used with the Electronic Equipment (with internal subassemblies removed) being stimulated by temperature, vibration or vibration/temperature to emulate the environment in which the fault originally occurred. MIL-PRF-32516, Appendices A through C, provide recommended guidelines for defining this external stimulation.

5. Integrated diagnostics. See guideline 77.

INDEX

INDEX

CONCLUDING MATERIAL

Custodians:
Army - CR
Navy - AS
Air Force – 11
DLA - CC

Review activities:
Army - AR, AV, MI, TE
Navy - EC, OS, SH
Air Force – 19, 85

Preparing activity:
DLA - CC

(Project SESS-2020-045)

NOTE: The activities listed above were interested in this document as of the date of this document. Since organizations and responsibilities can change, you should verify the currency of the information above using the ASSIST Online database at https://assist.dla.mil.

Congressional Response

Executive Summary

05 October 2021: The Office of the Under Secretary of Defense for Acquisition and Sustainment submitted a 28-page formal response to Senate Report 116-236, page 176, and accompanying H.R. 6395 to National Defense Authorization Act for Fiscal Year 2021.

The full report was sent to:

U.S. Senate

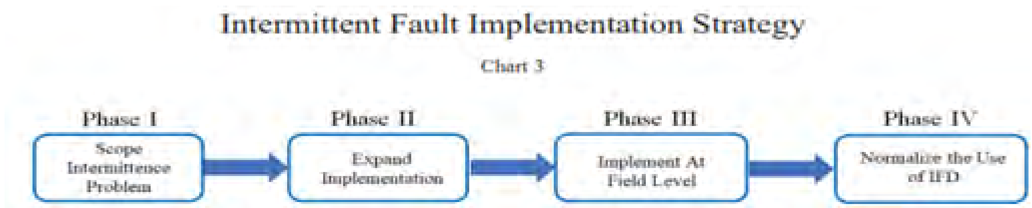
- o Committee on Armed Services
- o Committee on Appropriations

U.S. House of Representatives

- o Committee on Armed Services
- o Committee on Appropriation

The report examines the Department of Defense's strategic approach to address the persistent maintenance issue of intermittent electrical failures in DoD weapon system components.

- DoD and the Military Services are also applying "Big Data" analytics (e.g., DoD's Maintenance and Availability Data Warehouse (MADW)) and tailored toolsets to both better scope the intermittence problem and identify specific implementation opportunities.
- Intermittent electronics failures continue to be a leading contributor to DoD's $3 billion annual No Fault Found (NFF) problem, unnecessarily consuming approximately 25% of the electronics maintenance budget annually and is a leading contributor to weapon system materiel availability issues.
- Intermittent faults occur as a result of various operational environmental stimuli, including, but not limited to, thermal stress, vibrational stress, gravitational G-force loading, moisture, and/or contaminant exposure. These circuit path disruptions are frequently caused by cracked solder joints; intermittent coax lines (e.g., shield corrosion, damaged center conductor, etc.); broken, cracked, or frayed wires; loose clamps; and unsoldered pins.
- One main symptom of an intermittent fault failure (IFF) mode problem is a high rate of Cannot Duplicate (CND or A-799), NFF, No Trouble Found (NTF), and Re-test OK (RETOK) reported by the maintenance activities and is characterized by decreasing reliability and Time-on-Wing (TOW) and has been conclusively identified as a major contributor to NFF costs and decreased materiel availability.
- OO-ALC's utilization and data results from the Intermittent Fault Detection & Isolation System (IFDIS) were presented at the Maintenance Innovation Challenge (MIC) which leveraged Reduction in Total Ownership Cost (RTOC) funding to help industry develop and demonstrate the first IFDIS application in DoD. OO-ALC became the early adopter of this technology and implemented IFDIS to improve materiel availability and reduce costs for the F-16 MLPRF Line Replaceable Unit (LRU). Success and potential demonstrated at OO-ALC created a breakthrough moment at the DoD enterprise-level and led to the formation of the holistic strategy described in this report.



- The IFDIS and Portable Intermittent Fault Detector (PIFD) are the only objectively proven solutions to meet the requirements cited in MIL-PRF-32516 because of their ability to continuously and simultaneously detect and isolate random intermittent faults. IFDIS and PIFD automatically interrogate, through the use of Artificial Intelligence (AI), and store the as-designed wiring configuration of a known good unit, greatly reducing the time and cost associated with developing Test Program Sets (TPS), which are required for conventional testing.

(Note: throughout the report, Universal Synaptics is referred to eight (8) times, IFDIS 92 times, and the PIFD 22 times)

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION
AND SUSTAINMENT

October 5, 2021

The Honorable Adam Smith
Chairman
Committee on Armed Services
U. S. House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

Senate Report 116–236, page 176, accompanying H.R. 6395, the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 requests the Secretary of Defense provide a report that analyzes persistent maintenance issues caused by electronic component failures not later than December 31, 2020. The requested report is attached here for your review.

Should you have additional questions, please contact the Office of the Assistant Secretary of Defense for Legislative Affairs and your respective legislative liaison. I am sending an identical letter to the other congressional defense committees.

Sincerely,

KAUSNER.GREGORY.MICHAEL.1026551605
Digitally signed by KAUSNER.GREGORY.MICHAEL.1026551605
Date: 2021.10.05 17:21:11 -04'00'

Gregory M. Kausner
Executive Director, International Cooperation
Performing the Duties of the Under Secretary of Defense for Acquisition and Sustainment

Enclosure:
As stated

cc:
The Honorable Mike D. Rogers
Ranking Member

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION
AND SUSTAINMENT

October 5, 2021

The Honorable Jack Reed
Chairman
Committee on Armed Services
United States Senate
Washington, DC 20510

Dear Mr. Chairman,

SSenate Report 116–236, page 176, accompanying H.R. 6395, the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 requests the Secretary of Defense provide a report that analyzes persistent maintenance issues caused by electronic component failures not later than December 31, 2020. The requested report is attached here for your review.

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Sincerely,

KAUSNER.GREGORY.MICHAEL.1026551605
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Date: 2021.10.05 17:21:27 -04'00'

Gregory M. Kausner
Executive Director, International Cooperation
Performing the Duties of the Under Secretary of Defense for Acquisition and Sustainment

Enclosure:
As stated

cc:
The Honorable James M. Inhofe
Ranking Member

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION
AND SUSTAINMENT

October 5, 2021

The Honorable Patrick J. Leahy
Chairman
Committee on Appropriations
United States Senate
Washington, DC 20510

Dear Mr. Chairman,

Senate Report 116–236, page 176, accompanying H.R. 6395, the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 requests the Secretary of Defense provide a report that analyzes persistent maintenance issues caused by electronic component failures not later than December 31, 2020. The requested report is attached here for your review.

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Sincerely,

KAUSNER.GREGORY.MICHAEL.1026551605 Digitally signed by KAUSNER.GREGORY.MICHAEL.1026551605 Date: 2021.10.05 17:21:37 -04'00'

Gregory M. Kausner
Executive Director, International Cooperation
Performing the Duties of the Under Secretary of Defense for Acquisition and Sustainment

Enclosure:
As stated

cc:
The Honorable Richard C. Shelby
Vice Chairman

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION
AND SUSTAINMENT

October 5, 2021

The Honorable Rosa L. DeLauro
Chair
Committee on Appropriations
U.S. House of Representatives
Washington, DC 20515

Dear Madam Chair:

Senate Report 116–236, page 176, accompanying H.R. 6395, the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 requests the Secretary of Defense provide a report that analyzes persistent maintenance issues caused by electronic component failures not later than December 31, 2020. The requested report is attached here for your review.

Should you have additional questions, please contact the Office of the Assistant Secretary of Defense for Legislative Affairs and your respective legislative liaison. I am sending an identical letter to the other congressional defense committees.

Sincerely,

KAUSNER.GREGORY.MICHAEL.1026551605 Digitally signed by KAUSNER.GREGORY.MICHAEL.1026551605 Date: 2021.10.05 17:21:48 -04'00'

Gregory M. Kausner
Executive Director, International Cooperation
Performing the Duties of the Under Secretary of Defense for Acquisition and Sustainment

Enclosure:
As stated

cc:
The Honorable Kay Granger
Ranking Member

DEPARTMENT OF DEFENSE

ASSESSMENT OF ELECTRONICS MAINTENANCE AS A LEADING DRIVER OF WEAPON SYSTEMS NON-AVAILABILITY

Office of the Under Secretary of Defense
for Acquisition and Sustainment

2021

The estimated cost of this report or study for the Department of Defense is approximately $154,000 for the 2021 Fiscal Year. This includes $126,000 in expenses and $28,000 in DoD labor.

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Background

Senate Report 116-236, page 176, accompanying S. 4049, the National Defense Authorization Act for Fiscal Year (FY) 2021 states:

The committee notes that the Department of Defense (DoD) has found that electronics maintenance is a leading driver of weapon systems non-availability, accounting for over 470,000 days of end-item system availability loss in fiscal year 2018. Electronics maintenance is also a significant contributor to sustainment costs as well, accounting for over $12 billion in fiscal year 2018. A significant portion of the electronics maintenance non-availability and cost impact is caused by intermittent faults. DoD estimates that 278,000 days of weapon systems non-availability and approximately $3 billion in sustainment costs are due to this single issue.

To address these issues, the committee directs the Secretary of Defense to provide a report to the congressional defense committees, no later than December 31, 2020, that analyzes this persistent maintenance issue. The report should:

(1) Recommend best practices to be used by the DoD to address electronics component failures due to intermittent faults.
(2) Identify responsible organizations in the military services, and the Defense Agencies and Department of Defense Field Activities to address these issues; and,
(3) Include strategic plans and a roadmap to field intermittent fault detection and isolation capabilities.

Executive Summary

This report examines the Department of Defense's strategic approach to address the persistent maintenance issue of intermittent electrical failures in DoD components. As requested, best practices, both current and emerging, are reviewed, responsible organizations central to tackling this issue are identified, and strategic planning and a phased implementation approach to field intermittent fault detection and isolation capabilities is described. Several points characterize the context for the best practices, organizations, and plans included herein.

Most importantly, DoD's phased implementation approach to address intermittent electrical failures in DoD's weapon systems is a paradigm shift in current DoD electrical/electronic maintenance. Intermittent failures result in decreased meantime between failures, increased component material inventory, and decreased weapon system availability. Paradigm shifts involve fundamental changes that require senior leader support, time, focus, and long-term stakeholder engagement to implement. DoD's phased implementation approach, therefore, includes many reinforcing, collaborative, and outcome-focused activities intended to fully institutionalize intermittence faults testing requirements and capabilities in DoD's resource, sustainment, and technical maintenance communities over time. However, since an intermittent fault is a very difficult, complex, and costly equipment failure mode to detect, isolate, and address, implementing solutions can present risks in a DoD maintenance environment focused predominantly on meeting today's operational tempo-driven materiel requirements. In this demanding, fast paced environment, failure is not an option and true progress with near and long term operational impacts must be advanced deliberately. That is the key reason DoD's multi-faceted, long-term strategic implementation approach is structured and ongoing.

