OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION
AND SUSTAINMENT

October 5, 2021

The Honorable Adam Smith
Chairman
Committee on Armed Services
U. S. House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

Senate Report 116–236, page 176, accompanying H.R. 6395, the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 requests the Secretary of Defense provide a report that analyzes persistent maintenance issues caused by electronic component failures not later than December 31, 2020. The requested report is attached here for your review.

Should you have additional questions, please contact the Office of the Assistant Secretary of Defense for Legislative Affairs and your respective legislative liaison. I am sending an identical letter to the other congressional defense committees.

Sincerely,

KAUSNER.GREGORY.MICHAEL.1026551605
Digitally signed by KAUSNER.GREGORY.MICHAEL.1026551605
Date: 2021.10.05 17:21:11 -04'00'

Gregory M. Kausner
Executive Director, International Cooperation
Performing the Duties of the Under Secretary of Defense for Acquisition and Sustainment

Enclosure:
As stated

cc:
The Honorable Mike D. Rogers
Ranking Member

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION AND SUSTAINMENT

October 5, 2021

The Honorable Jack Reed
Chairman
Committee on Armed Services
United States Senate
Washington, DC 20510

Dear Mr. Chairman,

SSenate Report 116–236, page 176, accompanying H.R. 6395, the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 requests the Secretary of Defense provide a report that analyzes persistent maintenance issues caused by electronic component failures not later than December 31, 2020. The requested report is attached here for your review.

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Digitally signed by KAUSNER.GREGORY.MICHAEL.1026551605
Date: 2021.10.05 17:21:27 -04'00'

Gregory M. Kausner
Executive Director, International Cooperation
Performing the Duties of the Under Secretary of Defense for Acquisition and Sustainment

Enclosure:
As stated

cc:
The Honorable James M. Inhofe
Ranking Member

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION
AND SUSTAINMENT

October 5, 2021

The Honorable Patrick J. Leahy
Chairman
Committee on Appropriations
United States Senate
Washington, DC 20510

Dear Mr. Chairman,

Senate Report 116–236, page 176, accompanying H.R. 6395, the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 requests the Secretary of Defense provide a report that analyzes persistent maintenance issues caused by electronic component failures not later than December 31, 2020. The requested report is attached here for your review.

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KAUSNER.GREGORY.MICHAEL.1026551605
Digitally signed by KAUSNER.GREGORY.MICHAEL.1026551605
Date: 2021.10.05 17:21:37 -04'00'

Gregory M. Kausner
Executive Director, International Cooperation
Performing the Duties of the Under Secretary of Defense for Acquisition and Sustainment

Enclosure:
As stated

cc:
The Honorable Richard C. Shelby
Vice Chairman

OFFICE OF THE UNDER SECRETARY OF DEFENSE
3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION
AND SUSTAINMENT

October 5, 2021

The Honorable Rosa L. DeLauro
Chair
Committee on Appropriations
U.S. House of Representatives
Washington, DC 20515

Dear Madam Chair:

Senate Report 116–236, page 176, accompanying H.R. 6395, the William M. (Mac) Thornberry National Defense Authorization Act for Fiscal Year 2021 requests the Secretary of Defense provide a report that analyzes persistent maintenance issues caused by electronic component failures not later than December 31, 2020. The requested report is attached here for your review.

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KAUSNER.GREGORY.MICHAEL.1026551605 Digitally signed by KAUSNER.GREGORY.MICHAEL.1026551605 Date: 2021.10.05 17:21:48 -04'00'

Gregory M. Kausner
Executive Director, International Cooperation
Performing the Duties of the Under Secretary of Defense for Acquisition and Sustainment

Enclosure:
As stated

cc:
The Honorable Kay Granger
Ranking Member

DEPARTMENT OF DEFENSE

ASSESSMENT OF ELECTRONICS MAINTENANCE AS A LEADING DRIVER OF WEAPON SYSTEMS NON-AVAILABILITY

Office of the Under Secretary of Defense
for Acquisition and Sustainment

2021

The estimated cost of this report or study for the Department of Defense is approximately $154,000 for the 2021 Fiscal Year. This includes $126,000 in expenses and $28,000 in DoD labor.

Generated on 2021Mar24 RefID: C-1FC88CD

Background

Senate Report 116-236, page 176, accompanying S. 4049, the National Defense Authorization Act for Fiscal Year (FY) 2021 states:

The committee notes that the Department of Defense (DoD) has found that electronics maintenance is a leading driver of weapon systems non-availability, accounting for over 470,000 days of end-item system availability loss in fiscal year 2018. Electronics maintenance is also a significant contributor to sustainment costs as well, accounting for over $12 billion in fiscal year 2018. A significant portion of the electronics maintenance non-availability and cost impact is caused by intermittent faults. DoD estimates that 278,000 days of weapon systems non-availability and approximately $3 billion in sustainment costs are due to this single issue.

To address these issues, the committee directs the Secretary of Defense to provide a report to the congressional defense committees, no later than December 31, 2020, that analyzes this persistent maintenance issue. The report should:

(1) Recommend best practices to be used by the DoD to address electronics component failures due to intermittent faults.
(2) Identify responsible organizations in the military services, and the Defense Agencies and Department of Defense Field Activities to address these issues; and,
(3) Include strategic plans and a roadmap to field intermittent fault detection and isolation capabilities.

Executive Summary

This report examines the Department of Defense's strategic approach to address the persistent maintenance issue of intermittent electrical failures in DoD components. As requested, best practices, both current and emerging, are reviewed, responsible organizations central to tackling this issue are identified, and strategic planning and a phased implementation approach to field intermittent fault detection and isolation capabilities is described. Several points characterize the context for the best practices, organizations, and plans included herein.

Most importantly, DoD's phased implementation approach to address intermittent electrical failures in DoD's weapon systems is a paradigm shift in current DoD electrical/electronic maintenance. Intermittent failures result in decreased meantime between failures, increased component material inventory, and decreased weapon system availability. Paradigm shifts involve fundamental changes that require senior leader support, time, focus, and long-term stakeholder engagement to implement. DoD's phased implementation approach, therefore, includes many reinforcing, collaborative, and outcome-focused activities intended to fully institutionalize intermittence faults testing requirements and capabilities in DoD's resource, sustainment, and technical maintenance communities over time. However, since an intermittent fault is a very difficult, complex, and costly equipment failure mode to detect, isolate, and address, implementing solutions can present risks in a DoD maintenance environment focused predominantly on meeting today's operational tempo-driven materiel requirements. In this demanding, fast paced environment, failure is not an option and true progress with near and long term operational impacts must be advanced deliberately. That is the key reason DoD's multi-faceted, long-term strategic implementation approach is structured and ongoing.

In addition to these challenges, the type of maintenance equipment proven to detect and address intermittent faults is expensive and can be difficult to integrate into the portfolio of Automatic Test Equipment (ATE) in use across DoD's maintenance enterprise, which is incapable of continuous and simultaneous testing for intermittent faults. Because intermittent fault detection and isolation capabilities are new, they are different. Traditional maintenance programs, life-cycle management, operations resourcing, and technical streams are challenged when integrating innovative sustainment technologies into planning and implementation cycles. This can present resourcing and integration difficulties for Program Executive Offices (PEOs), Program Managers (PMs), and depot maintenance activities that do not have specific requirements from authoritative sources to introduce and resource these capabilities. Both achieving full recognition of the intermittent electronics failure mode throughout DoD and increasing integration of intermittent fault detection and isolation capabilities into DoD's traditional maintenance operations, are fundamental to and continue to be critical, to expanding the breadth and depth of its implementation.

DoD is addressing these challenges in our intermittent fault detection and isolation phased implementation approach by employing a myriad of integrated technology transition best practices. These best practices have baselined the capability and are used continuously to assess and scale it towards additional implementation outcomes. Objectives and activities of several technical Working Integrated Product Teams (WIPTs), Centers of Excellence, and commercial activities have collaborated to produce foundational documents and capabilities that have brought intermittence testing into broader DoD maintenance policy and implementation. These collaborative groups have also driven critical outcomes, including the development of the original intermittent electrical failure mode definition as well as issuing the specification that defines the breakthrough capability required to detect and isolate intermittent faults in electrical components and electrical wiring interconnect systems (EWIS). As the use of intermittent fault detection and isolation capabilities expands, DoD and the Military Services are also applying "Big Data" analytics (e.g., DoD's Maintenance and Availability Data Warehouse (MADW)) and tailored tool sets to both better scope the intermittence problem and identify specific implementation opportunities. These activities promote fact-based technical demonstration and best practice interchange as intermittence solution sets are shared and applied among the Military Services and their industry partners.

While the four-phased strategic intermittent fault and detection implementation approach explained in this report shows meaningful progress, challenges remain to institutionalize this capability and normalize its use in DoD electronics maintenance and initial manufacture. Intermittent electronics failures continue to be a leading contributor to DoD's $3 billion annual No Fault Found (NFF) problem, consuming approximately 25% of the electronics maintenance budget and contributing to weapon system materiel availability issues. Challenges such as gaining and sustaining enterprise awareness and ensuring electronics technicians understand intermittent fault detection and isolation demand solutions that entail leadership, resourcing, and innovative organizations responsible and accountable to drive authoritative action and outcomes. DoD's on-going implementation approach includes activities to generate and accelerate these kinds of solutions. DoD's goal is to field intermittent fault detection and isolation capabilities to achieve objective electronic component, and EWIS availability, a key component to target weapon system readiness at the best cost. DoD is roughly at the mid-point of its projected intermittent fault and detection implementation activities. Substantial time and effort was invested in developing an understanding of the failure mode, scoping the problem, and identifying the potential benefit of solving intermittence (Phase I); but it was essential to generate the strategic approach and tactics driving the paradigm shift in electronics maintenance these game-changing capabilities are enabling.

