Solving the Department of Defense (DoD) Intermittence Problem

A Framework for an Intermittent Fault Detection (IFD) Solution

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Deputy Assistant Secretary of Defense Materiel Readiness

Forward from DASD(MR)

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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.

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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

[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.

[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%.

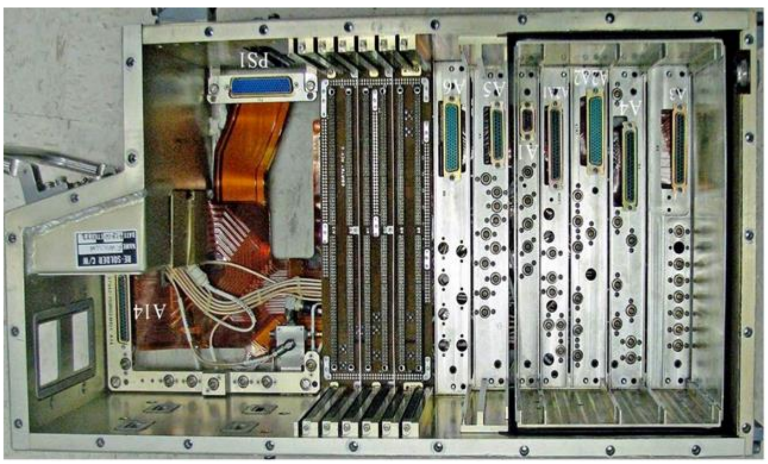


Figure 2. MLPRF Chassis

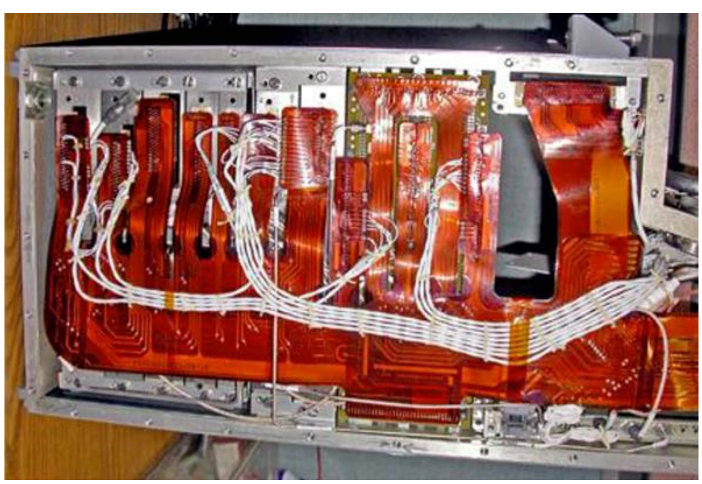


Figure 3. MLPRF Chassis with Ribbon Cable

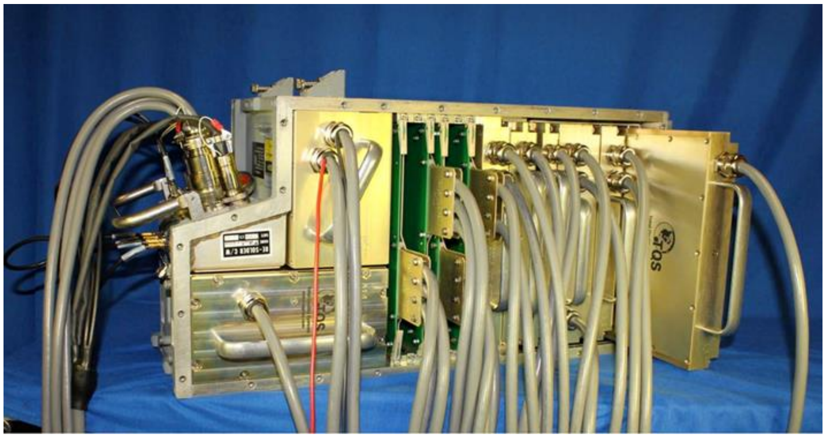


Figure 4. MLPRF with ITA Installed and Ready for Test

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

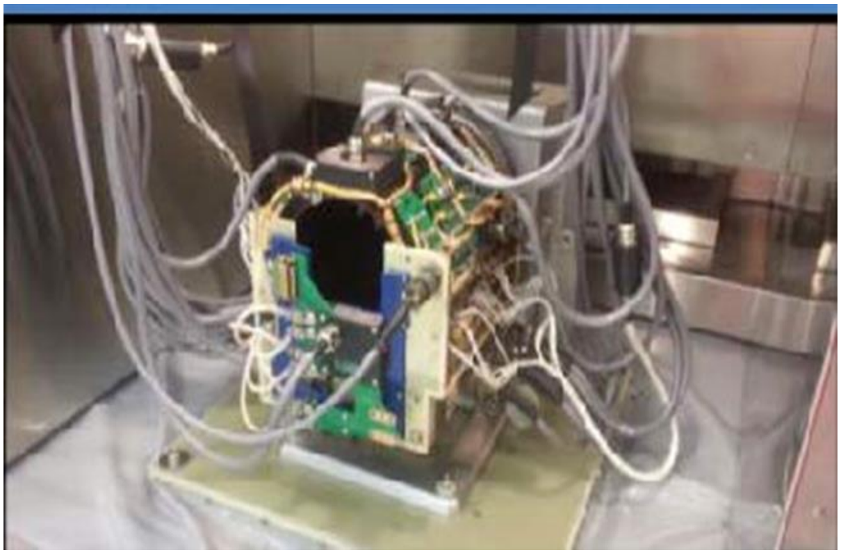