In addition to these challenges, the type of maintenance equipment proven to detect and address intermittent faults is expensive and can be difficult to integrate into the portfolio of Automatic Test Equipment (ATE) in use across DoD's maintenance enterprise, which is incapable of continuous and simultaneous testing for intermittent faults. Because intermittent fault detection and isolation capabilities are new, they are different. Traditional maintenance programs, life-cycle management, operations resourcing, and technical streams are challenged when integrating innovative sustainment technologies into planning and implementation cycles. This can present resourcing and integration difficulties for Program Executive Offices (PEOs), Program Managers (PMs), and depot maintenance activities that do not have specific requirements from authoritative sources to introduce and resource these capabilities. Both achieving full recognition of the intermittent electronics failure mode throughout DoD and increasing integration of intermittent fault detection and isolation capabilities into DoD's traditional maintenance operations, are fundamental to and continue to be critical, to expanding the breadth and depth of its implementation.

DoD is addressing these challenges in our intermittent fault detection and isolation phased implementation approach by employing a myriad of integrated technology transition best practices. These best practices have baselined the capability and are used continuously to assess and scale it towards additional implementation outcomes. Objectives and activities of several technical Working Integrated Product Teams (WIPTs), Centers of Excellence, and commercial

activities have collaborated to produce foundational documents and capabilities that have brought intermittence testing into broader DoD maintenance policy and implementation. These collaborative groups have also driven critical outcomes, including the development of the original intermittent electrical failure mode definition as well as issuing the specification that defines the breakthrough capability required to detect and isolate intermittent faults in electrical components and electrical wiring interconnect systems (EWIS). As the use of intermittent fault detection and isolation capabilities expands, DoD and the Military Services are also applying "Big Data" analytics (e.g., DoD's Maintenance and Availability Data Warehouse (MADW)) and tailored tool sets to both better scope the intermittence problem and identify specific implementation opportunities. These activities promote fact-based technical demonstration and best practice interchange as intermittence solution sets are shared and applied among the Military Services and their industry partners.

While the four-phased strategic intermittent fault and detection implementation approach explained in this report shows meaningful progress, challenges remain to institutionalize this capability and normalize its use in DoD electronics maintenance and initial manufacture. Intermittent electronics failures continue to be a leading contributor to DoD's $3 billion annual No Fault Found (NFF) problem, consuming approximately 25% of the electronics maintenance budget and contributing to weapon system materiel availability issues. Challenges such as gaining and sustaining enterprise awareness and ensuring electronics technicians understand intermittent fault detection and isolation demand solutions that entail leadership, resourcing, and innovative organizations responsible and accountable to drive authoritative action and outcomes. DoD's on-going implementation approach includes activities to generate and accelerate these kinds of solutions. DoD's goal is to field intermittent fault detection and isolation capabilities to achieve objective electronic component, and EWIS availability, a key component to target weapon system readiness at the best cost. DoD is roughly at the mid-point of its projected intermittent fault and detection implementation activities. Substantial time and effort was invested in developing an understanding of the failure mode, scoping the problem, and identifying the potential benefit of solving intermittence (Phase I); but it was essential to generate the strategic approach and tactics driving the paradigm shift in electronics maintenance these game-changing capabilities are enabling.

As an informational baseline, the definition of intermittent faults is provided in the footnote below.[1]

[1] Intermittent faults are short duration impedance variations (opens/shorts) that occur in conductive paths in Line Replaceable Unit/Weapon Replaceable Assembly chassis and backplanes or weapon system EWIS. Intermittent faults occur as a result of various operational environmental stimuli, including, but not limited to, thermal stress, vibrational stress, gravitational G-force loading, moisture and/or contaminant exposure, as well as changes in the material due to age and use, such as the growth of tin whiskers, metal migration, and delamination of materials. These faults can occur individually and/or in rapid succession on any chassis or backplane circuit or weapon system EWIS. Fault durations range in time from nanoseconds to milliseconds and have variable impedances. These circuit path disruptions are frequently caused by cracked solder joints; intermittent coax lines (e.g., shield corrosion, damaged center conductor, etc.); broken, cracked or frayed wires; loose clamps; and unsoldered pins. These circuit path disruptions often cause functional failures/faults in Line Replaceable Unit/Weapon Replaceable Assembly chassis and backplanes or weapon system EWIS whose root cause(s) cannot be detected and isolated using traditional automatic test equipment and troubleshooting processes. Lacking the ability to detect and isolate intermittent failures and provide environmental stimuli during test and repair process, such assets are commonly reported as NFF or as one of the reported-NFF repair codes (e.g., cannot duplicate, retest OK, beyond capability of maintenance, disassemble-clean-reassemble).

Introduction

DoD maintenance operations sustain and restore weapon systems and materiel to inherent performance, safety, and reliability levels. Maintenance generates and sustains materiel readiness – ensuring weapon systems, equipment, and platforms are available to support training and exercises, and ultimately, to deploy in support of warfighter requirements to respond to any humanitarian or contingency situation. Roughly $95 billion of DoD's total FY 2019 expenditure was applied to maintenance activities and services (not including facilities), with aircraft maintenance being the greatest expenditure at approximately $32 billion. Electronics maintenance, a leading driver of weapon systems non-availability, accounted for over $12 billion in FY 2019 maintenance costs. (Chart 1)

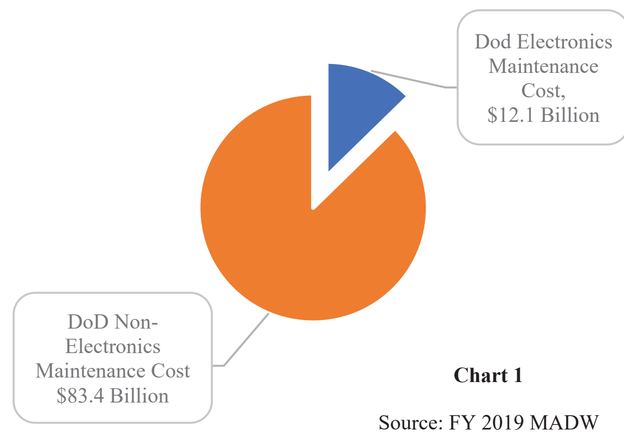

Chart 1

Source: FY 2019 MADW

Intermittent electrical failures continue to be a leading contributor to DoD's $3 billion annual NFF problem, unnecessarily consuming 25% of the electronics maintenance budget. Many aircraft maintenance issues are directly related to interconnectivity problems on the EWIS or within electronic components or assemblies. Intermittent faults are mechanical in nature and can include failures in solder joints, wiring, wire wraps, connectors, etc., which manifest as operational failures due to temperature, vibration, and other external environmental stimuli. Hard failures, where wiring issues are evident, are relatively routine to detect and repair, and not all hard failures involve wiring. However, major electrical issues and even critical down-line failures may occur when an electrical fault appears only intermittently, on multiple conductive paths in short duration, under operational conditions (such as high G-force loading and extremes in temperature or stress, or vibrational states) that are difficult to replicate during ground testing and maintenance. The duration of these intermittent events can range from nanoseconds to seconds and may oscillate repeatedly during an event or may be a single occurrence during a given testing session.

These circuit path disruptions often cause operationally evident functional failures/faults in Line Replaceable Unit (LRU)/Weapon Replaceable Assembly (WRA) chassis and backplanes whose root cause(s) cannot be detected and isolated using conventional ATE and troubleshooting processes. Intermediate and depot maintenance actions, such as the reseating of a degraded connection, solder joint, etc., can temporarily cause the intermittent connection to function properly for days, or even weeks after, and may only manifest as a repeat operational failure after several months.

This situation results in a revolving cycle for EWIS and the WRA/LRU removal, maintenance and testing resulting in NFF, and subsequent reinstall on aircraft. Additionally, as the adjacent Chart 2 displays, considerable preventive and corrective DoD electronics maintenance costs are applied to this issue. Even while these resources are consumed, WRA/LRU and system wiring with intermittent faults become known as the Military Services' "bad actors" and are repeatedly sent to DoD and commercial repair facilities, but the current intermittent test equipment void prevents accurate problem diagnosis -- in many instances leading to unnecessary condemnation of weapons systems components. One main symptom of an intermittent fault failure (IFF) mode problem is a high rate of Cannot Duplicate (CND or A-799), NFF, No Trouble Found (NTF), and Re-test OK (RETOK) reported by the maintenance activities. In addition, although diagnostic equipment with the capability to monitor all conductive paths simultaneously and continuously while simulating the specified Type/Model/Series (TMS) operating environment is not yet widely available, such equipment has been identified as an excellent objectively proven solution.

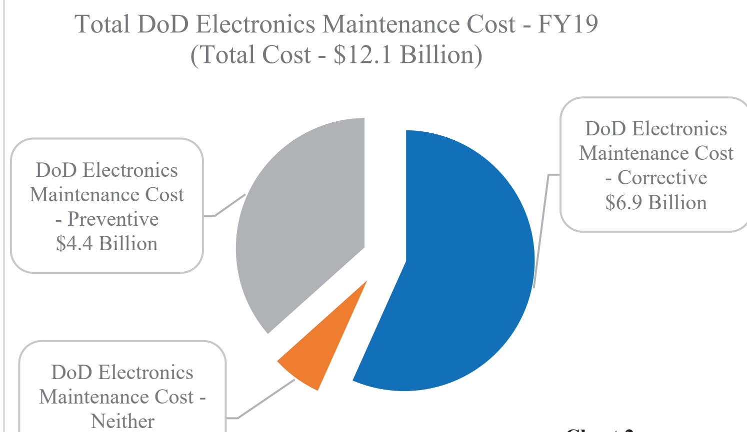

Chart 2

Source: FY 2019 MADW

Intermittent faults phenomenon, while persistent and pervasive for some time, is now gaining, traction and emerging as an accepted failure mode within DoD. It is characterized by decreasing reliability and Time-on-Wing (TOW) and has been conclusively identified as a major contributor to NFF costs and decreased materiel availability. DoD now operates approximately 400 types of traditional diagnostic test systems valued at $50 billion dollars. However, these test systems do not continuously and simultaneously test all conductive paths, they have very limited or no capability to detect and isolate intermittent faults or reduce NFF costs.

Background of DoD Initiative and Overarching Strategy

DoD is meeting the challenge by addressing key dimensions of the complex electronics intermittence challenge. The Department's approach is strategic, enterprise-wide, and outcome oriented. This section highlights the origin of the approach and outlines the phased activities that scoped, articulated, and continue to address DoD's electronics intermittence problem. While some challenges remain,[2] this approach is enabling deliberate, forward-looking fielding of intermittent fault detection and isolation capabilities.

DoD-level leadership focused on innovation, industry engagement, and Military Service awareness has sparked interest and action to address electronics intermittence. In 2008, Ogden Air Logistics Complex (OO-ALC) was grappling with availability issues related to the Modular

[2] These challenges will be detailed in a subsequent section of the report.

Low Power Radio Frequency (MLPRF) LRU on the F-16 aircraft that seemed to be intermittence related. In 2010, a first of its kind industry solution deployed at OO-ALC that could identify and isolate electrical intermittence was selected as the winner of the DoD "Great Ideas" Competition (later renamed the Maintenance Innovation Challenge (MIC)). The MIC, a key feature of DoD's annual Maintenance Symposium, provides a venue to spur competition and innovation and offers a unique, rapid "concept to solution" path to address DoD's materiel availability and cost issues. The 2010 winner of the MIC was the Universal Synaptics' Intermittent Fault Detection & Isolation System (IFDIS).