As an informational baseline, the definition of intermittent faults is provided in the footnote below.[1]

[1] Intermittent faults are short duration impedance variations (opens/shorts) that occur in conductive paths in Line Replaceable Unit/Weapon Replaceable Assembly chassis and backplanes or weapon system EWIS. Intermittent faults occur as a result of various operational environmental stimuli, including, but not limited to, thermal stress, vibrational stress, gravitational G-force loading, moisture and/or contaminant exposure, as well as changes in the material due to age and use, such as the growth of tin whiskers, metal migration, and delamination of materials. These faults can occur individually and/or in rapid succession on any chassis or backplane circuit or weapon system EWIS. Fault durations range in time from nanoseconds to milliseconds and have variable impedances. These circuit path disruptions are frequently caused by cracked solder joints; intermittent coax lines (e.g., shield corrosion, damaged center conductor, etc.); broken, cracked or frayed wires; loose clamps; and unsoldered pins. These circuit path disruptions often cause functional failures/faults in Line Replaceable Unit/Weapon Replaceable Assembly chassis and backplanes or weapon system EWIS whose root cause(s) cannot be detected and isolated using traditional automatic test equipment and troubleshooting processes. Lacking the ability to detect and isolate intermittent failures and provide environmental stimuli during test and repair process, such assets are commonly reported as NFF or as one of the reported-NFF repair codes (e.g., cannot duplicate, retest OK, beyond capability of maintenance, disassemble-clean-reassemble).

Introduction

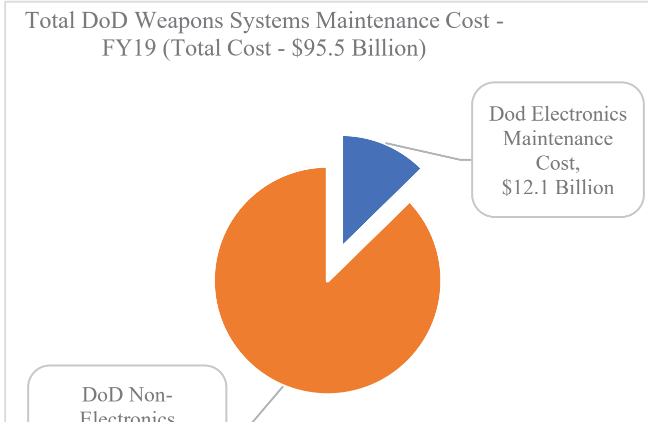

Chart 1

Source: FY 2019 MADW

DoD maintenance operations sustain and restore weapon systems and materiel to inherent performance, safety, and reliability levels. Maintenance generates and sustains materiel readiness – ensuring weapon systems, equipment, and platforms are available to support training and exercises, and ultimately, to deploy in support of warfighter requirements to respond to any humanitarian or contingency situation. Roughly $95 billion of DoD's total FY 2019 expenditure was applied to maintenance activities and services (not including facilities), with aircraft maintenance being the greatest expenditure at approximately $32 billion. Electronics maintenance, a leading driver of weapon systems non-availability, accounted for over $12 billion in FY 2019 maintenance costs. (Chart 1)

Intermittent electrical failures continue to be a leading contributor to DoD's $3 billion annual NFF problem, unnecessarily consuming 25% of the electronics maintenance budget. Many aircraft maintenance issues are directly related to interconnectivity problems on the EWIS or within electronic components or assemblies. Intermittent faults are mechanical in nature and can include failures in solder joints, wiring, wire wraps, connectors, etc., which manifest as operational failures due to temperature, vibration, and other external environmental stimuli. Hard failures, where wiring issues are evident, are relatively routine to detect and repair, and not all hard failures involve wiring. However, major electrical issues and even critical down-line failures may occur when an electrical fault appears only intermittently, on multiple conductive paths in short duration, under operational conditions (such as high G-force loading and extremes in temperature or stress, or vibrational states) that are difficult to replicate during ground testing and maintenance. The duration of these intermittent events can range from nanoseconds to seconds and may oscillate repeatedly during an event or may be a single occurrence during a given testing session.

These circuit path disruptions often cause operationally evident functional failures/faults in Line Replaceable Unit (LRU)/Weapon Replaceable Assembly (WRA) chassis and backplanes whose root cause(s) cannot be detected and isolated using conventional ATE and troubleshooting processes. Intermediate and depot maintenance actions, such as the reseating of a degraded connection, solder joint, etc., can temporarily cause the intermittent connection to function properly for days, or even weeks after, and may only manifest as a repeat operational failure after several months.

This situation results in a revolving cycle for EWIS and the WRA/LRU removal, maintenance and testing resulting in NFF, and subsequent reinstall on aircraft. Additionally, as the adjacent Chart 2 displays, considerable preventive and corrective DoD electronics maintenance costs are applied to this issue. Even while these resources are consumed, WRA/LRU and system wiring with intermittent faults become known as the Military Services' "bad actors" and are repeatedly sent to DoD and commercial repair facilities, but the current intermittent test equipment void prevents accurate problem diagnosis -- in many instances leading to unnecessary condemnation of weapons systems components. One main symptom of an intermittent fault failure (IFF) mode problem is a high rate of Cannot Duplicate (CND or A-799), NFF, No Trouble Found (NTF), and Re-test OK (RETOK) reported by the maintenance activities. In addition, although diagnostic equipment with the capability to monitor all conductive paths simultaneously and continuously while simulating the specified Type/Model/Series (TMS) operating environment is not yet widely available, such equipment has been identified as an excellent objectively proven solution.

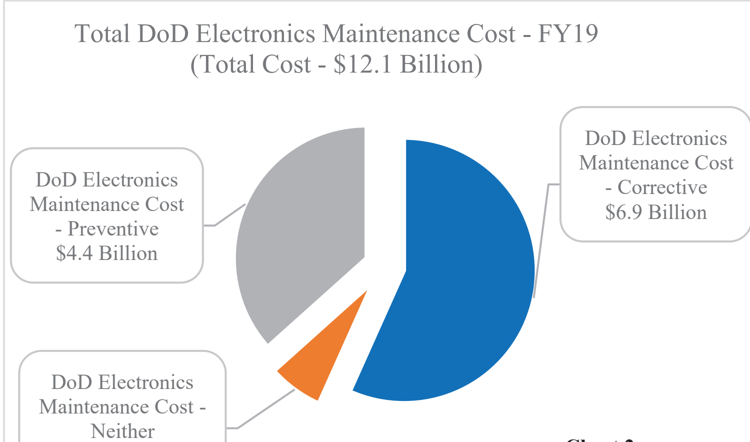

Chart 2

Source: FY 2019 MADW

Intermittent faults phenomenon, while persistent and pervasive for some time, is now gaining, traction and emerging as an accepted failure mode within DoD. It is characterized by decreasing reliability and Time-on-Wing (TOW) and has been conclusively identified as a major contributor to NFF costs and decreased materiel availability. DoD now operates approximately 400 types of traditional diagnostic test systems valued at $50 billion dollars. However, these test systems do not continuously and simultaneously test all conductive paths, they have very limited or no capability to detect and isolate intermittent faults or reduce NFF costs.

Background of DoD Initiative and Overarching Strategy

DoD is meeting the challenge by addressing key dimensions of the complex electronics intermittence challenge. The Department's approach is strategic, enterprise-wide, and outcome oriented. This section highlights the origin of the approach and outlines the phased activities that scoped, articulated, and continue to address DoD's electronics intermittence problem. While some challenges remain,[2] this approach is enabling deliberate, forward-looking fielding of intermittent fault detection and isolation capabilities.

DoD-level leadership focused on innovation, industry engagement, and Military Service awareness has sparked interest and action to address electronics intermittence. In 2008, Ogden Air Logistics Complex (OO-ALC) was grappling with availability issues related to the Modular

[2] These challenges will be detailed in a subsequent section of the report.

Low Power Radio Frequency (MLPRF) LRU on the F-16 aircraft that seemed to be intermittence related. In 2010, a first of its kind industry solution deployed at OO-ALC that could identify and isolate electrical intermittence was selected as the winner of the DoD "Great Ideas" Competition (later renamed the Maintenance Innovation Challenge (MIC)). The MIC, a key feature of DoD's annual Maintenance Symposium, provides a venue to spur competition and innovation and offers a unique, rapid "concept to solution" path to address DoD's materiel availability and cost issues. The 2010 winner of the MIC was the Universal Synaptics' Intermittent Fault Detection & Isolation System (IFDIS).

OO-ALC's utilization and data results from the IFDIS was presented at the MIC which leveraged Reduction in Total Ownership Cost (RTOC) funding to help industry develop and demonstrate the first IFDIS application in DoD. OO-ALC became the early adopter of this technology and implemented IFDIS to improve materiel availability and reduce costs for the F-16 MLPRF LRU. The Air Force's results were subsequently leveraged by the Navy in additional implementations.

The success and promise demonstrated at OO-ALC created a breakthrough moment at the DoD enterprise level and led to the formation of the holistic strategy described in this report. An important early element of this strategy was collaboration with the Military Services and their industry partners regarding "Big Data" analytics (i.e., MADW). The Office of the Deputy Assistant Secretary of Defense for Materiel Readiness (ODASD(MR)) determined that authoritative, reliable data and information, coupled with rigorous analytics, was crucial to engage DoD's maintenance community in the electrical intermittent failure issue. Collecting and analyzing authoritative Military Service maintenance data enabled DoD to scope the intermittence problem, identify the corresponding materiel availability degradation it contributes to, and distinguish the negative cost impacts that can be attributed to intermittent faults.[3] The establishment of this data-based platform (called the MADW) has been key to promoting intermittence solutions more widely across DoD and to building a community of advocates as DoD's phased implementation continues.

A robust team, comprised of respected subject matter experts (SMEs) and technical leadership throughout DoD and industry, was formed to guide DoD's strategic approach. The ODASD(MR) chartered the Condition-Based Maintenance Plus (CBM^+) Joint Intermittent Testing (JIT) Working Integrated Program Team (WIPT) as the body to develop and coordinate the DoD-wide effort. The JIT WIPT's goals are to achieve full recognition of the intermittence electrical failure mode across DoD and to increase integration of intermittent fault detection and isolation capabilities into DoD's maintenance operations. This team of leaders and SMEs express the strategic vision and tactics required to address electrical intermittence throughout DoD's maintenance enterprise. The JIT WIPT was formally chartered in 2012 and continues to define and execute tasks required to implement intermittence maintenance technology through a drumbeat of coordinated activities.