Figure 6. F/A-18 E/F GCU with ITA Installed

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)

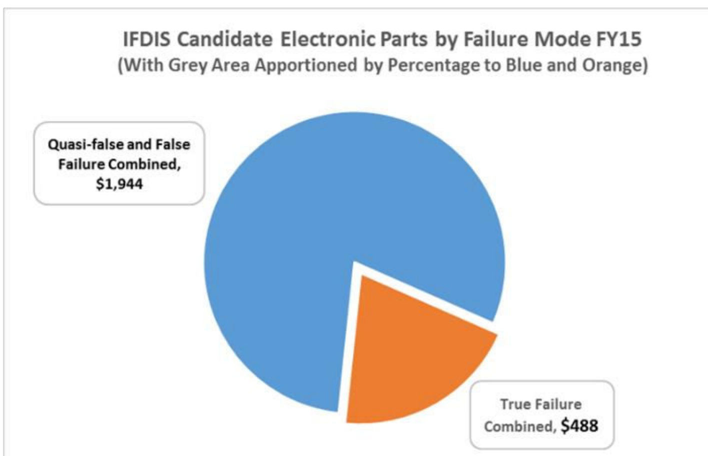
A.1.2.1 MADW Background

- 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.

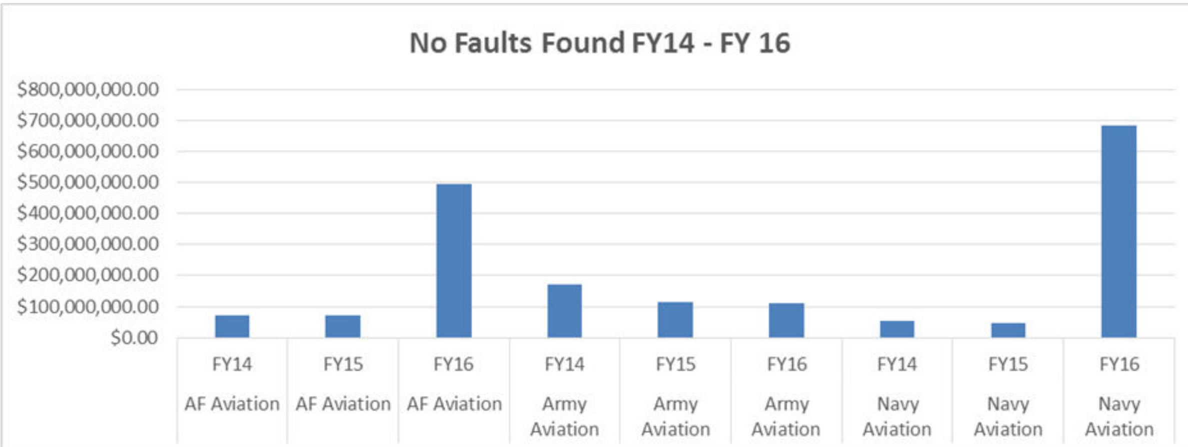


Figure A-2. NFF FY14 – FY16

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.

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[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.

<u>Results</u>: 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.

<u>Results</u>: 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.

<u>Results</u>: 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.

<u>Results</u> 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.

<u>Results</u>: 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.

<u>Results</u>: 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).

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