OO-ALC's utilization and data results from the IFDIS was presented at the MIC which leveraged Reduction in Total Ownership Cost (RTOC) funding to help industry develop and demonstrate the first IFDIS application in DoD. OO-ALC became the early adopter of this technology and implemented IFDIS to improve materiel availability and reduce costs for the F-16 MLPRF LRU. The Air Force's results were subsequently leveraged by the Navy in additional implementations.

The success and promise demonstrated at OO-ALC created a breakthrough moment at the DoD enterprise level and led to the formation of the holistic strategy described in this report. An important early element of this strategy was collaboration with the Military Services and their industry partners regarding "Big Data" analytics (i.e., MADW). The Office of the Deputy Assistant Secretary of Defense for Materiel Readiness (ODASD(MR)) determined that authoritative, reliable data and information, coupled with rigorous analytics, was crucial to engage DoD's maintenance community in the electrical intermittent failure issue. Collecting and analyzing authoritative Military Service maintenance data enabled DoD to scope the intermittence problem, identify the corresponding materiel availability degradation it contributes to, and distinguish the negative cost impacts that can be attributed to intermittent faults.[3] The establishment of this data-based platform (called the MADW) has been key to promoting intermittence solutions more widely across DoD and to building a community of advocates as DoD's phased implementation continues.

A robust team, comprised of respected subject matter experts (SMEs) and technical leadership throughout DoD and industry, was formed to guide DoD's strategic approach. The ODASD(MR) chartered the Condition-Based Maintenance Plus (CBM^+) Joint Intermittent Testing (JIT) Working Integrated Program Team (WIPT) as the body to develop and coordinate the DoD-wide effort. The JIT WIPT's goals are to achieve full recognition of the intermittence electrical failure mode across DoD and to increase integration of intermittent fault detection and isolation capabilities into DoD's maintenance operations. This team of leaders and SMEs express the strategic vision and tactics required to address electrical intermittence throughout DoD's maintenance enterprise. The JIT WIPT was formally chartered in 2012 and continues to define and execute tasks required to implement intermittence maintenance technology through a drumbeat of coordinated activities.

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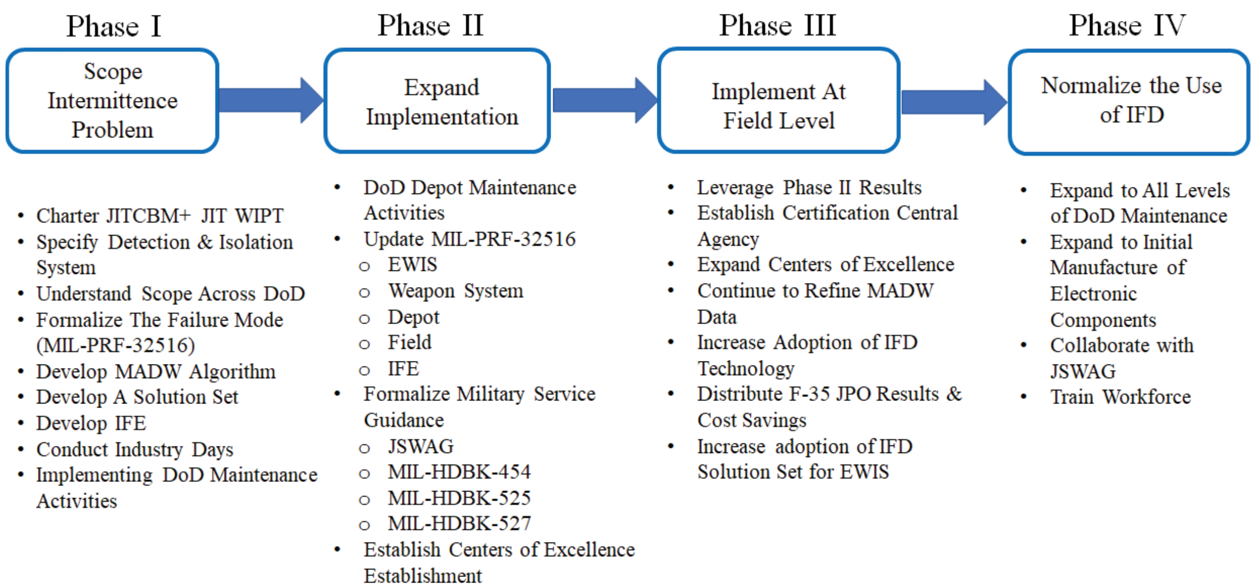
[3] It is important to note that the DoD's MADW, Enterprise Sustainment Dashboard, and various Military Service data analytical tools have been leveraged and adapted throughout DoD's phased efforts to address electrical intermittence. From a macro perspective, MADW has enabled initial quantification of the intermittence problem (as illustrated in the Introduction to this report) and through continuous refinement and upgrade, this and other Big Data tools now support specific, increasingly prescriptive approaches to identify the most effective intermittence detection implementation opportunities. These capabilities are now able to help identify and target "best candidates" (cost and non-availability drivers) at the Part of National Item Identification Number (NIIN) level. These capabilities continue to be refined and applied and are discussed in some detail in the body and appendices of this report.

The JIT WIPT's strategies and tactics are being implemented in phases (Chart 3). While each phase is intended to achieve clear goals, the approach contains a mixture of continuing, sequential, and combined activities to meet required outcomes, foster implementation momentum, and incorporate feedback from previous phases flexibly and responsively.

Intermittent Fault Implementation Strategy

Chart 3



Phase I included the "spade work" required to take on intermittence isolation and detection at the DoD enterprise level. The impact of the intermittent fault problem and benefits of addressing it have been determined empirically and are well understood by the DoD electronics maintenance community. The JIT WIPT guided and continues to drive project partners like the Commercial Activities for Maintenance Activities (CTMA) Program, and the Joint Technology Exchange Group (JTEG) to provide official recognition of intermittence as a definitive failure mode. A Department approved testbed to validate testing capabilities and intermittent fault detection and isolation efficacy was established and Government-sponsored Industry Days have identified practical solutions to confront the intermittent failure mode. Streamlined execution venues have also been established and continue to occur to refine the capability to objectively assess intermittence implementation in various operational environments. Finally, Intra-Service best practice sharing drove initial experimentation and implementation of intermittent capabilities and continues to increase technical awareness for leadership, sustainment managers, and electronics technicians. Phase I resulted in significant development and expansion of detection and isolation of intermittent fault and detection capabilities at several DoD depot maintenance activities.

Phase II is currently underway and is driving further implementation of intermittent fault and detection capabilities in DoD depot maintenance activities. Implementation targets are supported by continually refined data-based decision-making processes. Military Service specific and enterprise-wide cost and availability variables are driving growth in depot maintenance implementation. A draft Framework for Implementing Intermittent Fault Detection and Isolation across the Military Services was developed, and Centers of Excellence (CoEs) were proposed as a best practice source to foster implementation of intermittence capabilities in both a greater range of DoD weapon systems and at additional DoD maintenance levels. More open, secure access to intermittence-related knowledge, innovative examples and approaches, and the ability to identify "best of breed" maintenance technologies are shaping DoD Phase II implementation activities. A key function of the CoEs, for example, is to maintain a validated list of products that have demonstrated ability to detect Category 1 intermittent faults (see MIL-PRF-32516) in their intended fault environment.

Recently, the F-35 Joint Program Office (JPO) has evaluated the Universal Synaptics Portable Intermittent Fault Detector (PIFD) (Figure 1). The PIFD meets or exceeds all F-35 JPO EWIS intermittent fault detection and general wiring testing capability requirements, cyber compliance, and has achieved Authority to Operate (ATO) approval from the F-35 JPO. The F-35 JPO is moving forward with acquisition, and deployment of the PIFD to F-35 repair depots and operational squadrons across the globe. Additionally, during Phase II, an update to the official DoD intermittence specification has been initiated to authoritatively define field level intermittent detection and fault isolation capability. Implementation of intermittent fault detection and isolation capability at the field maintenance level for the F-35 program and beyond offers prospective cost savings and materiel availability improvements.

Figure 1. The F-35 JPO Portable Intermittent Fault Detector (PIFD)

Phase III will be focused on implementing intermittent fault detection and isolation capabilities at DoD field level maintenance operations to address aircraft EWIS intermittent and general wiring failures. Delivering advanced intermittent fault diagnostic capability closer to the weapon system, prior to depot-level induction, enables intermittent failures to be detected, isolated, and repaired rapidly, reducing logistics and supply chain time and cost. Development and demonstration activities are underway at this time to detect and isolate intermittence in wiring harnesses while installed in weapon systems during field maintenance beyond the F-35 Joint Strike Fighter. F-35 EWIS test data, readiness improvements and cost saving will be shared with all weapon systems program offices in an effort to gain adoption across legacy platforms.

Phase IV will normalize the use of intermittent fault detection and isolation capabilities at all levels of DoD maintenance and during electronic components' initial manufacture. As a result of on-going leadership advocacy, as well as empirical and numerical based quantification of impact and implementation benefits, Phase IV's goal is to have intermittence recognized formally and widely as a recurring common failure mode for both legacy and new electronics assets. Given proven successes of Phases I-III, implementation in growing numbers of DoD maintenance activities will continue based upon a commercial application that, in tandem with DoD specifications, will require intermittence recognition and focused activities through all stages of the electronics lifecycle. The goal of Phase IV is to put intermittent faults on a steep decline, both as an electronics materiel availability and cost challenge for DoD and its industry partners.

Given this overview of DoD's initiative and strategy to increase implementation of intermittent fault detection and isolation capabilities, the following sections of this report provide more detailed descriptions of each implementation phase and highlight best practice enablers and processes essential to both outcomes achieved and planned actions. Following the phase descriptions, the report offers an assessment of remaining challenges to implementation and a brief conclusion. Considering the true paradigm shift these game-changing intermittence capabilities are enabling in DoD's electronics maintenance community, significant progress has been made. Remaining implementation challenges involve maintaining unity of effort to drive deeper understanding, resourcing, and application of these new intermittent detection and isolation technologies.

Phase I: Scoping the Enterprise Electronics Intermittence Problem, Formalizing the Failure Mode, Developing a Solution Set, & Deploying at DoD Maintenance Activities

Phase I began in 2010 and was approximately six years in duration. In this timeframe DoD achieved fundamental milestones that established and executed the foundation of a strategic approach to address its electrical intermittence fault problem. The establishment of a DoD-led, highly respected Joint Service working group enabled identification and dissemination of the size and scope of the intermittent/NFF problem across the DoD electronics maintenance community.[4] This led to development of a military performance specification (MIL-PRF-32516) that officially defined the electrical intermittence fault. An update to MIL-PRF-32516 will be released in 2021 that will include minimum performance requirements for intermittent fault diagnostic equipment

[4] The size, scope, and impact of DoD's electronics intermittence problem is detailed in the Introduction section of this report.

for weapon systems. Weapons systems include the weapon system or military equipment, ground vehicles (wheeled, tracked, etc.), missiles, ships, space vehicles, etc.