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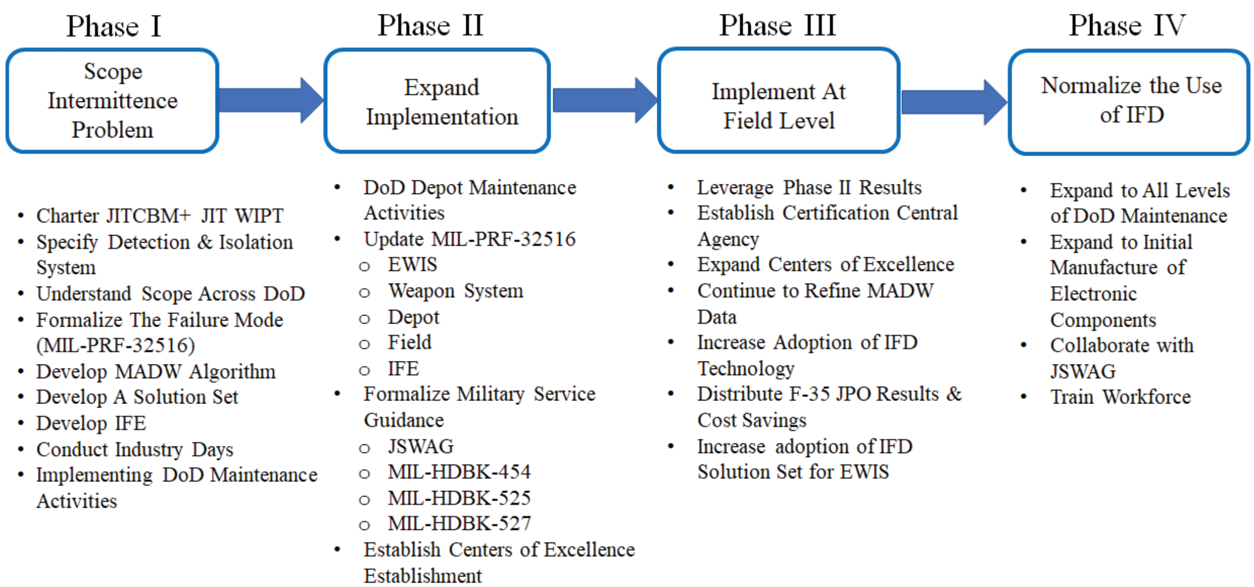
[3] It is important to note that the DoD's MADW, Enterprise Sustainment Dashboard, and various Military Service data analytical tools have been leveraged and adapted throughout DoD's phased efforts to address electrical intermittence. From a macro perspective, MADW has enabled initial quantification of the intermittence problem (as illustrated in the Introduction to this report) and through continuous refinement and upgrade, this and other Big Data tools now support specific, increasingly prescriptive approaches to identify the most effective intermittence detection implementation opportunities. These capabilities are now able to help identify and target "best candidates" (cost and non-availability drivers) at the Part of National Item Identification Number (NIIN) level. These capabilities continue to be refined and applied and are discussed in some detail in the body and appendices of this report.

The JIT WIPT's strategies and tactics are being implemented in phases (Chart 3). While each phase is intended to achieve clear goals, the approach contains a mixture of continuing, sequential, and combined activities to meet required outcomes, foster implementation momentum, and incorporate feedback from previous phases flexibly and responsively.

Intermittent Fault Implementation Strategy

Chart 3



Phase I included the "spade work" required to take on intermittence isolation and detection at the DoD enterprise level. The impact of the intermittent fault problem and benefits of addressing it have been determined empirically and are well understood by the DoD electronics maintenance community. The JIT WIPT guided and continues to drive project partners like the Commercial Activities for Maintenance Activities (CTMA) Program, and the Joint Technology Exchange Group (JTEG) to provide official recognition of intermittence as a definitive failure mode. A Department approved testbed to validate testing capabilities and intermittent fault detection and isolation efficacy was established and Government-sponsored Industry Days have identified practical solutions to confront the intermittent failure mode. Streamlined execution venues have also been established and continue to occur to refine the capability to objectively assess intermittence implementation in various operational environments. Finally, Intra-Service best practice sharing drove initial experimentation and implementation of intermittent capabilities and continues to increase technical awareness for leadership, sustainment managers, and electronics technicians. Phase I resulted in significant development and expansion of detection and isolation of intermittent fault and detection capabilities at several DoD depot maintenance activities.

Phase II is currently underway and is driving further implementation of intermittent fault and detection capabilities in DoD depot maintenance activities. Implementation targets are supported by continually refined data-based decision-making processes. Military Service specific and enterprise-wide cost and availability variables are driving growth in depot maintenance implementation. A draft Framework for Implementing Intermittent Fault Detection and Isolation across the Military Services was developed, and Centers of Excellence (CoEs) were proposed as a best practice source to foster implementation of intermittence capabilities in both a greater range of DoD weapon systems and at additional DoD maintenance levels. More open, secure access to intermittence-related knowledge, innovative examples and approaches, and the ability to identify “best of breed” maintenance technologies are shaping DoD Phase II implementation activities. A key function of the CoEs, for example, is to maintain a validated list of products that have demonstrated ability to detect Category 1 intermittent faults (see MIL-PRF-32516) in their intended fault environment.

Recently, the F-35 Joint Program Office (JPO) has evaluated the Universal Synaptics Portable Intermittent Fault Detector (PIFD) (Figure 1). The PIFD meets or exceeds all F-35 JPO EWIS intermittent fault detection and general wiring testing capability requirements, cyber compliance, and has achieved Authority to Operate (ATO) approval from the F-35 JPO. The F-35 JPO is moving forward with acquisition, and deployment of the PIFD to F-35 repair depots and operational squadrons across the globe. Additionally, during Phase II, an update to the official DoD intermittence specification has been initiated to authoritatively define field level intermittent detection and fault isolation capability. Implementation of intermittent fault detection and isolation capability at the field maintenance level for the F-35 program and beyond offers prospective cost savings and materiel availability improvements.

Figure 1. The F-35 JPO Portable Intermittent Fault Detector (PIFD)

Phase III will be focused on implementing intermittent fault detection and isolation capabilities at DoD field level maintenance operations to address aircraft EWIS intermittent and general wiring failures. Delivering advanced intermittent fault diagnostic capability closer to the weapon system, prior to depot-level induction, enables intermittent failures to be detected, isolated, and repaired rapidly, reducing logistics and supply chain time and cost. Development and demonstration activities are underway at this time to detect and isolate intermittence in wiring harnesses while installed in weapon systems during field maintenance beyond the F-35 Joint Strike Fighter. F-35 EWIS test data, readiness improvements and cost saving will be shared with all weapon systems program offices in an effort to gain adoption across legacy platforms.

Phase IV will normalize the use of intermittent fault detection and isolation capabilities at all levels of DoD maintenance and during electronic components' initial manufacture. As a result of on-going leadership advocacy, as well as empirical and numerical based quantification of impact and implementation benefits, Phase IV's goal is to have intermittence recognized formally and widely as a recurring common failure mode for both legacy and new electronics assets. Given proven successes of Phases I-III, implementation in growing numbers of DoD maintenance activities will continue based upon a commercial application that, in tandem with DoD specifications, will require intermittence recognition and focused activities through all stages of the electronics lifecycle. The goal of Phase IV is to put intermittent faults on a steep decline, both as an electronics materiel availability and cost challenge for DoD and its industry partners.

Given this overview of DoD's initiative and strategy to increase implementation of intermittent fault detection and isolation capabilities, the following sections of this report provide more detailed descriptions of each implementation phase and highlight best practice enablers and processes essential to both outcomes achieved and planned actions. Following the phase descriptions, the report offers an assessment of remaining challenges to implementation and a brief conclusion. Considering the true paradigm shift these game-changing intermittence capabilities are enabling in DoD's electronics maintenance community, significant progress has been made. Remaining implementation challenges involve maintaining unity of effort to drive deeper understanding, resourcing, and application of these new intermittent detection and isolation technologies.

Phase I: Scoping the Enterprise Electronics Intermittence Problem, Formalizing the Failure Mode, Developing a Solution Set, & Deploying at DoD Maintenance Activities

Phase I began in 2010 and was approximately six years in duration. In this timeframe DoD achieved fundamental milestones that established and executed the foundation of a strategic approach to address its electrical intermittence fault problem. The establishment of a DoD-led, highly respected Joint Service working group enabled identification and dissemination of the size and scope of the intermittent/NFF problem across the DoD electronics maintenance community.[4] This led to development of a military performance specification (MIL-PRF-32516) that officially defined the electrical intermittence fault. An update to MIL-PRF-32516 will be released in 2021 that will include minimum performance requirements for intermittent fault diagnostic equipment

[4] The size, scope, and impact of DoD's electronics intermittence problem is detailed in the Introduction section of this report.

for weapon systems. Weapons systems include the weapon system or military equipment, ground vehicles (wheeled, tracked, etc.), missiles, ships, space vehicles, etc.

Once the intermittent fault gained traction and emerged as an accepted failure mode, work began to identify a solution set and objectively assess potential offerings. This was done through focused, collaborative activities that produced a solution that is fully operational at four DoD maintenance activities and accessible to the DoD electronics maintenance community. Major successes included establishment of a validated test bed (i.e., Intermittent Fault Emulator) to determine test equipment MIL-PRF-32516 compliance, development of an enterprise-wide business case analysis (BCA), and formation of Office of the Secretary of Defense (OSD) sponsored Technology Demonstration Projects (TDPs) to generate interest and innovation related to electronics intermittence.

Several dynamic organizations employed best practices and fostered DoD and Industry collaboration to both establish DoD's enterprise approach and then drive innovation and results. A degree of detail will now be provided about the most important of these groups and activities to illustrate the scope and intensity of effort required to drive acceptance and implementation of a paradigm shifting maintenance technology. This effort is made more difficult because there is no officially designated organizational champion or clear resource sponsor.

The Condition-Based Maintenance Plus (CBM^+) Charter, JIT WIPT

The ODASD(MR) (formerly, Maintenance Policy and Programs) formed and chartered the CBM^+ JIT WIPT in September 2012. This group includes voluntary participants from the Air Force, Army, Navy, and other Defense Agencies and works in close cooperation with Industry. This group has been instrumental in shaping the strategic and tactical activities required to identify diagnostic equipment capable of detecting intermittent faults. Through JIT WIPT collaboration, the Military Services concluded that Intermittent Fault Detection Equipment (IFDE) standardization is critical to addressing electronics component failures.