Once the intermittent fault gained traction and emerged as an accepted failure mode, work began to identify a solution set and objectively assess potential offerings. This was done through focused, collaborative activities that produced a solution that is fully operational at four DoD maintenance activities and accessible to the DoD electronics maintenance community. Major successes included establishment of a validated test bed (i.e., Intermittent Fault Emulator) to determine test equipment MIL-PRF-32516 compliance, development of an enterprise-wide business case analysis (BCA), and formation of Office of the Secretary of Defense (OSD) sponsored Technology Demonstration Projects (TDPs) to generate interest and innovation related to electronics intermittence.

Several dynamic organizations employed best practices and fostered DoD and Industry collaboration to both establish DoD's enterprise approach and then drive innovation and results. A degree of detail will now be provided about the most important of these groups and activities to illustrate the scope and intensity of effort required to drive acceptance and implementation of a paradigm shifting maintenance technology. This effort is made more difficult because there is no officially designated organizational champion or clear resource sponsor.

The Condition-Based Maintenance Plus (CBM^+) Charter, JIT WIPT

The ODASD(MR) (formerly, Maintenance Policy and Programs) formed and chartered the CBM^+ JIT WIPT in September 2012. This group includes voluntary participants from the Air Force, Army, Navy, and other Defense Agencies and works in close cooperation with Industry. This group has been instrumental in shaping the strategic and tactical activities required to identify diagnostic equipment capable of detecting intermittent faults. Through JIT WIPT collaboration, the Military Services concluded that Intermittent Fault Detection Equipment (IFDE) standardization is critical to addressing electronics component failures.

The JIT WIPT galvanized electronics maintenance community interest and support in intermittent fault detection and isolation capabilities. It also sponsored and continues to update and refine the technical framework enabling further implementation of proven capabilities. Among other activities, the JIT WIPT classified and validated joint performance requirements for a Joint Service intermittent fault detection system, defined the minimum fault detection threshold requirements for the applicable wiring systems, component types, and system architectures, and identified and validated test methods for ensuring specified minimum performance requirements for detecting and isolating intermittence are met (MIL-HDBK-527, MIL-HDBK-525, and proposed MIL-HDBK-454 Intermittent Fault Diagnosis Guideline).

The JIT WIPT continues to lead the electrical intermittence "charge." It drives key implementation activities and originates and updates technical publications essential to maintain momentum and focus on the intermittence topic. It also develops briefings and publishes technical reports to assist the Military Services as they develop intermittence solutions supportive of their operational environments.

The accomplishment that best illustrates the JIT WIPT's effectiveness in terms of technical competence, Government and Industry collaboration, and action orientation is publication of

MIL-PRF-32516. The Electronic Test Equipment, Intermittent Fault Detection and Isolation for Chassis and Backplane Conductive Paths (MIL-PRF-32516) was published in March 2015 and formally recognized intermittence as a DoD failure mode and addressed the intermittent fault capability gap. This specification defined the minimum performance requirements for equipment to detect and isolate nanosecond, microsecond, and millisecond conductive paths and intermittent faults which can occur in all the hundreds to thousands of LRU/WRA chassis and backplane circuits and their wiring harnesses in DoD's equipment. Prior to this publication, no specification/standard for intermittent faults or technologies required to remediate the problem existed.

Development of an Intermittent Fault Emulator (IFE) further demonstrates the JIT WIPT's effectiveness in terms of technical competence, Government and Industry collaboration, and action orientation. The challenge is validating intermittent fault diagnostic equipment capability. This equipment must detect and isolate intermittent faults of very short duration that can occur on multiple conductive paths simultaneously. The IFE can be programmed to emulate intermittent faults of very short duration on multiple conductive paths simultaneously, so that the diagnostic equipment capability can be validated. This is of paramount importance because there is significant amount of test equipment which purports to detect and isolate intermittent faults.

Taken as a whole, the JIT WIPT has facilitated intermittence problem identification and solution development by leading a forum for Government, Military Service, and Industry professionals to collaborate and exchange information on intermittent issues across many platforms through briefs, industry days, outreach, and technology transition activities. The JIT WIPT serves as an enterprise wide technology insertion best practice. It has brought synergy and commonality to the required transformation of DoD's electrical maintenance capabilities to support today's and tomorrow's electronics maintenance communities across DoD. By helping to define the intermittence problem at the appropriate levels within the DoD and then continually setting the conditions to offer solutions tied to clear technical requirements, the JIT WIPT is instrumental in facilitating action to address intermittence related readiness and cost drivers.

The Commercial Technologies for Maintenance Activities Cooperative Agreement

During Phase I, the Joint Staff recognized the scope of the intermittent fault problem and held an industry day and worked on developing the MIL-PRF-31516, funded through the Logistics Initiative Fund. Active Joint Staff advocacy and sponsorship is critical because it signals the importance of the issue to the joint warfighter. The JIT WIPT was then able to employ a unique venue to demonstrate and evaluate commercially available maintenance, sustainment, and logistics technologies with an emphasis on successful technology transition prior to acquisition. The Commercial Technologies for Maintenance Activities (CTMA) cooperative agreement is a partnership between the ODASD(MR) and the National Center for Manufacturing Sciences (NCMS). Since 1998, the CTMA Program has connected industry and academia to introduce innovative technologies within DoD's operational space.

Utilizing a best-of-breed, agile 45 to 90-day cradle to execution process, this non-Federal Acquisition Regulation (FAR) based program is a risk reducer that enables an innovative "try it before you buy it" setting. Requirements are identified during demonstrations to facilitate successful technology transition. The CTMA Program enables and encourages project partners to provide and share assets, tacit knowledge, facilities, and personnel where feasible, thereby reducing costs and optimizing resources. While one Military Service may be the primary on a CTMA initiative, other Military Services are invited to observe and glean results from demonstrations and evaluations to adopt best practices within their own maintenance and sustainment environment. This process limits the costs and time to initiate and organize individual projects. It also promotes sharing within the DoD enterprise and demonstrates sound stewardship of taxpayer dollars. The CTMA Program was leveraged by the JIT WIPT as the optimal vehicle to demonstrate and evaluate the initial intermittent fault detection and isolation technology and to share the results DoD-wide.

To do this, the CTMA Program leveraged its wide network of partners, members, and communication channels, to help facilitate an “Industry Day.” Industry Days have proven to be excellent opportunities for DoD decision makers to compare similar technologies side-by-side or answer focused requests for solutions. These events also allow DoD attendees to observe technologies, ask questions one-on-one with Industry representatives, learn the pluses and deltas of technology attributes, and determine if a technology may answer unmet needs.

Sponsored by the Joint Staff in FY 2015 and executed within the CTMA Program, an “Industry Week” was conducted with select respondents to Request for Information (RFI) no. N68335-15-RFI-0505, issued on May 28, 2015. Selected respondents were asked to bring equipment to Naval Air Warfare Center Aircraft Division (NAWCAD) Lakehurst to demonstrate and discuss their intermittent fault detection capabilities and systems. Technology evaluations were held on January 4, 2016. Three of the six companies that responded to the RFI were extended an invitation to participate in the Industry Week: Eclypse International, Universal Synaptics Corporation, and Solavitek, Inc. A fourth company, Ridgetop Group (responding to a previous RFI) accepted an invitation to present its technology. Universal Synaptics’ IFDIS (discussed above) and its PIFD were the only capabilities that met MIL-PRF-31516 specified requirements.

The IFDIS and PIFD met the requirements cited in MIL-PRF-32516 because of their ability to continuously and simultaneously detect and isolate random intermittent faults. Additionally, Universal Synaptics’ demonstrations focused exclusively on solving NFF and finding intermittent faults. In addition to detecting and isolating intermittent faults, the IFDIS and portable PIFD automatically interrogate, through the use of Artificial Intelligence (AI), and store the as-designed wiring configuration of a known good unit, greatly reducing the time and cost associated with developing Test Program Sets (TPS) which is required for conventional testing (see Chart 4).

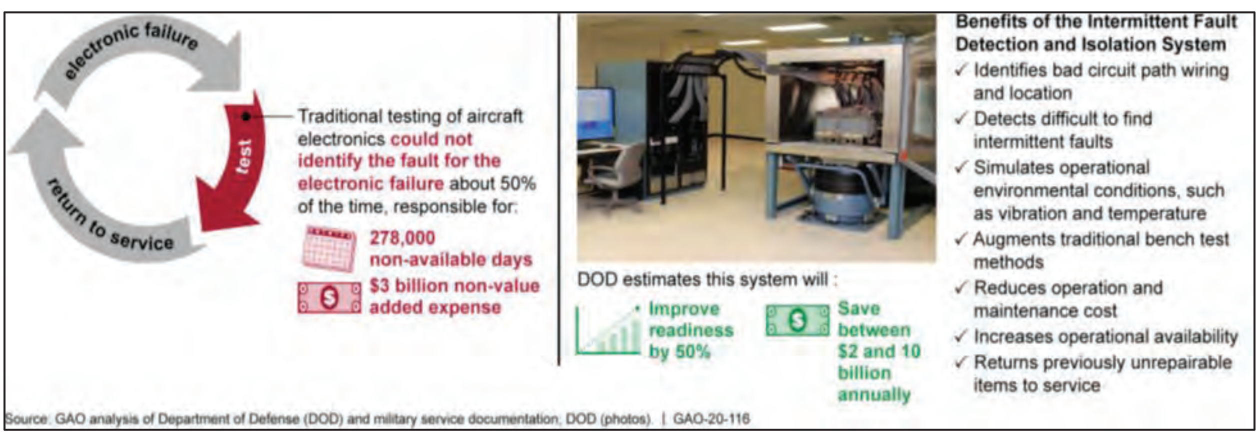


Chart 4.

During Phase I of DoD's phased intermittence implementation approach, the JIT WIPT's use of the CTMA venue, through the advocacy of the Joint Staff and the Logistics Initiative Fund, provided the means to both generate industry interest in solving the intermittence issue and sponsored an objective evaluation mechanism for capability demonstration that could be formalized into a DoD specification. Through additional Joint Staff advocacy, DoD standardized the newly developed Intermittent Fault Detection equipment verification process utilizing the IFE that was established in Phase I. The IFE emulates intermittent faults of known duration on a conductive path to verify the capability of test equipment to detect and isolate the simulated faults. MIL-PRF-32516 requires, as part of first article testing, Government validation of prospective offers using the IFE to validate Intermittent Fault diagnostic equipment capabilities.

Figure 2. 128-Channel IFE

Other key activities occurred under the auspices of the JIT WIPT to address electrical component failures due to intermittent faults. The Air Force and the Navy are the vanguard of current application at maintenance activities and have successfully applied and shared best practices and lessons learned. The following Phase I examples illustrate the "bottom up" recognition of the intermittence fault and the willingness to work across Military Services to identify and implement solutions.