The JIT WIPT galvanized electronics maintenance community interest and support in intermittent fault detection and isolation capabilities. It also sponsored and continues to update and refine the technical framework enabling further implementation of proven capabilities. Among other activities, the JIT WIPT classified and validated joint performance requirements for a Joint Service intermittent fault detection system, defined the minimum fault detection threshold requirements for the applicable wiring systems, component types, and system architectures, and identified and validated test methods for ensuring specified minimum performance requirements for detecting and isolating intermittence are met (MIL-HDBK-527, MIL-HDBK-525, and proposed MIL-HDBK-454 Intermittent Fault Diagnosis Guideline).

The JIT WIPT continues to lead the electrical intermittence "charge." It drives key implementation activities and originates and updates technical publications essential to maintain momentum and focus on the intermittence topic. It also develops briefings and publishes technical reports to assist the Military Services as they develop intermittence solutions supportive of their operational environments.

The accomplishment that best illustrates the JIT WIPT's effectiveness in terms of technical competence, Government and Industry collaboration, and action orientation is publication of

MIL-PRF-32516. The Electronic Test Equipment, Intermittent Fault Detection and Isolation for Chassis and Backplane Conductive Paths (MIL-PRF-32516) was published in March 2015 and formally recognized intermittence as a DoD failure mode and addressed the intermittent fault capability gap. This specification defined the minimum performance requirements for equipment to detect and isolate nanosecond, microsecond, and millisecond conductive paths and intermittent faults which can occur in all the hundreds to thousands of LRU/WRA chassis and backplane circuits and their wiring harnesses in DoD's equipment. Prior to this publication, no specification/standard for intermittent faults or technologies required to remediate the problem existed.

Development of an Intermittent Fault Emulator (IFE) further demonstrates the JIT WIPT's effectiveness in terms of technical competence, Government and Industry collaboration, and action orientation. The challenge is validating intermittent fault diagnostic equipment capability. This equipment must detect and isolate intermittent faults of very short duration that can occur on multiple conductive paths simultaneously. The IFE can be programmed to emulate intermittent faults of very short duration on multiple conductive paths simultaneously, so that the diagnostic equipment capability can be validated. This is of paramount importance because there is significant amount of test equipment which purports to detect and isolate intermittent faults.

Taken as a whole, the JIT WIPT has facilitated intermittence problem identification and solution development by leading a forum for Government, Military Service, and Industry professionals to collaborate and exchange information on intermittent issues across many platforms through briefs, industry days, outreach, and technology transition activities. The JIT WIPT serves as an enterprise wide technology insertion best practice. It has brought synergy and commonality to the required transformation of DoD's electrical maintenance capabilities to support today's and tomorrow's electronics maintenance communities across DoD. By helping to define the intermittence problem at the appropriate levels within the DoD and then continually setting the conditions to offer solutions tied to clear technical requirements, the JIT WIPT is instrumental in facilitating action to address intermittence related readiness and cost drivers.

The Commercial Technologies for Maintenance Activities Cooperative Agreement

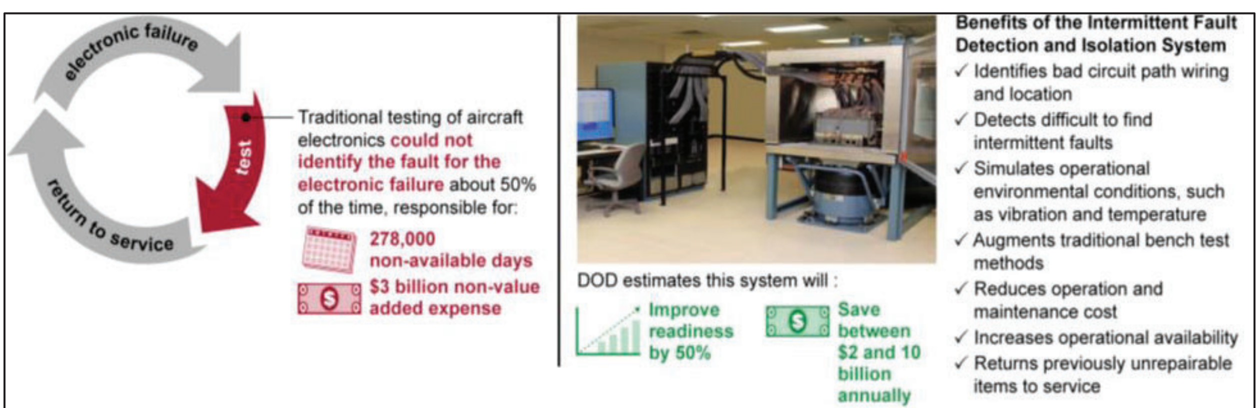
During Phase I, the Joint Staff recognized the scope of the intermittent fault problem and held an industry day and worked on developing the MIL-PRF-31516, funded through the Logistics Initiative Fund. Active Joint Staff advocacy and sponsorship is critical because it signals the importance of the issue to the joint warfighter. The JIT WIPT was then able to employ a unique venue to demonstrate and evaluate commercially available maintenance, sustainment, and logistics technologies with an emphasis on successful technology transition prior to acquisition. The Commercial Technologies for Maintenance Activities (CTMA) cooperative agreement is a partnership between the ODASD(MR) and the National Center for Manufacturing Sciences (NCMS). Since 1998, the CTMA Program has connected industry and academia to introduce innovative technologies within DoD's operational space.

Utilizing a best-of-breed, agile 45 to 90-day cradle to execution process, this non-Federal Acquisition Regulation (FAR) based program is a risk reducer that enables an innovative "try it before you buy it" setting. Requirements are identified during demonstrations to facilitate successful technology transition. The CTMA Program enables and encourages project partners to provide and share assets, tacit knowledge, facilities, and personnel where feasible, thereby reducing costs and optimizing resources. While one Military Service may be the primary on a CTMA initiative, other Military Services are invited to observe and glean results from demonstrations and evaluations to adopt best practices within their own maintenance and sustainment environment. This process limits the costs and time to initiate and organize individual projects. It also promotes sharing within the DoD enterprise and demonstrates sound stewardship of taxpayer dollars. The CTMA Program was leveraged by the JIT WIPT as the optimal vehicle to demonstrate and evaluate the initial intermittent fault detection and isolation technology and to share the results DoD-wide.

To do this, the CTMA Program leveraged its wide network of partners, members, and communication channels, to help facilitate an "Industry Day." Industry Days have proven to be excellent opportunities for DoD decision makers to compare similar technologies side-by-side or answer focused requests for solutions. These events also allow DoD attendees to observe technologies, ask questions one-on-one with Industry representatives, learn the pluses and deltas of technology attributes, and determine if a technology may answer unmet needs.

Sponsored by the Joint Staff in FY 2015 and executed within the CTMA Program, an "Industry Week" was conducted with select respondents to Request for Information (RFI) no. N68335-15-RFI-0505, issued on May 28, 2015. Selected respondents were asked to bring equipment to Naval Air Warfare Center Aircraft Division (NAWCAD) Lakehurst to demonstrate and discuss their intermittent fault detection capabilities and systems. Technology evaluations were held on January 4, 2016. Three of the six companies that responded to the RFI were extended an invitation to participate in the Industry Week: Eclypse International, Universal Synaptics Corporation, and Solavitek, Inc. A fourth company, Ridgetop Group (responding to a previous RFI) accepted an invitation to present its technology. Universal Synaptics' IFDIS (discussed above) and its PIFD were the only capabilities that met MIL-PRF-31516 specified requirements.

The IFDIS and PIFD met the requirements cited in MIL-PRF-32516 because of their ability to continuously and simultaneously detect and isolate random intermittent faults. Additionally, Universal Synaptics' demonstrations focused exclusively on solving NFF and finding intermittent faults. In addition to detecting and isolating intermittent faults, the IFDIS and portable PIFD automatically interrogate, through the use of Artificial Intelligence (AI), and store the as-designed wiring configuration of a known good unit, greatly reducing the time and cost associated with developing Test Program Sets (TPS) which is required for conventional testing (see Chart 4).



Source: GAO analysis of Department of Defense (DOD) and military service documentation; DOD (photos). | GAO-20-116

Chart 4.

During Phase I of DoD's phased intermittence implementation approach, the JIT WIPT's use of the CTMA venue, through the advocacy of the Joint Staff and the Logistics Initiative Fund, provided the means to both generate industry interest in solving the intermittence issue and sponsored an objective evaluation mechanism for capability demonstration that could be formalized into a DoD specification. Through additional Joint Staff advocacy, DoD standardized the newly developed Intermittent Fault Detection equipment verification process utilizing the IFE that was established in Phase I. The IFE emulates intermittent faults of known duration on a conductive path to verify the capability of test equipment to detect and isolate the simulated faults. MIL-PRF-32516 requires, as part of first article testing, Government validation of prospective offers using the IFE to validate Intermittent Fault diagnostic equipment capabilities.

Figure 2. 128-Channel IFE

Other key activities occurred under the auspices of the JIT WIPT to address electrical component failures due to intermittent faults. The Air Force and the Navy are the vanguard of current application at maintenance activities and have successfully applied and shared best practices and lessons learned. The following Phase I examples illustrate the "bottom up" recognition of the intermittence fault and the willingness to work across Military Services to identify and implement solutions.

Air Force Modular Low Powered Radio Frequency (MLPRF)

In 2008, OO-ALC became aware of Universal Synaptics' IFDIS technology. Depot personnel procured the IFDIS commercial tester and applied it to the F-16 aircraft Radar System MLPRF LRU, which at that time was OO-ALC's number one Mission Impaired Capability Awaiting Parts (MICAP) issue on F-16s. The IFDIS was procured by the OO-ALC depot utilizing RTOC funding and was the first IFDIS procured and utilized in DoD.

In 2010, the Avionics Advanced Maintenance Team (AAMT) at OO-ALC launched into full scale IFDIS testing of the F-16 MLPRF LRU. Upon depot induction of every MLPRF, all the Shop Replaceable Units (SRUs) were removed and the MLPRF LRU chassis were IFDIS tested. The IFDIS first tested the LRU for open circuits by ensuring continuity in all circuit paths. The IFDIS then tested for shorted circuits by verifying between each circuit and every other circuit to ensure there are no shorted circuits in the LRU. The IFDIS then tested for intermittent faults. This is conducted by monitoring all circuits in the LRU, simultaneously and continuously, while a vibration table and an environmental chamber simulate operational conditions for the F-16 MLPRF. If any circuit experiences an intermittent fault for durations as short as 50 nanoseconds, the IFDIS detects and precisely isolates the location of each intermittent circuit. In addition to cracked solder joints, other intermittent conditions were detected, isolated, and repaired, including broken wires, sprung connector receptacles, and loose crimp connections.

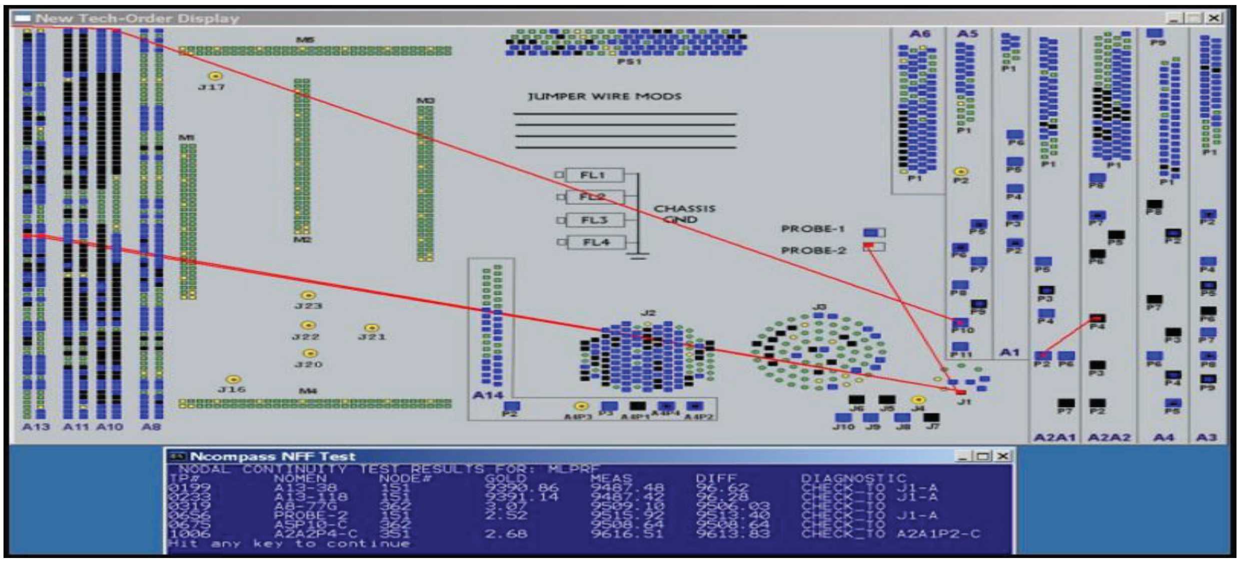


Figure 3. IFDIS Fault Isolation Graphic identifying the exact location of detected and isolated intermittent faults in the F-16 MLPRF LRU

These results highlighted that an ongoing, extensive F-16 MLPRF LRU re-soldering program was no longer required. IFDIS testing either exonerated each LRU by verifying there were no open, short, or intermittent circuits, or IFDIS testing identified and precisely detected and isolated each problem within the LRU. Repairing a cracked solder joint or broken wire is not difficult. The challenge is and has been detecting and isolating these elusive problems.

Over 500 F-16 MLPRF LRUs have been IFDIS tested at OO-ALC with 68% of the LRUs having one or more intermittent circuits that conventional depot test equipment had not detected or isolated. Each intermittent circuit detected and isolated by the IFDIS was repaired and each serial number was retested to ensure quality of the repair and that the asset was intermittent free.

These MLPRF LRUs were returned to service and the average number of operating hours of the IFDIS tested MLPRFs was calculated and found to have increased from 289 to 926 hours. Reliability had increased over 300% due to IFDIS testing. The number of MLPRFs being inducted into the depot has dropped from 50 to four per month. The induction decrease saved over $20 million in annual depot maintenance costs. Additionally, $42 million worth of MLPRF LRUs that had previously been designated as non-repairable and slated for condemnation were repaired and returned to service as a direct result of IFDIS testing.

Not only has the IFDIS testing enabled numerous previously undetectable F-16 MLPRF LRU intermittent problems to be detected and repaired, but the time required to repair MLPRFs has been reduced considerably. Previously, technicians had been spending days or weeks trying to track down intermittent problems in these LRUs. The IFDIS enables technicians to identify the precise location of all intermittent circuits in minutes. Because of the tremendous success that was realized in detecting intermittent faults with the IFDIS, substantially reducing the incidence of NFF and significantly increasing time on wing for the F-16 MLPRF, the AAMT expanded IFDIS testing to the F-16 AN/APG-68 Radar System Antenna LRU, the F-16 Central Air Data Computer (CADC) and the F-16 AN/APG-68 Radar System Programmable System Processor (PSP). Several studies undertaken since FY 2011 show that there are many LRUs that have an even more severe NFF problems than the F-16 MLPRF LRU.

OO-ALC currently owns and operates three IFDIS test benches. By detecting, isolating, and repairing the intermittent faults in LRUs at OO-ALC, time on wing of IFDIS tested LRUs has increased by 300%, substantially increasing the reliability of the F-16, reducing maintenance costs by $20 million annually, and achieving $150 million in cost avoidance, while also reducing the need to acquire LRU spares and perform expensive OEM recommended upgrades.

Navy F/A-18 Aircraft Generator Converter Unit (GCU) Chassis Best Practice Implementation

The Air Force, with the OSD's assistance, enabled the Navy to address a long-term MICAP problem by sharing best practices even as it focused on solving its F-16 MLPRF LRU intermittent fault problem. The F/A-18 GCU chassis, a critical safety item is a historically challenging MICAP for the Navy over the last 20 years, causing repeated availability loss and driving unnecessary repair costs. As the Air Force began to address NFF for the F-16 MLPRF LRU, the Navy's F/A-18 GCU chassis reliability and availability issues had reached a peak, receiving the attention of the Commander of the Naval Air Systems Command (NAVAIR). This leadership focus created great urgency within the Navy's electronics maintenance community to step up efforts to address its GCU difficulties.

As the Navy considered GCU solutions, DoD sponsored a first of its kind "Concurrent Technology Showcase" as part of the CTMA Partners Meeting. This event was unique because it was held directly on the shop floor of an aviation repair facility (Naval Aviation Depot North Island) and included leading industry partners who were invited directly into the maintenance depot. This kind of venue enabled artisans[5] to learn first-hand about capabilities from both Industry and other Military Services that could help them solve their problems. The venue also enabled information technology specialists and the depot's management team to get first-hand knowledge of available capabilities and solutions. It was at this Concurrent Technology Showcase that North Island's Navy artisans first learned of the IFDIS capability from the Air Force. The Navy quickly realized the potential value of this capability, and shortly thereafter started to implement solutions to address the GCU issues in their organizational context. OSD facilitated the pace of knowledge sharing and IFDIS implementation by sponsoring not only this concurrent technology venue, but a CTMA event that drove development of an interface adapter.

[5] Artisans – Definition = A worker in a skilled trade

This adapter became the pacing item for the Navy's ability to implement IFDIS and to leverage Air Force MLPRF LRU lessons learned in their IFDIS technology insertion activities.

The early IFDIS successes in both the Air Force and Navy resulted primarily from innovation and "out of the box" thinking exhibited by talented technology insertion teams, sustainment and maintenance professionals in the face of extremely serious materiel readiness issues. The MLPRF and the GCU chassis were holding down aircraft to such an extent that reaffirming conventional solutions was not going to get the job done. Each Military Service deserves great credit for taking an initial chance on IFDIS and for making time to collaborate in order to increase the scale of benefits achieved. DoD also played an important role by continuously channeling this innovation through the appropriate kinds of technical and knowledge sharing venues. These events not only drove the initiation and execution of good ideas but provided the technical forums to focus and enable the right SMEs to develop and tailor the technical framework to grow intermittent fault and detection capabilities at the appropriate pace.

The Navy collaborated with the Air Force after participating in a CTMA Partners Meeting, where Universal Synaptics provided a briefing on the IFDIS application utilizing this advanced technology at OO-ALC, Hill Air Force Base (AFB), which could test and isolate wiring issues within chassis and backplanes to the precise location of the intermittent fault. The Fleet Readiness Center Southwest (FRCSW) Fleet Support and Advanced Technology team engineers visited OO-ALC at Hill AFB in 2010 to investigate the technology and its potential application for the F/A-18 GCU. In 2012, during an initial engineering demonstration that leveraged the OO-ALC visit, six ready for issue GCUs (two from each variant group G1, G2, & G3 GCU modifications) were tested and resulted in five out of six failing for intermittence related issues. FRCSW was able to repair the intermittent failures on five of the six failing GCU's and return to supply intermittence free.

In response to the intermittent wiring issues detected and isolated by the IFDIS during FRCSW's engineering demonstration and data from the Air Force F-16 aircraft radar findings, FRCSW invested in IFDIS capability via the Capital Investment Program (CIP). In 2016, the first IFDIS was installed at FRCSW and further testing was undertaken to scope the F/A-18 GCU intermittent testing requirement. Commander, Fleet Readiness Centers (COMFRC), FRCSW, Fleet Readiness Center West (FRC-W), Marine Fighter Attack Squadron-122, and the F/A-18 Program Office (PMA-265) collaborated on a one-year GCU pilot program.

The purpose of the F/A-18 GCU IFDIS pilot program was to gather IFDIS test data to validate that intermittent faults are a significant cause of NFF, validate that unidentified and repeated operational on-aircraft failures in the GCU chassis are intermittent faults, and validate that Intermittent Fault Detection technology detects and isolates faults in WRA chassis. Additionally, the IFDIS pilot program was to document F/A-18 GCU TOW improvements in a controlled environment by utilizing a Lemoore Super Hornet Training squadron where GCUs were installed as a pair and a supply officer controlling GCU usage and flight performance reporting, simulate IFDIS tested GCU impact on normal I-level fleet operations by re-installing original GCU components and replacing only those components that failed during final WRA testing to keep pilot costs low. As a baseline, the team documented F/A-18 GCU TOW across the fleet at 121 hours. Finally, the last objective was to validate the assumption that traditional ATE cannot detect and isolate intermittence.