Air Force Modular Low Powered Radio Frequency (MLPRF)

In 2008, OO-ALC became aware of Universal Synaptics' IFDIS technology. Depot personnel procured the IFDIS commercial tester and applied it to the F-16 aircraft Radar System MLPRF LRU, which at that time was OO-ALC's number one Mission Impaired Capability Awaiting Parts (MICAP) issue on F-16s. The IFDIS was procured by the OO-ALC depot utilizing RTOC funding and was the first IFDIS procured and utilized in DoD.

In 2010, the Avionics Advanced Maintenance Team (AAMT) at OO-ALC launched into full scale IFDIS testing of the F-16 MLPRF LRU. Upon depot induction of every MLPRF, all the Shop Replaceable Units (SRUs) were removed and the MLPRF LRU chassis were IFDIS tested. The IFDIS first tested the LRU for open circuits by ensuring continuity in all circuit paths. The IFDIS then tested for shorted circuits by verifying between each circuit and every other circuit to ensure there are no shorted circuits in the LRU. The IFDIS then tested for intermittent faults. This is conducted by monitoring all circuits in the LRU, simultaneously and continuously, while a vibration table and an environmental chamber simulate operational conditions for the F-16 MLPRF. If any circuit experiences an intermittent fault for durations as short as 50 nanoseconds, the IFDIS detects and precisely isolates the location of each intermittent circuit. In addition to cracked solder joints, other intermittent conditions were detected, isolated, and repaired, including broken wires, sprung connector receptacles, and loose crimp connections.

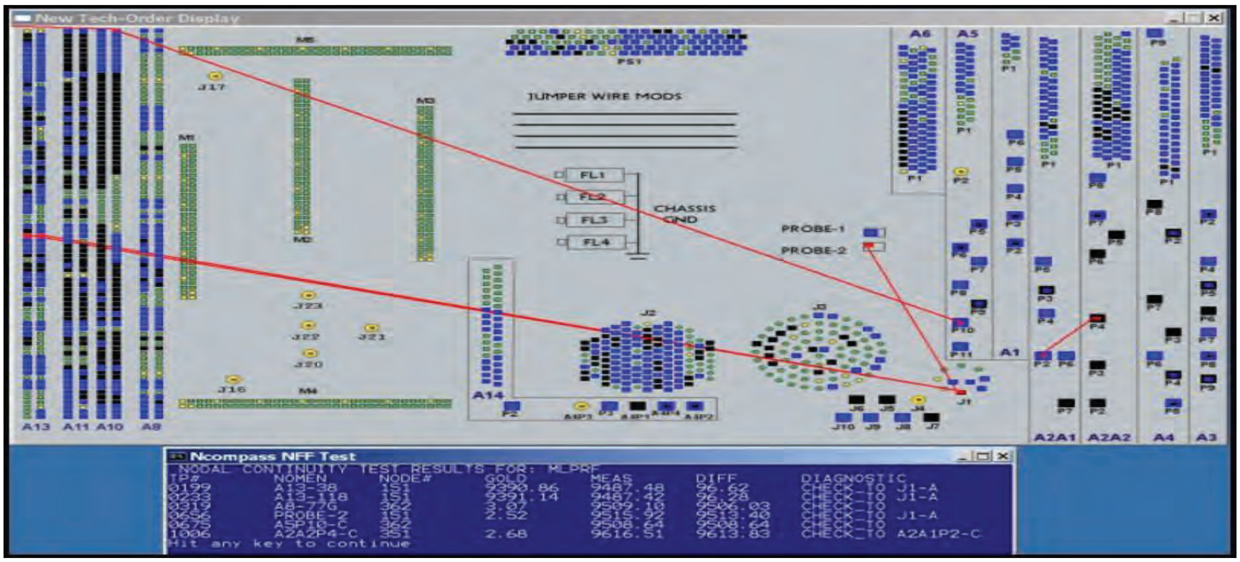


Figure 3. IFDIS Fault Isolation Graphic identifying the exact location of detected and isolated intermittent faults in the F-16 MLPRF LRU

These results highlighted that an ongoing, extensive F-16 MLPRF LRU re-soldering program was no longer required. IFDIS testing either exonerated each LRU by verifying there were no open, short, or intermittent circuits, or IFDIS testing identified and precisely detected and isolated each problem within the LRU. Repairing a cracked solder joint or broken wire is not difficult. The challenge is and has been detecting and isolating these elusive problems.

Over 500 F-16 MLPRF LRUs have been IFDIS tested at OO-ALC with 68% of the LRUs having one or more intermittent circuits that conventional depot test equipment had not detected or isolated. Each intermittent circuit detected and isolated by the IFDIS was repaired and each serial number was retested to ensure quality of the repair and that the asset was intermittent free.

These MLPRF LRUs were returned to service and the average number of operating hours of the IFDIS tested MLPRFs was calculated and found to have increased from 289 to 926 hours. Reliability had increased over 300% due to IFDIS testing. The number of MLPRFs being inducted into the depot has dropped from 50 to four per month. The induction decrease saved over $20 million in annual depot maintenance costs. Additionally, $42 million worth of MLPRF LRUs that had previously been designated as non-repairable and slated for condemnation were repaired and returned to service as a direct result of IFDIS testing.

Not only has the IFDIS testing enabled numerous previously undetectable F-16 MLPRF LRU intermittent problems to be detected and repaired, but the time required to repair MLPRFs has been reduced considerably. Previously, technicians had been spending days or weeks trying to track down intermittent problems in these LRUs. The IFDIS enables technicians to identify the precise location of all intermittent circuits in minutes. Because of the tremendous success that was realized in detecting intermittent faults with the IFDIS, substantially reducing the incidence of NFF and significantly increasing time on wing for the F-16 MLPRF, the AAMT expanded IFDIS testing to the F-16 AN/APG-68 Radar System Antenna LRU, the F-16 Central Air Data Computer (CADC) and the F-16 AN/APG-68 Radar System Programmable System Processor (PSP). Several studies undertaken since FY 2011 show that there are many LRUs that have an even more severe NFF problems than the F-16 MLPRF LRU.

OO-ALC currently owns and operates three IFDIS test benches. By detecting, isolating, and repairing the intermittent faults in LRUs at OO-ALC, time on wing of IFDIS tested LRUs has increased by 300%, substantially increasing the reliability of the F-16, reducing maintenance costs by $20 million annually, and achieving $150 million in cost avoidance, while also reducing the need to acquire LRU spares and perform expensive OEM recommended upgrades.

Navy F/A-18 Aircraft Generator Converter Unit (GCU) Chassis Best Practice Implementation

The Air Force, with the OSD's assistance, enabled the Navy to address a long-term MICAP problem by sharing best practices even as it focused on solving its F-16 MLPRF LRU intermittent fault problem. The F/A-18 GCU chassis, a critical safety item is a historically challenging MICAP for the Navy over the last 20 years, causing repeated availability loss and driving unnecessary repair costs. As the Air Force began to address NFF for the F-16 MLPRF LRU, the Navy's F/A-18 GCU chassis reliability and availability issues had reached a peak, receiving the attention of the Commander of the Naval Air Systems Command (NAVAIR). This leadership focus created great urgency within the Navy's electronics maintenance community to step up efforts to address its GCU difficulties.

As the Navy considered GCU solutions, DoD sponsored a first of its kind "Concurrent Technology Showcase" as part of the CTMA Partners Meeting. This event was unique because it was held directly on the shop floor of an aviation repair facility (Naval Aviation Depot North Island) and included leading industry partners who were invited directly into the maintenance depot. This kind of venue enabled artisans[5] to learn first-hand about capabilities from both Industry and other Military Services that could help them solve their problems. The venue also enabled information technology specialists and the depot's management team to get first-hand knowledge of available capabilities and solutions. It was at this Concurrent Technology Showcase that North Island's Navy artisans first learned of the IFDIS capability from the Air Force. The Navy quickly realized the potential value of this capability, and shortly thereafter started to implement solutions to address the GCU issues in their organizational context. OSD facilitated the pace of knowledge sharing and IFDIS implementation by sponsoring not only this concurrent technology venue, but a CTMA event that drove development of an interface adapter.

[5] Artisans – Definition = A worker in a skilled trade

This adapter became the pacing item for the Navy's ability to implement IFDIS and to leverage Air Force MLPRF LRU lessons learned in their IFDIS technology insertion activities.

The early IFDIS successes in both the Air Force and Navy resulted primarily from innovation and "out of the box" thinking exhibited by talented technology insertion teams, sustainment and maintenance professionals in the face of extremely serious materiel readiness issues. The MLPRF and the GCU chassis were holding down aircraft to such an extent that reaffirming conventional solutions was not going to get the job done. Each Military Service deserves great credit for taking an initial chance on IFDIS and for making time to collaborate in order to increase the scale of benefits achieved. DoD also played an important role by continuously channeling this innovation through the appropriate kinds of technical and knowledge sharing venues. These events not only drove the initiation and execution of good ideas but provided the technical forums to focus and enable the right SMEs to develop and tailor the technical framework to grow intermittent fault and detection capabilities at the appropriate pace.

The Navy collaborated with the Air Force after participating in a CTMA Partners Meeting, where Universal Synaptics provided a briefing on the IFDIS application utilizing this advanced technology at OO-ALC, Hill Air Force Base (AFB), which could test and isolate wiring issues within chassis and backplanes to the precise location of the intermittent fault. The Fleet Readiness Center Southwest (FRCSW) Fleet Support and Advanced Technology team engineers visited OO-ALC at Hill AFB in 2010 to investigate the technology and its potential application for the F/A-18 GCU. In 2012, during an initial engineering demonstration that leveraged the OO-ALC visit, six ready for issue GCUs (two from each variant group G1, G2, & G3 GCU modifications) were tested and resulted in five out of six failing for intermittence related issues. FRCSW was able to repair the intermittent failures on five of the six failing GCU's and return to supply intermittence free.

In response to the intermittent wiring issues detected and isolated by the IFDIS during FRCSW's engineering demonstration and data from the Air Force F-16 aircraft radar findings, FRCSW invested in IFDIS capability via the Capital Investment Program (CIP). In 2016, the first IFDIS was installed at FRCSW and further testing was undertaken to scope the F/A-18 GCU intermittent testing requirement. Commander, Fleet Readiness Centers (COMFRC), FRCSW, Fleet Readiness Center West (FRC-W), Marine Fighter Attack Squadron-122, and the F/A-18 Program Office (PMA-265) collaborated on a one-year GCU pilot program.

The purpose of the F/A-18 GCU IFDIS pilot program was to gather IFDIS test data to validate that intermittent faults are a significant cause of NFF, validate that unidentified and repeated operational on-aircraft failures in the GCU chassis are intermittent faults, and validate that Intermittent Fault Detection technology detects and isolates faults in WRA chassis. Additionally, the IFDIS pilot program was to document F/A-18 GCU TOW improvements in a controlled environment by utilizing a Lemoore Super Hornet Training squadron where GCUs were installed as a pair and a supply officer controlling GCU usage and flight performance reporting, simulate IFDIS tested GCU impact on normal I-level fleet operations by re-installing original GCU components and replacing only those components that failed during final WRA testing to keep pilot costs low. As a baseline, the team documented F/A-18 GCU TOW across the fleet at 121 hours. Finally, the last objective was to validate the assumption that traditional ATE cannot detect and isolate intermittence.