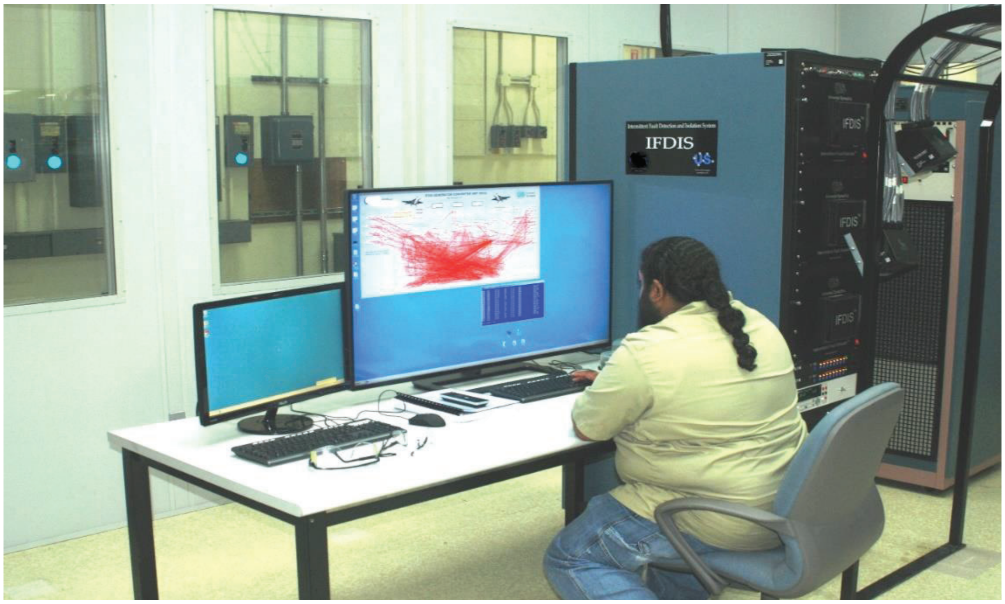


Figure 4. Technician operates the IFDIS to test the GCU chassis of an F/A-18. The IFDIS not only checks the connection points in the GCU harness for intermittent shorts or opens, but also has the capability to simulate the flight stresses and conditions which F/A-18 aircraft are exposed. (U.S. Navy Photo)

The results of the F/A-18 GCU IFDIS pilot program generated unprecedented results. IFDIS detected and isolated intermittence failures in 70% of pilot program GCUs that traditional ATE did not detect or isolate. This discovery validated the assumption that traditional ATE testing is incapable of detecting and isolating intermittent faults. This was validated because all pilot program GCUs had passed traditional bench testing with no wiring failures detected in comparison with those found by utilizing the IFDIS. The F/A-18 TOW for IFDIS tested GCUs in some cases tripled in comparison to the fleet average of non-IFDIS tested GCUs. The IFDIS also reduced the impact and cost to the supply chain (e.g., erroneous subassembly replaceable assembly failures due to chassis intermittence) for all pilot program GCUs. Additional results achieved were a reduction in maintenance turnaround time (TAT) and man hours expended at the Intermediate and Depot level for ready for issue testing by 67%, falling from 22-hour average testing/repair to seven-hour average testing/repair per GCU.

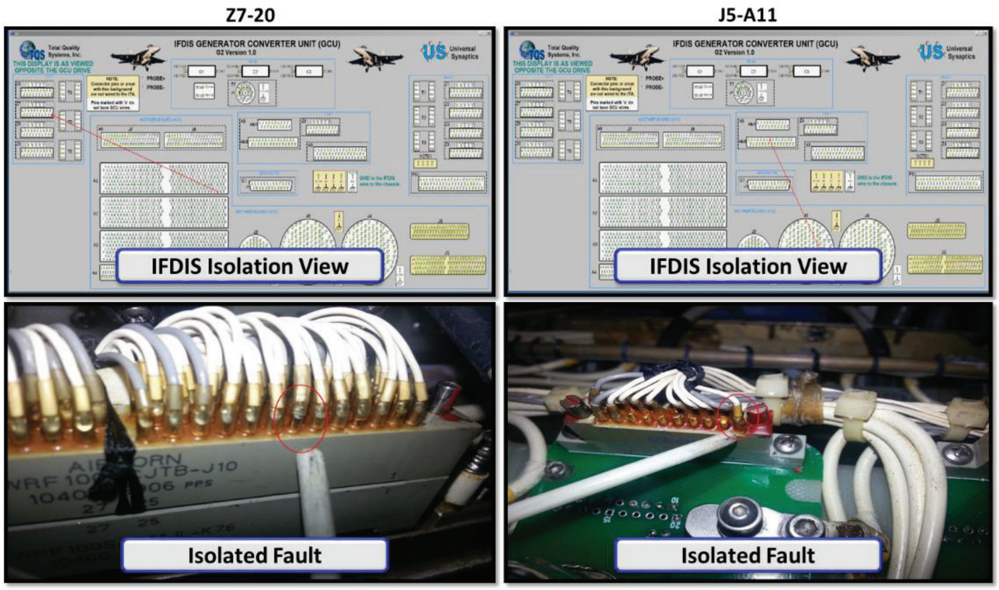


Figure 5. An example from the pilot: IFDIS test results showed three intermittent circuits due to broken wires at Z7-20, J5-A11, and A5-A13 (shown above: Z7-20 and J5-A11 broken wire conductive paths). The IFDIS demonstrated the ability to find faulty wiring that was not detected by traditional bench or visual inspection. Post IFDIS Pilot TOW results tripled. (US Navy Photos).

The F/A-18 GCU IFDIS pilot results led to the realization that GCUs could be returned to fleet operations with wiring issues that could lead to F/A-18 on aircraft GCU failures. As a result, Field Support Team (FST) engineers drafted a Local Engineering Specification directing 100% of F/A-18 A-D group G1and G2 GCU testing across the IFDIS and extended this testing to 100% of all F/A-18 E-F GCUs in 2019. Additional funding was provided by NAVAIR, Lakehurst for the purchase of additional IFDIS to support Intermediate-level processes that included IFDIS capability for FRC-W (Lemoore, California) and FRC-Mid-Atlantic (Oceana, Virginia) to test F/A-18 E/F Super Hornet aircraft GCUs that have NFF issues from the squadrons. The Fleet Readiness Centers operate three IFDIS for F/A-18 GCU testing.

Army UH-60, AH-64, and Patriot Missile System Intermittence Technology Demonstrations

Letterkenny Army Depot (LEAD) and Fort Campbell were chosen as locations to demonstrate PIFD capabilities utilizing patented MIL-PRF-32516 "*Electronic Test Equipment, Intermittent Fault Detection and Isolation*" compliant PIFD. The PIFD was applied to the Patriot Missile System, UH-60, and AH-64 EWIS. In addition, detecting intermittent faults, the PIFD provided the ability to isolate wiring problems that enabled root cause repair and directly addressed the NFF problem.

The primary result of this project was successful demonstration of the elements necessary to enable detection and isolation of intermittent, open, and short circuits within weapon system EWIS at LEAD and Fort Campbell. Intermittent faults were detected and isolated in the first unit tested with the PIFD at LEAD. The detailed identification of the faults and their precise locations enabled the maintenance technicians to fix the root cause of the intermittent faults in UH-60 and AH-64 EWIS.

In summary, Phase I of DoD's holistic approach to increase implementation of intermittent fault detection and isolation capabilities concluded in 2016. It was particularly successful in scoping DoD's electrical intermittence problem and beginning the integration of intermittent fault and detection capabilities into DoD's traditional maintenance operations. The intermittence failure mode was appreciated at key organizations within DoD and an innovative solution was objectively evaluated and became operational at several DoD maintenance activities. Through effective organizational approaches, knowledge sharing occurred that enabled Military Services to target several weapons system platforms where NFF is driving low readiness and high costs. Phase I positioned the DoD to further leverage data and analytics to identify additional implementation opportunities and to begin to establish additional guidance and intermittence-focused technical organizations.

Phase II: Expanding Implementation at DoD Depot Maintenance Activities, Formalizing Military Service Guidance, and Developing Centers of Excellence

Phase II, which began in 2017, is underway and expanding the IFDIS/PIFD implementation framework within DoD maintenance activities. IFDIS implementation across the DoD was launched and funded through NCMS, CTMA, Joint Staff and the ODASD(MR). A DoD-wide framework to implement intermittent fault detection (IFD) technologies across all levels of maintenance was developed by the JIT WIPT leveraging the MIL-PRF-32516 and the DoD MADW.

The MIL-PRF-32516 framework, which was defined in Phase I, is supporting growth of IFD and isolation capabilities across the Military Services. The JIT WIPT went on to publish "*Solving the Department of Defense (DoD) Intermittence Problem, a framework for an Intermittent Fault Detection (IFD) solution*" (December 2018). This document recommends steps an organization may utilize to successfully implement IFD and isolation of EWIS and LRUs/WRAs. The recommended steps outlined in this publication are:

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

The first two steps are actions that the JIT WIPT and the ODASD(MR) can assist to build awareness and support within the DoD organization/agency or platform Program Office. Once these entities are engaged, the second step involves identifying the LRUs/WRAs most affected and the appropriate maintenance level for implementation. The Military Services are targeting the "bad actors" that account for ~$618M in non-value-added maintenance costs annually. Additionally, leveraging historical IFDIS data and results can possibly net an estimated $300M in cost savings with a 50% increase in material readiness on the initial IFDIS target weapons system components being addressed in Phase II. The JIT WIPT can employ available data tools and previous experience to assist with this analysis. Step three is the DoD organization/agency or platform program office's responsibility to acquire and implement the capability. In step four, the organization/agency, with the JIT WIPT's assistance, will validate the results and support the expansion of IFD equipment implementation.

Developing Technology CoEs will enable DoD to review and evaluate new and innovative technologies for detecting and analyzing intermittent faults through integrated, expert organizations. Implementation targets can then be supported by continually refined data-based decision-making processes, driven by leveraging the MADW data to identify target opportunities for IFDIS deployment. Continuous awareness and buy-in will increase throughout the Military Services as more implementations occur and information is shared through Technology CoEs about the benefits of electronics intermittent fault detection and isolation.

These CoEs will serve as "information hubs," able to identify lessons learned and communicate these throughout DoD. The CoEs will also focus on identifying the best of breed electronics intermittence maintenance technologies and advancing and integrating these capabilities, while developing and maintaining validated lists of products that have demonstrated ability to detect Category 1 intermittent faults (per MIL-PRF-32516) in their intended fault environment. The JIT WIPT will continue to present and/or demonstrate potential IFDIS capabilities and benefits to platform managers and applicable leadership levels to garner support and advocacy. Enterprise-wide cost and availability variables will continue to drive the growth in depot maintenance implementation.

The Technology CoEs under assessment are:

- Naval Surface Warfare Center (NSWC) Crane (Airborne Electronic Attack Fleet Support Team), which covers the Navy and Marine Corps, to include NAVAIR and the Naval Sea Systems Command (NAVSEA). The Fleet Support Team at NSWC Crane is uniquely suited to serve as a Technology CoE because of its current responsibilities in support of airborne electronic attack WRAs installed on EA-6B, EA-18G, and P-8 aircraft.

- The Air Force IFD Technology CoE located at Hill AFB (Air Force Sustainment Center 309th Electrical Maintenance Group). The Maintenance Group at Hill AFB is well positioned to become an IFD CoE due to a decade of experience and success restoring F-16 LRUs back to their original design reliability.

Both CoEs will evaluate new technologies through participation in recurring Industry Days.

Phase II is continuous and ongoing. The JIT WIPT, in collaboration with the Military Services, will continue to leverage MADW data to identify DoD's IFDIS best opportunities to influence leadership awareness and buy-in. The Military Services will also persist in identifying the "bad actors" to ensure intermittence related readiness improvements and cost savings. The Military Services continue working with their field level organizations to identify IFD opportunities and introduce IFD solutions. The ODASD(MR), in collaboration with the JIT WIPT, will have overall oversight to continue to keep all stakeholders informed of this issue. Historical IFDIS data and results, with a conservative estimate of $300M in cost savings with a 50% increase in material readiness on the initial IFDIS target weapons system components, are achievable in Phase II.

Phase III: Implementing IFD and Isolation Capabilities at Field Level Maintenance Operations

Phase III began in 2018, overlapping with Phase II to expand and focus to focus IFDIS implementation at field level maintenance operations. Delivering advanced IFD capability closer to the weapon system enables intermittent failures to be detected, isolated, and repaired rapidly, reducing the logistics and supply chain burden. Additionally, DoD will need to increase adoption of the intermittent fault failure mode and solution set for EWIS. MIL-PRF-32516 (March 2015) is the current guidance being used to define performance requirements for equipment to detect and isolate electronic intermittent faults. The ODASD(MR) will continue to leverage the Military Services' "bad actors" from Phase II to guide strategic IFDIS implementation as the list of "bad actors" is updated and refined during Phase III implementation. Socializing IFDIS results with the Military Services through collaboration from various organizations and programs (e.g., the JIT WIPT, CTMA, CBM^+ Working Group, JTEG, Maintenance Symposiums) may increase standardization and adoption of IFD technologies.

Development and demonstration activities are underway to detect and isolate intermittence in wiring harnesses while installed in weapon systems during field maintenance with the use of Universal Synaptics' PIFD that has an ATO approval from the F-35 JPO. Implementation of PIFD capability at the field level offers tremendous benefit in terms of cost savings and readiness improvements for additional weapon system platforms.

The JIT WIPT has used two iterations of the MADW data (FY 2012 and FY 2019) to identify the top 10 false or supposedly false intermittent LRUs/WRAs for each Military Service that would be candidates for IFDIS testing and analysis. The Military Services, in coordination with the JIT WIPT, will continue to identify the top 10 false or supposedly false intermittent LRU/WRA candidates for IFDIS testing and analysis. For the purposes of data analysis, certain business rules have been established to ensure accuracy of the data. For example, the use of all Engineering Investigation (EI) codes should be identified, Performance Based Logistics (PBL) contract repairs should be excluded from any list of new candidates for testing and analysis, and critical safety items should be included. Key discriminators to this analysis must include but not limited to cost, availability, and cost per day of availability (C/DA). These discriminators will enable the Military Services to better forecast new cost, availability, and C/DA results. The overall intent of the data is to identify LRUs/WRAs that are potential candidates for IFDIS due to LRU/WRA criticality, maintenance cost, and non-availability days.

On May 18, 2021, the Chief Financial Officer Data Transformation Office and the Undersecretary of Defense for Acquisition and Sustainment signed a memorandum of agreement directing the migration of MADW to Advana. With its name derived from the term "advanced analytics," Advana is a centralized data and analytics platform that supplies Department of Defense (DoD) users with common business data, decision support analytics, and data tools. Adding MADW to the suite of Advana capabilities will offer users a central location for data analytics concerning acquisition and sustainment costs and outcomes. The migration will support a larger MADW platform, ensuring consistent and reliable resourcing for MADW curation and development.

The ODASD(MR) intends to issue a memorandum in calendar year 2021 requesting each Military Service to review the MADW candidates and perform a thorough analysis based on additional data and subject matter expertise. The Military Services will also provide an updated list of best candidate components to address during depot-level visits for eliminating NFF where electrical intermittence is the suspect cause. The draft memorandum will also ask each Military Service to review the MADW IFDIS candidate data and validate and/or recommend IFDIS candidates based on their "local knowledge" of what is impacting their operations.

Phase III will establish the framework in collaboration with various organizations (e.g., NAWCAD Lakehurst, OO-ALC, NSWC Crane, Hill AFB) that presents an opportunity for standardization and centralization of DoD IFD policy and practice in a way that would not be feasible for diagnostic systems that detect hard faults.

A collaborative effort with the JIT WIPT and various organizations is to propose and develop a DoD Joint Intermittent Test CoE with the primary function of maintaining a validated products list of items with demonstrated ability to detect Category 1 intermittent faults in accordance with MIL-PRF-32516 in their intended fault environment. This Joint CoE will be capable of testing new technologies to determine if the technologies can, in fact, detect intermittent faults, and how short of a time duration the intermittent fault candidate technology can detect. The responsibilities of these collaborative efforts shall include, but not be limited to, diagnostic equipment validation; participation in Industry Days; updating and developing new test capabilities/procedures; updating test methods as needed; updating the IFE; and updating MIL-PRF-32516 and MIL-HDBK-527. In addition, the JIT WIPT is collaborating with various organizations to ensure compliance with the DoD Automatic Test Systems (ATS) Master Plan, including review of existing ATS and coordination with the ATS Executive Directorate.

An ODASD(MR) memorandum, dated April 2019, advised the electrical maintenance community to rapidly promulgate intermittence detection and isolation capabilities, as defined by MIL-PRF-32516, across the enterprise. Each Military Service senior leader was requested to address recommendations focused upon intermittence as an electronics failure mode and to provide a plan to address and field intermittent fault detection and isolation capabilities.

The major Phase III activities include:

- Leveraging the Military Services' "bad actors" for IFDIS test, repair data, readiness improvements, and cost savings from Phase II to guide strategic IFDIS implementation for the next Top 20 "bad actors";
- Continuing to refine MADW Military Service data;
- Socializing IFDIS results achieved in Phase II, increasing adoption of IFD technology;
- Developing a specification sheet addendum for field level IFD and isolation capabilities;
- Distributing F-35 JPO PIFD test, repair data, readiness improvements, and cost savings from Phase II to weapon system wiring groups and engineering competencies; and

- Increasing adoption of intermittent failure mode and solution set for EWIS.

The tremendous benefit of a comprehensive Phase III implementation is that "catching" intermittence at the field level will not only increase materiel availability more quickly and directly, but will save the enormous distribution, labor, and storage costs associated with addressing intermittence at the depot level. Therefore, DoD will strongly pursue implementation of intermittent fault isolation and detection capabilities at field level maintenance activities. However, implementing these capabilities at the field level is much more complex than depot level implementation.

Several challenges contribute to this complexity. First, DoD needs a precise, repeatable, and safe way to create the environmental conditions that simulate intermittence on aircraft at field level maintenance locations. The current technical gap DoD is addressing is that onboard environmental stimulus is very difficult to emulate accurately in a field environment. CTMA issued a sources sought to Industry in July 2020 to collect potential solutions that could fill this technical gap. One of three responses was considered to be responsive. However, due to funding constraints, no additional actions have occurred. Proper locations must be established in order to ensure technical fidelity and substantial training and workforce development is required in order to normalize the capabilities at the field level. Second, field level maintenance, by design, does not commonly require substantial facilities and infrastructure to complete. New or additional equipment requirements, even if portable or relatively small, will drive maintenance process changes that will take time to put into operation. Finally, field level maintainers are charged with providing today's materiel readiness in accordance with demanding operational tempo requirements. Adding a different, reasonably sophisticated, tester to their busy workflow will be disruptive, at least initially. These maintainers will need to see the value of new intermittence capabilities in order to apply the effort required to make workflow adjustments permanent. Successful implementation requires active leadership at the Department and Service level, as well as effective best practice communication at "unit level maintenance" in order to leverage lessons learned and "value add" quickly and broadly.

Phase IV: Normalize the Use of IFD and Isolation Capabilities at All Levels of DoD Maintenance and During Initial Electronic Component Manufacture

DoD's vision for its Phase IV IFD and isolation implementation end state has both technical and organizational elements. Technically, intermittence will be widely recognized as an accepted failure mode for both legacy and initially manufactured assets. Testing for intermittence will be the norm throughout DoD and Industry for electrical maintenance and testing information will be collected and analyzed to make electrical components twice as reliable as they are now. These advances will dramatically increase affordability and availability over the life-cycle for all electronics components and the weapon systems they operate.

Organizationally, DoD will have taken steps to provide additional official guidance on all aspects of intermittence detection and maintenance to the electronics stakeholder community. It will provide refined and reissued guidance to establish a comprehensive intermittent fault and isolation concepts of operation that will work in unison with other ATE to identify and address steady state electronics failures. Supportive policy will also be developed to drive on-going collaboration between DoD and Industry to address topics such as first article testing, quality assurance, and production lot testing in the intermittence context. Intermittence workforce training and development will be established and fully integrated into career progression paths to institutionalize isolation and detection capabilities that are effective in an organization as large and complex as DoD. CoEs will be established and leveraged commensurate with capability advancement and collaborative venues will continue to share best practices and move the community forward.

Phase IV, to begin in late 2021, will begin to synthesize and expand existing IFDIS/PIFD implementations in order to scale the adoption of capabilities to all levels of DoD electronic component maintenance and manufacturing. DoD will continue to build and leverage collaborative groups to further integrate intermittence into the DoD technical community in order to normalize the appreciation and use of IFDIS capabilities. For example, a key target will be the integration of the JIT WIPT with other DoD wiring technical groups, such as the Joint Services Wiring Action Group (JSWAG).[6] While the JSWAG Executive Steering Committee has been receptive to collaborating with the JIT WIPT, it has not met since the proposal for collaboration was submitted, due to the coronavirus disease 2019 (COVID-19) pandemic.