Figure 4. Technician operates the IFDIS to test the GCU chassis of an F/A-18. The IFDIS not only checks the connection points in the GCU harness for intermittent shorts or opens, but also has the capability to simulate the flight stresses and conditions which F/A-18 aircraft are exposed. (U.S. Navy Photo)

The results of the F/A-18 GCU IFDIS pilot program generated unprecedented results. IFDIS detected and isolated intermittence failures in 70% of pilot program GCUs that traditional ATE did not detect or isolate. This discovery validated the assumption that traditional ATE testing is incapable of detecting and isolating intermittent faults. This was validated because all pilot program GCUs had passed traditional bench testing with no wiring failures detected in comparison with those found by utilizing the IFDIS. The F/A-18 TOW for IFDIS tested GCUs in some cases tripled in comparison to the fleet average of non-IFDIS tested GCUs. The IFDIS also reduced the impact and cost to the supply chain (e.g., erroneous subassembly replaceable assembly failures due to chassis intermittence) for all pilot program GCUs. Additional results achieved were a reduction in maintenance turnaround time (TAT) and man hours expended at the Intermediate and Depot level for ready for issue testing by 67%, falling from 22-hour average testing/repair to seven-hour average testing/repair per GCU.

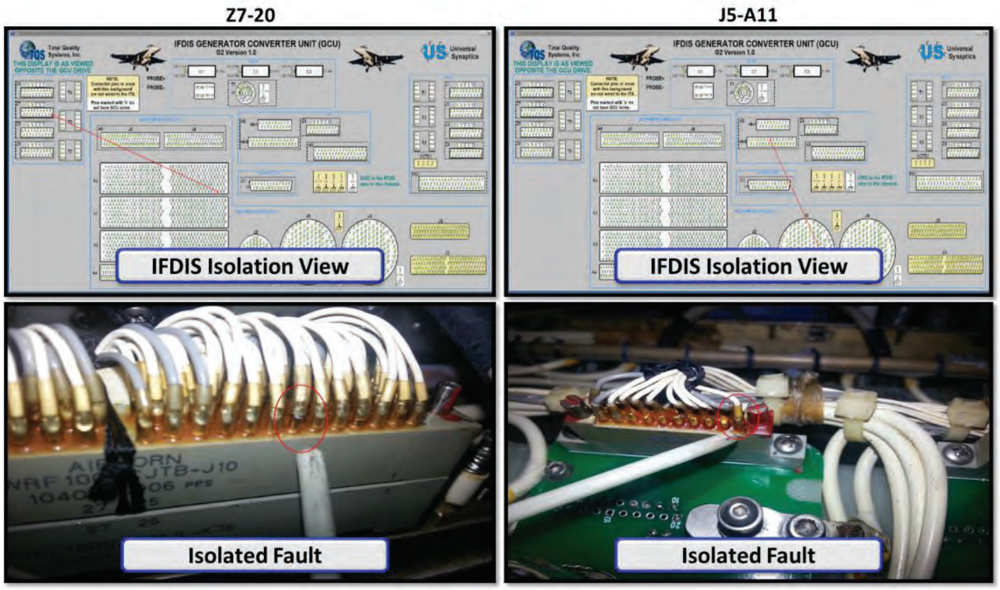


Figure 5. An example from the pilot: IFDIS test results showed three intermittent circuits due to broken wires at Z7-20, J5-A11, and A5-A13 (shown above: Z7-20 and J5-A11 broken wire conductive paths). The IFDIS demonstrated the ability to find faulty wiring that was not detected by traditional bench or visual inspection. Post IFDIS Pilot TOW results tripled. (US Navy Photos).

The F/A-18 GCU IFDIS pilot results led to the realization that GCUs could be returned to fleet operations with wiring issues that could lead to F/A-18 on aircraft GCU failures. As a result, Field Support Team (FST) engineers drafted a Local Engineering Specification directing 100% of F/A-18 A-D group G1and G2 GCU testing across the IFDIS and extended this testing to 100% of all F/A-18 E-F GCUs in 2019. Additional funding was provided by NAVAIR, Lakehurst for the purchase of additional IFDIS to support Intermediate-level processes that included IFDIS capability for FRC-W (Lemoore, California) and FRC-Mid-Atlantic (Oceana, Virginia) to test F/A-18 E/F Super Hornet aircraft GCUs that have NFF issues from the squadrons. The Fleet Readiness Centers operate three IFDIS for F/A-18 GCU testing.

Army UH-60, AH-64, and Patriot Missile System Intermittence Technology Demonstrations

Letterkenny Army Depot (LEAD) and Fort Campbell were chosen as locations to demonstrate PIFD capabilities utilizing patented MIL-PRF-32516 "*Electronic Test Equipment, Intermittent Fault Detection and Isolation*" compliant PIFD. The PIFD was applied to the Patriot Missile System, UH-60, and AH-64 EWIS. In addition, detecting intermittent faults, the PIFD provided the ability to isolate wiring problems that enabled root cause repair and directly addressed the NFF problem.

The primary result of this project was successful demonstration of the elements necessary to enable detection and isolation of intermittent, open, and short circuits within weapon system EWIS at LEAD and Fort Campbell. Intermittent faults were detected and isolated in the first unit tested with the PIFD at LEAD. The detailed identification of the faults and their precise locations enabled the maintenance technicians to fix the root cause of the intermittent faults in UH-60 and AH-64 EWIS.

In summary, Phase I of DoD's holistic approach to increase implementation of intermittent fault detection and isolation capabilities concluded in 2016. It was particularly successful in scoping DoD's electrical intermittence problem and beginning the integration of intermittent fault and detection capabilities into DoD's traditional maintenance operations. The intermittence failure mode was appreciated at key organizations within DoD and an innovative solution was objectively evaluated and became operational at several DoD maintenance activities. Through effective organizational approaches, knowledge sharing occurred that enabled Military Services to target several weapons system platforms where NFF is driving low readiness and high costs. Phase I positioned the DoD to further leverage data and analytics to identify additional implementation opportunities and to begin to establish additional guidance and intermittence-focused technical organizations.

Phase II: Expanding Implementation at DoD Depot Maintenance Activities, Formalizing Military Service Guidance, and Developing Centers of Excellence

Phase II, which began in 2017, is underway and expanding the IFDIS/PIFD implementation framework within DoD maintenance activities. IFDIS implementation across the DoD was launched and funded through NCMS, CTMA, Joint Staff and the ODASD(MR). A DoD-wide framework to implement intermittent fault detection (IFD) technologies across all levels of maintenance was developed by the JIT WIPT leveraging the MIL-PRF-32516 and the DoD MADW.

The MIL-PRF-32516 framework, which was defined in Phase I, is supporting growth of IFD and isolation capabilities across the Military Services. The JIT WIPT went on to publish "*Solving the Department of Defense (DoD) Intermittence Problem, a framework for an Intermittent Fault Detection (IFD) solution*" (December 2018). This document recommends steps an organization may utilize to successfully implement IFD and isolation of EWIS and LRUs/WRAs. The recommended steps outlined in this publication are:

1. Build awareness and buy-in within the organization that short duration intermittence is a failure mode that is affecting readiness and efficiency.
2. Identify IFD opportunities and introduce the IFD solutions.
3. Acquire and implement the IFD solutions.
4. Validate the results and expand IFD implementation.

The first two steps are actions that the JIT WIPT and the ODASD(MR) can assist to build awareness and support within the DoD organization/agency or platform Program Office. Once these entities are engaged, the second step involves identifying the LRUs/WRAs most affected and the appropriate maintenance level for implementation. The Military Services are targeting the "bad actors" that account for ~$618M in non-value-added maintenance costs annually. Additionally, leveraging historical IFDIS data and results can possibly net an estimated $300M in cost savings with a 50% increase in material readiness on the initial IFDIS target weapons system components being addressed in Phase II. The JIT WIPT can employ available data tools and previous experience to assist with this analysis. Step three is the DoD organization/agency or platform program office's responsibility to acquire and implement the capability. In step four, the organization/agency, with the JIT WIPT's assistance, will validate the results and support the expansion of IFD equipment implementation.

Developing Technology CoEs will enable DoD to review and evaluate new and innovative technologies for detecting and analyzing intermittent faults through integrated, expert organizations. Implementation targets can then be supported by continually refined data-based decision-making processes, driven by leveraging the MADW data to identify target opportunities for IFDIS deployment. Continuous awareness and buy-in will increase throughout the Military Services as more implementations occur and information is shared through Technology CoEs about the benefits of electronics intermittent fault detection and isolation.

These CoEs will serve as "information hubs," able to identify lessons learned and communicate these throughout DoD. The CoEs will also focus on identifying the best of breed electronics intermittence maintenance technologies and advancing and integrating these capabilities, while developing and maintaining validated lists of products that have demonstrated ability to detect Category 1 intermittent faults (per MIL-PRF-32516) in their intended fault environment. The JIT WIPT will continue to present and/or demonstrate potential IFDIS capabilities and benefits to platform managers and applicable leadership levels to garner support and advocacy. Enterprise-wide cost and availability variables will continue to drive the growth in depot maintenance implementation.

The Technology CoEs under assessment are:

- Naval Surface Warfare Center (NSWC) Crane (Airborne Electronic Attack Fleet Support Team), which covers the Navy and Marine Corps, to include NAVAIR and the Naval Sea Systems Command (NAVSEA). The Fleet Support Team at NSWC Crane is uniquely suited to serve as a Technology CoE because of its current responsibilities in support of airborne electronic attack WRAs installed on EA-6B, EA-18G, and P-8 aircraft.

- The Air Force IFD Technology CoE located at Hill AFB (Air Force Sustainment Center 309th Electrical Maintenance Group). The Maintenance Group at Hill AFB is well positioned to become an IFD CoE due to a decade of experience and success restoring F-16 LRUs back to their original design reliability.

Both CoEs will evaluate new technologies through participation in recurring Industry Days.

Phase II is continuous and ongoing. The JIT WIPT, in collaboration with the Military Services, will continue to leverage MADW data to identify DoD's IFDIS best opportunities to influence leadership awareness and buy-in. The Military Services will also persist in identifying the "bad actors" to ensure intermittence related readiness improvements and cost savings. The Military Services continue working with their field level organizations to identify IFD opportunities and introduce IFD solutions. The ODASD(MR), in collaboration with the JIT WIPT, will have overall oversight to continue to keep all stakeholders informed of this issue. Historical IFDIS data and results, with a conservative estimate of $300M in cost savings with a 50% increase in material readiness on the initial IFDIS target weapons system components, are achievable in Phase II.

Phase III: Implementing IFD and Isolation Capabilities at Field Level Maintenance Operations

Phase III began in 2018, overlapping with Phase II to expand and focus to focus IFDIS implementation at field level maintenance operations. Delivering advanced IFD capability closer to the weapon system enables intermittent failures to be detected, isolated, and repaired rapidly, reducing the logistics and supply chain burden. Additionally, DoD will need to increase adoption of the intermittent fault failure mode and solution set for EWIS. MIL-PRF-32516 (March 2015) is the current guidance being used to define performance requirements for equipment to detect and isolate electronic intermittent faults. The ODASD(MR) will continue to leverage the Military Services' "bad actors" from Phase II to guide strategic IFDIS implementation as the list of "bad actors" is updated and refined during Phase III implementation. Socializing IFDIS results with the Military Services through collaboration from various organizations and programs (e.g., the JIT WIPT, CTMA, CBM^+ Working Group, JTEG, Maintenance Symposiums) may increase standardization and adoption of IFD technologies.

Development and demonstration activities are underway to detect and isolate intermittence in wiring harnesses while installed in weapon systems during field maintenance with the use of Universal Synaptics' PIFD that has an ATO approval from the F-35 JPO. Implementation of PIFD capability at the field level offers tremendous benefit in terms of cost savings and readiness improvements for additional weapon system platforms.

The JIT WIPT has used two iterations of the MADW data (FY 2012 and FY 2019) to identify the top 10 false or supposedly false intermittent LRUs/WRAs for each Military Service that would be candidates for IFDIS testing and analysis. The Military Services, in coordination with the JIT WIPT, will continue to identify the top 10 false or supposedly false intermittent LRU/WRA candidates for IFDIS testing and analysis. For the purposes of data analysis, certain business rules have been established to ensure accuracy of the data. For example, the use of all Engineering Investigation (EI) codes should be identified, Performance Based Logistics (PBL) contract repairs should be excluded from any list of new candidates for testing and analysis, and critical safety items should be included. Key discriminators to this analysis must include but not limited to cost, availability, and cost per day of availability (C/DA). These discriminators will enable the Military Services to better forecast new cost, availability, and C/DA results. The overall intent of the data is to identify LRUs/WRAs that are potential candidates for IFDIS due to LRU/WRA criticality, maintenance cost, and non-availability days.

On May 18, 2021, the Chief Financial Officer Data Transformation Office and the Undersecretary of Defense for Acquisition and Sustainment signed a memorandum of agreement directing the migration of MADW to Advana. With its name derived from the term "advanced analytics," Advana is a centralized data and analytics platform that supplies Department of Defense (DoD) users with common business data, decision support analytics, and data tools. Adding MADW to the suite of Advana capabilities will offer users a central location for data analytics concerning acquisition and sustainment costs and outcomes. The migration will support a larger MADW platform, ensuring consistent and reliable resourcing for MADW curation and development.

The ODASD(MR) intends to issue a memorandum in calendar year 2021 requesting each Military Service to review the MADW candidates and perform a thorough analysis based on additional data and subject matter expertise. The Military Services will also provide an updated list of best candidate components to address during depot-level visits for eliminating NFF where electrical intermittence is the suspect cause. The draft memorandum will also ask each Military Service to review the MADW IFDIS candidate data and validate and/or recommend IFDIS candidates based on their "local knowledge" of what is impacting their operations.

Phase III will establish the framework in collaboration with various organizations (e.g., NAWCAD Lakehurst, OO-ALC, NSWC Crane, Hill AFB) that presents an opportunity for standardization and centralization of DoD IFD policy and practice in a way that would not be feasible for diagnostic systems that detect hard faults.

A collaborative effort with the JIT WIPT and various organizations is to propose and develop a DoD Joint Intermittent Test CoE with the primary function of maintaining a validated products list of items with demonstrated ability to detect Category 1 intermittent faults in accordance with MIL-PRF-32516 in their intended fault environment. This Joint CoE will be capable of testing new technologies to determine if the technologies can, in fact, detect intermittent faults, and how short of a time duration the intermittent fault candidate technology can detect. The responsibilities of these collaborative efforts shall include, but not be limited to, diagnostic equipment validation; participation in Industry Days; updating and developing new test capabilities/procedures; updating test methods as needed; updating the IFE; and updating MIL-PRF-32516 and MIL-HDBK-527. In addition, the JIT WIPT is collaborating with various organizations to ensure compliance with the DoD Automatic Test Systems (ATS) Master Plan, including review of existing ATS and coordination with the ATS Executive Directorate.

An ODASD(MR) memorandum, dated April 2019, advised the electrical maintenance community to rapidly promulgate intermittence detection and isolation capabilities, as defined by MIL-PRF-32516, across the enterprise. Each Military Service senior leader was requested to address recommendations focused upon intermittence as an electronics failure mode and to provide a plan to address and field intermittent fault detection and isolation capabilities.

The major Phase III activities include:

- Leveraging the Military Services' "bad actors" for IFDIS test, repair data, readiness improvements, and cost savings from Phase II to guide strategic IFDIS implementation for the next Top 20 "bad actors";
- Continuing to refine MADW Military Service data;
- Socializing IFDIS results achieved in Phase II, increasing adoption of IFD technology;
- Developing a specification sheet addendum for field level IFD and isolation capabilities;
- Distributing F-35 JPO PIFD test, repair data, readiness improvements, and cost savings from Phase II to weapon system wiring groups and engineering competencies; and

- Increasing adoption of intermittent failure mode and solution set for EWIS.

The tremendous benefit of a comprehensive Phase III implementation is that "catching" intermittence at the field level will not only increase materiel availability more quickly and directly, but will save the enormous distribution, labor, and storage costs associated with addressing intermittence at the depot level. Therefore, DoD will strongly pursue implementation of intermittent fault isolation and detection capabilities at field level maintenance activities. However, implementing these capabilities at the field level is much more complex than depot level implementation.

Several challenges contribute to this complexity. First, DoD needs a precise, repeatable, and safe way to create the environmental conditions that simulate intermittence on aircraft at field level maintenance locations. The current technical gap DoD is addressing is that onboard environmental stimulus is very difficult to emulate accurately in a field environment. CTMA issued a sources sought to Industry in July 2020 to collect potential solutions that could fill this technical gap. One of three responses was considered to be responsive. However, due to funding constraints, no additional actions have occurred. Proper locations must be established in order to ensure technical fidelity and substantial training and workforce development is required in order to normalize the capabilities at the field level. Second, field level maintenance, by design, does not commonly require substantial facilities and infrastructure to complete. New or additional equipment requirements, even if portable or relatively small, will drive maintenance process changes that will take time to put into operation. Finally, field level maintainers are charged with providing today's materiel readiness in accordance with demanding operational tempo requirements. Adding a different, reasonably sophisticated, tester to their busy workflow will be disruptive, at least initially. These maintainers will need to see the value of new intermittence capabilities in order to apply the effort required to make workflow adjustments permanent. Successful implementation requires active leadership at the Department and Service level, as well as effective best practice communication at "unit level maintenance" in order to leverage lessons learned and "value add" quickly and broadly.

Phase IV: Normalize the Use of IFD and Isolation Capabilities at All Levels of DoD Maintenance and During Initial Electronic Component Manufacture

DoD's vision for its Phase IV IFD and isolation implementation end state has both technical and organizational elements. Technically, intermittence will be widely recognized as an accepted failure mode for both legacy and initially manufactured assets. Testing for intermittence will be the norm throughout DoD and Industry for electrical maintenance and testing information will be collected and analyzed to make electrical components twice as reliable as they are now. These advances will dramatically increase affordability and availability over the life-cycle for all electronics components and the weapon systems they operate.

Organizationally, DoD will have taken steps to provide additional official guidance on all aspects of intermittence detection and maintenance to the electronics stakeholder community. It will provide refined and reissued guidance to establish a comprehensive intermittent fault and isolation concepts of operation that will work in unison with other ATE to identify and address steady state electronics failures. Supportive policy will also be developed to drive on-going collaboration between DoD and Industry to address topics such as first article testing, quality assurance, and production lot testing in the intermittence context. Intermittence workforce training and development will be established and fully integrated into career progression paths to institutionalize isolation and detection capabilities that are effective in an organization as large and complex as DoD. CoEs will be established and leveraged commensurate with capability advancement and collaborative venues will continue to share best practices and move the community forward.

Phase IV, to begin in late 2021, will begin to synthesize and expand existing IFDIS/PIFD implementations in order to scale the adoption of capabilities to all levels of DoD electronic component maintenance and manufacturing. DoD will continue to build and leverage collaborative groups to further integrate intermittence into the DoD technical community in order to normalize the appreciation and use of IFDIS capabilities. For example, a key target will be the integration of the JIT WIPT with other DoD wiring technical groups, such as the Joint Services Wiring Action Group (JSWAG).[6] While the JSWAG Executive Steering Committee has been receptive to collaborating with the JIT WIPT, it has not met since the proposal for collaboration was submitted, due to the coronavirus disease 2019 (COVID-19) pandemic.

As illustrated below, there is commonality between the JIT WIPT's and the JSWAG's objectives and increased collaboration will enhance awareness of the intermittence failure mode throughout the electronics wiring community.

The JSWAG's objectives are:

- Providing a forum for the service of industrial, maintenance, and product support activities to improve wiring, fiber optics, and interconnect systems. Designated representatives use the JSWAG to improve safety, reliability, maintainability, standardization, cost effectiveness and overall readiness of DoD Aviation Weapon Systems by improving their wiring and fiber optic systems. This is accomplished by the regular and timely exchange of technical information and application of principles by wiring systems experts from across DoD.
- Coordinating with other DoD agencies to develop standard procedures whenever possible and sharing information of benefit to all activities to obtain user requirements, assist in program budgeting, identify funding, develop actions, and recommend prioritized solutions.

JSWAG membership is composed of the Air Force, the Army, the Navy, the U.S. Marine Corps, the U.S. Coast Guard, the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), commercial airline maintainers, and Government support contractors.

The JIT WIPT forwarded a draft revision to the JSWAG charter to add a new JIT Committee in August 2019. The new committee has the following objectives:

- Advise and assist in implementing a DoD IFD solution.
- Leverage current and emerging IFD technology for demonstration, testing, and cost-benefit analysis.

[6] The JSWAG, previously known as the Naval Aerospace Vehicle Wiring Action Group (NAVWAG), has been chartered since May, 2002.

- Educate and inform program management and electronics and EWIS maintenance community on IFD.
- Define and validate joint performance requirements for a Joint Service IFD system.
- Collect and analyze implementation and operational data on IFD systems currently in use.
- Identify, define, and validate test methods for ensuring that specified minimum performance requirements for detecting and isolating intermittence are met.
- Leverage DoD's MADW to assist in identifying intermittence related readiness and cost drivers and recommend IFD opportunities.
- Investigate and develop plans for integrating IFD with existing EWIS maintenance and repair diagnostics and diagnostic equipment.
- Investigate intermittence-driven EWIS unscheduled maintenance.
- Develop recommendations and plans for decreasing intermittence-driven unscheduled maintenance and shifting to schedule-based IFD proactive maintenance.
- Collaborate with Industry and Academia on innovative intermittence-driven NFF solutions and methods.

This type of collaborative engagement can ensure continued communication with the Military Services and Program Offices and will be key to normalizing the use of intermittent fault detection and isolation capabilities at all levels of DoD maintenance.

Training the workforce will also be key to normalizing this capability. Establishing an IFD awareness and training program at the organizational and Military Service level where the IFD equipment will be utilized will ensure the workforce is trained and will ensure continued recognition of the severity of this failure mode.

Phase IV is the future state and continued collaboration amongst the Military Services, Program Offices, and working groups will increase the buy-in and awareness of this failure mode. A solid communication plan and training program will enable organizations to better understand the severity of this failure mode and enable all levels of DoD maintenance to identify IFDIS/IFD capabilities that will provide impacts to cost savings and readiness improvements.

Implementation Challenges and Keys to Successful Way Ahead

Intermittent faults have been recognized as top cost drivers as well as, number one MICAP issues as discussed with the Air Force's F-16 MILPRF and Navy's F/A-18 GCU failures. Increased leadership buy-in and awareness that intermittence is a recognized, accepted failure mode is key to ensuring the success of IFDIS/PIFD implementation. The capability exists to detect and isolate intermittent failures. The implementation of any new capability encounters challenges in the form of resistance to change, requirements determination, procurement costs, and not being aware of the magnitude and impact of the problem. The Military Services are challenged with identifying resources to begin implementation and resources will be key to organizations that want to obtain appropriate capability demonstrations, and subsequent implementation (if applicable), through the Military Services, Defense Agencies, or OSD. The following are some of the resources that may be available to assist in the implementation of IFDIS/PIFD equipment:

- **The Department of Defense Planning, Programming, Budgeting, and Execution (PPBE) process**

  Military Services and defense agencies utilize PPBE to identify requirements and compete for resources. PPEE is the department's process to manage, prioritize, and allocate resources to support activities consistent with the National Defense Strategy, National Military Strategy, and Department of Defense strategic objectives.

- **Capital Investment Program (CIP)**
  CIP is a potential source of funding for acquiring IFD equipment. CIP was established under the DoD Financial Management Regulation for all DoD activities under Defense Business Operations Fund (DBOF).

- **Depot Activation Workload Stand-Up**
  DoD Instruction 5000.02, Operation of the Defense Acquisition System, Paragraph 5.d(14)(b)(1), states that: "the Program Manager will ensure resources are programmed and necessary [intellectual property (IP)] deliverables and associated license rights, tools, equipment, and facilities are acquired to support each of the levels of maintenance that will provide product support; and will establish necessary organic depot maintenance capability in compliance with statute and the Life Cycle Sustainment Plan (LCSP)."

- **The Small Business Technology Transfer (STTR) Program**
  The STTR Program expands funding opportunities in the Federal innovation research and development (R&D) arena. Expansion of public/private sector partnerships, including joint venture opportunities for small businesses and nonprofit research institutions, is central to the STTR program. One unique feature of the STTR Program is the requirement for a participating small business to formally collaborate with a research institution in Phase I and Phase II of the Program. The STTR Program's most important role is to bridge the gap between performance of basic science and commercialization of resulting innovations.

  Note: The IFDIS procured by both the U.S. Air Force and U.S. Navy were procured under a Phase III SBIR Topic AF01-296.

- **The CTMA Program**
  Created in 1998, the CTMA Program is a joint effort between DoD and NCMS. Its objective is to ensure American troops and their equipment are ready to face any situation, with the most up-to-date and best-maintained platforms and tools available. The CTMA Program provides technology development and insertion in support of reliability and sustainment, and must always benefit the U.S. Military, industrial base and the public good.

- **Cooperative Research and Development Agreement (CRADA)**
  A CRADA is an agreement between a Federal laboratory and a non-Federal party to perform collaborative R&D in any area that is consistent with the Federal laboratory's mission. CRADAs are the most frequently used mechanism for formalizing interactions

and partnerships between private industry and Federal laboratories and the only mechanism for receiving funds from non-Federal sources for collaborative work.

There will need to be continued Government endorsement, Industry involvement, and data-driven implementation targets. Continued guidance promulgation to fully integrate intermittent capabilities into DoD maintenance vernacular, shop floor processes, and life-cycle management organizations are key to the successful way ahead. The JIT WIPT, in conjunction with other DoD working groups, can begin to demonstrate the tie from electronic component NFF corrections to weapon system readiness improvement. Additionally, the JIT WIPT and the Military Services will need to formalize processes, standardize tools to increase industry awareness, and assess potential IFD and isolation capabilities.

The introduction of a new failure mode and implementation of a technical solution has shown partial success but must be continually reinforced to receive full consideration as part of a weapon system sustainment plan. Establishing these collaborative arrangements discussed in Phase II and III become more critical to a successful way ahead. The success of these collaborative arrangements will increase awareness to the Electronics Community and ensure that those intermittent fault detection and isolation capabilities that have been recognized through various public awards or accolades are identified and that new technologies are still being sought. It is also vitally important to monitor the results and impact on LRU/WRA availability and costs. These results can be used in efforts to expand IFD implementation across the DoD.

As mentioned in the April 2019 ODASD(MR) memorandum, the Military Services need to utilize the "Framework for Implementing Intermittent Fault Detection and Isolation Capabilities" to implement this critical capability which will result in a significant increase in weapon system availability and a corresponding reduction in sustainment costs.

Finally, to ensure a successful way ahead, DoD must continue to update guidance to the community of interest regarding this intermittent failure mode and how current technology addresses it. The introduction of a new failure mode and implementation of a technical solution has been successful but must be continually reinforced to receive full consideration as part of key planning and execution documents, such as weapon system sustainment plans. As its structured and on-going implementation shows, DoD has accepted that institutionalizing this paradigm shifting intermittence technology is a marathon, not a sprint. DoD has been on this journey for over a decade and recognizes that work will continue for many years to come. The proper end state drives the Department's activities, and DoD will continue to fully leverage and share its successes on its way to fundamentally transforming electrical/electronic maintenance.

Conclusion

The Department's phased implementation approach is enabling the Military Services to address electrical intermittence by leveraging best practices across the DoD maintenance enterprise and providing the necessary building blocks and capabilities. The phased approach has articulated a well-defined and validated need, established clear performance specifications, supported an objective analysis of potential solutions, and produced sound results to meet the requirement.

It is imperative that additional DoD organizations recognize intermittent electrical faults as a failure mode that is significantly affecting weapon system availability and sustainment costs, and that a capability exists to improve materiel availability and save significant sustainment resources. However, the implementation of any new capability that fundamentally changes established paradigms encounters challenges such as cultural acceptance, organizational alignment, requirements determination and resourcing, and lack of recognition of the magnitude and impact of the problem. This report informs Congress of the strategic approach DoD has underway to address these challenges and to assist organizations to gain awareness of intermittence problems including their effect on readiness and cost, and subsequently to implement an objectively proven capability to help resolve them.

Weapon system program offices own the requirements process for procuring new diagnostic capabilities and integrating them into the maintenance and repair process. This management construct promotes stove-pipe implementation of novel sustainment technologies and necessitates a weapon system by weapon system exploration and buy-in process in order to stand up new sustainment capabilities. In order to effectively implement a sustainment capability such as IFDIS and PIFD broadly across DoD, the Military Services must take an enterprise-wide approach supported by leadership advocacy, policy, guidance, and training, Recent COMFRC efforts to instantiate IFDIS and explore PIFD are good examples of enterprise-level activity that is underway to broadly apply these capabilities to a wider range of electronic systems, and can be achieved with the anticipated savings referenced earlier in this report.

IFDIS and PIFD are proven IFD and isolation capabilities that can be leveraged at scale and institutionalized across the DoD maintenance enterprise to help reduce the 278,000 non-available days of end-item subcomponents and reduce the annual $3 billion NFF cost burden to the DoD. Broader acceptance of the intermittence failure mode would enhance DoD's ability to facilitate focused availability recovery efforts and positively impact sustained readiness recovery.

Addressing the "bad actors" from each Military Service that account for $618M in non-value-added maintenance costs annually is the immediate next step in DoD's Phase II efforts. Leveraging historical IFDIS data and results, a conservative estimate of $300M in cost savings with a 50% increase in material availability on the initial IFDIS target weapons system components, is achievable in Phase II. Further materiel readiness and total lifecycle cost reductions will then follow in Phases III and IV through broader and deeper implementation of proven intermittent fault detection and isolation test capabilities.

A significant point raised by this assessment is that the resource and incentive structures required to reinvigorate innovation and agile technology insertion within the nation's Defense Industrial Base must be more systematic. While DoD has shown resourcefulness and persistence in this electronics maintenance, further work is required to ensure these activities are closely aligned with DoD's technology insertion management and prioritization processes.

Improvements in this area could institutionalize the many successful aspects of the strategic intermittence approach described in this report and apply them more broadly to drive consistent, authoritative sustainment technology insertion across DoD. This would provide effective pathways to identify, scale, and implement emerging technology and temper the cultural resistance that comes with disruptive technological change.

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WASHINGTON, DC 20301-3500

SUSTAINMENT

MEMORANDUM FOR DEPUTY ASSISTANT SECRETARY OF THE AIR FORCE FOR LOGSTICS AND PRODUCT SUPPORT, OFFICE OF THE ASSISTANT SECRETARY OF THE AIR FORCE FOR ACQUISITION, HEADQUARTERS U.S. AIR FORCE

SUBJECT: Addressing Electronics Intermittence Across DoD's Sustainment Enterprise

Reference: (a) Memo from DASD(MR) Titled "Addressing Electronics Intermittence Across DoD's Sustainment Enterprise," dated April 11, 2019

In April 2019, reference (a) requested each Military Service provide recommendations regarding the best practices used to address intermittence as an electronics failure mode and provide overarching strategic plans to widely and rapidly field intermittent fault detection and isolation (IFDI) capabilities. Your responses were greatly appreciated.

To assess progress in this area, the Joint Intermittent Testing (JIT) Working Group used the DoD's Maintenance and Availability Data Warehouse (MADW) algorithms to reveal current effects of electronics intermittence as a failure mode on availability and cost (Attachment 1). Results indicate that no-fault-found (NFF) caused by intermittent electronic failures drive over 383,254 non-mission-capable days and nearly $5.5B in non-value-added cost to DoD weapon systems annually. These updated results indicate a significant increase from those stated in reference (a). The MADW analysis also identifies weapon systems and components within your Military Service that present the greatest potential for the application of available IFDI test capabilities when undergoing Depot-level maintenance (Attachment 2).

In a continuing effort to improve intermittent fault detection and drive down sustainment costs, request your Military Service provide the following:

- An updated list of best candidate components to address eliminating NFF failures where electronics intermittence is the suspected cause. This list should be the result of root cause analyses based on data and your subject matter expertise. Additional MADW data that may support your analysis is available in Attachment 3.

- An overarching plan of action to reduce electronics NFF effects across your Military Service and a Concept of Operations for integrating IFDI capabilities into Depot-level electronics repair and overhaul. Attachment 4 provides some factors to consider when assessing the best potential applications of IFDI capabilities that meet MIL-PRF-32516.

Please reply to this request by June 15, 2022. My point of contact and the chair of the DoD JIT Working Group is Mr. Steve McKee, (571) 969-0662, stephen.e.mckee.civ@mail.mil.

Vic S. Ramdass, Ph.D.
Deputy Assistant Secretary of Defense
(Materiel Readiness)

Attachments:
TAB A - Maintenance and Availability Warehouse (MADW) Information
TAB B - MADW IFDI Application Candidates (Air Force Aviation)
TAB C – Air Force Aviation IFDI Non-NIIN Summary with Work Unit Code
TAB D - IFDI Candidate Additional Information to Consider