As illustrated below, there is commonality between the JIT WIPT's and the JSWAG's objectives and increased collaboration will enhance awareness of the intermittence failure mode throughout the electronics wiring community.

The JSWAG's objectives are:

- Providing a forum for the service of industrial, maintenance, and product support activities to improve wiring, fiber optics, and interconnect systems. Designated representatives use the JSWAG to improve safety, reliability, maintainability, standardization, cost effectiveness and overall readiness of DoD Aviation Weapon Systems by improving their wiring and fiber optic systems. This is accomplished by the regular and timely exchange of technical information and application of principles by wiring systems experts from across DoD.
- Coordinating with other DoD agencies to develop standard procedures whenever possible and sharing information of benefit to all activities to obtain user requirements, assist in program budgeting, identify funding, develop actions, and recommend prioritized solutions.

JSWAG membership is composed of the Air Force, the Army, the Navy, the U.S. Marine Corps, the U.S. Coast Guard, the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA), commercial airline maintainers, and Government support contractors.

The JIT WIPT forwarded a draft revision to the JSWAG charter to add a new JIT Committee in August 2019. The new committee has the following objectives:

- Advise and assist in implementing a DoD IFD solution.
- Leverage current and emerging IFD technology for demonstration, testing, and cost-benefit analysis.

[6] The JSWAG, previously known as the Naval Aerospace Vehicle Wiring Action Group (NAVWAG), has been chartered since May, 2002.

- Educate and inform program management and electronics and EWIS maintenance community on IFD.
- Define and validate joint performance requirements for a Joint Service IFD system.
- Collect and analyze implementation and operational data on IFD systems currently in use.
- Identify, define, and validate test methods for ensuring that specified minimum performance requirements for detecting and isolating intermittence are met.
- Leverage DoD's MADW to assist in identifying intermittence related readiness and cost drivers and recommend IFD opportunities.
- Investigate and develop plans for integrating IFD with existing EWIS maintenance and repair diagnostics and diagnostic equipment.
- Investigate intermittence-driven EWIS unscheduled maintenance.
- Develop recommendations and plans for decreasing intermittence-driven unscheduled maintenance and shifting to schedule-based IFD proactive maintenance.
- Collaborate with Industry and Academia on innovative intermittence-driven NFF solutions and methods.

This type of collaborative engagement can ensure continued communication with the Military Services and Program Offices and will be key to normalizing the use of intermittent fault detection and isolation capabilities at all levels of DoD maintenance.

Training the workforce will also be key to normalizing this capability. Establishing an IFD awareness and training program at the organizational and Military Service level where the IFD equipment will be utilized will ensure the workforce is trained and will ensure continued recognition of the severity of this failure mode.

Phase IV is the future state and continued collaboration amongst the Military Services, Program Offices, and working groups will increase the buy-in and awareness of this failure mode. A solid communication plan and training program will enable organizations to better understand the severity of this failure mode and enable all levels of DoD maintenance to identify IFDIS/IFD capabilities that will provide impacts to cost savings and readiness improvements.

Implementation Challenges and Keys to Successful Way Ahead

Intermittent faults have been recognized as top cost drivers as well as, number one MICAP issues as discussed with the Air Force's F-16 MILPRF and Navy's F/A-18 GCU failures. Increased leadership buy-in and awareness that intermittence is a recognized, accepted failure mode is key to ensuring the success of IFDIS/PIFD implementation. The capability exists to detect and isolate intermittent failures. The implementation of any new capability encounters challenges in the form of resistance to change, requirements determination, procurement costs, and not being aware of the magnitude and impact of the problem. The Military Services are challenged with identifying resources to begin implementation and resources will be key to organizations that want to obtain appropriate capability demonstrations, and subsequent implementation (if applicable), through the Military Services, Defense Agencies, or OSD. The following are some of the resources that may be available to assist in the implementation of IFDIS/PIFD equipment:

- **The Department of Defense Planning, Programming, Budgeting, and Execution (PPBE) process**

  Military Services and defense agencies utilize PPBE to identify requirements and compete for resources. PPEE is the department's process to manage, prioritize, and allocate resources to support activities consistent with the National Defense Strategy, National Military Strategy, and Department of Defense strategic objectives.

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

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

- **The Small Business Technology Transfer (STTR) Program**
  The STTR Program expands funding opportunities in the Federal innovation research and development (R&D) arena. Expansion of public/private sector partnerships, including joint venture opportunities for small businesses and nonprofit research institutions, is central to the STTR program. One unique feature of the STTR Program is the requirement for a participating small business to formally collaborate with a research institution in Phase I and Phase II of the Program. The STTR Program's most important role is to bridge the gap between performance of basic science and commercialization of resulting innovations.

  Note: The IFDIS procured by both the U.S. Air Force and U.S. Navy were procured under a Phase III SBIR Topic AF01-296.

- **The CTMA Program**
  Created in 1998, the CTMA Program is a joint effort between DoD and NCMS. Its objective is to ensure American troops and their equipment are ready to face any situation, with the most up-to-date and best-maintained platforms and tools available. The CTMA Program provides technology development and insertion in support of reliability and sustainment, and must always benefit the U.S. Military, industrial base and the public good.

- **Cooperative Research and Development Agreement (CRADA)**
  A CRADA is an agreement between a Federal laboratory and a non-Federal party to perform collaborative R&D in any area that is consistent with the Federal laboratory's mission. CRADAs are the most frequently used mechanism for formalizing interactions

and partnerships between private industry and Federal laboratories and the only mechanism for receiving funds from non-Federal sources for collaborative work.

There will need to be continued Government endorsement, Industry involvement, and data-driven implementation targets. Continued guidance promulgation to fully integrate intermittent capabilities into DoD maintenance vernacular, shop floor processes, and life-cycle management organizations are key to the successful way ahead. The JIT WIPT, in conjunction with other DoD working groups, can begin to demonstrate the tie from electronic component NFF corrections to weapon system readiness improvement. Additionally, the JIT WIPT and the Military Services will need to formalize processes, standardize tools to increase industry awareness, and assess potential IFD and isolation capabilities.

The introduction of a new failure mode and implementation of a technical solution has shown partial success but must be continually reinforced to receive full consideration as part of a weapon system sustainment plan. Establishing these collaborative arrangements discussed in Phase II and III become more critical to a successful way ahead. The success of these collaborative arrangements will increase awareness to the Electronics Community and ensure that those intermittent fault detection and isolation capabilities that have been recognized through various public awards or accolades are identified and that new technologies are still being sought. It is also vitally important to monitor the results and impact on LRU/WRA availability and costs. These results can be used in efforts to expand IFD implementation across the DoD.

As mentioned in the April 2019 ODASD(MR) memorandum, the Military Services need to utilize the "Framework for Implementing Intermittent Fault Detection and Isolation Capabilities" to implement this critical capability which will result in a significant increase in weapon system availability and a corresponding reduction in sustainment costs.

Finally, to ensure a successful way ahead, DoD must continue to update guidance to the community of interest regarding this intermittent failure mode and how current technology addresses it. The introduction of a new failure mode and implementation of a technical solution has been successful but must be continually reinforced to receive full consideration as part of key planning and execution documents, such as weapon system sustainment plans. As its structured and on-going implementation shows, DoD has accepted that institutionalizing this paradigm shifting intermittence technology is a marathon, not a sprint. DoD has been on this journey for over a decade and recognizes that work will continue for many years to come. The proper end state drives the Department's activities, and DoD will continue to fully leverage and share its successes on its way to fundamentally transforming electrical/electronic maintenance.

Conclusion

The Department's phased implementation approach is enabling the Military Services to address electrical intermittence by leveraging best practices across the DoD maintenance enterprise and providing the necessary building blocks and capabilities. The phased approach has articulated a well-defined and validated need, established clear performance specifications, supported an objective analysis of potential solutions, and produced sound results to meet the requirement.

It is imperative that additional DoD organizations recognize intermittent electrical faults as a failure mode that is significantly affecting weapon system availability and sustainment costs, and that a capability exists to improve materiel availability and save significant sustainment resources. However, the implementation of any new capability that fundamentally changes established paradigms encounters challenges such as cultural acceptance, organizational alignment, requirements determination and resourcing, and lack of recognition of the magnitude and impact of the problem. This report informs Congress of the strategic approach DoD has underway to address these challenges and to assist organizations to gain awareness of intermittence problems including their effect on readiness and cost, and subsequently to implement an objectively proven capability to help resolve them.

Weapon system program offices own the requirements process for procuring new diagnostic capabilities and integrating them into the maintenance and repair process. This management construct promotes stove-pipe implementation of novel sustainment technologies and necessitates a weapon system by weapon system exploration and buy-in process in order to stand up new sustainment capabilities. In order to effectively implement a sustainment capability such as IFDIS and PIFD broadly across DoD, the Military Services must take an enterprise-wide approach supported by leadership advocacy, policy, guidance, and training, Recent COMFRC efforts to instantiate IFDIS and explore PIFD are good examples of enterprise-level activity that is underway to broadly apply these capabilities to a wider range of electronic systems, and can be achieved with the anticipated savings referenced earlier in this report.

IFDIS and PIFD are proven IFD and isolation capabilities that can be leveraged at scale and institutionalized across the DoD maintenance enterprise to help reduce the 278,000 non-available days of end-item subcomponents and reduce the annual $3 billion NFF cost burden to the DoD. Broader acceptance of the intermittence failure mode would enhance DoD's ability to facilitate focused availability recovery efforts and positively impact sustained readiness recovery.

Addressing the "bad actors" from each Military Service that account for $618M in non-value-added maintenance costs annually is the immediate next step in DoD's Phase II efforts. Leveraging historical IFDIS data and results, a conservative estimate of $300M in cost savings with a 50% increase in material availability on the initial IFDIS target weapons system components, is achievable in Phase II. Further materiel readiness and total lifecycle cost reductions will then follow in Phases III and IV through broader and deeper implementation of proven intermittent fault detection and isolation test capabilities.

A significant point raised by this assessment is that the resource and incentive structures required to reinvigorate innovation and agile technology insertion within the nation's Defense Industrial Base must be more systematic. While DoD has shown resourcefulness and persistence in this electronics maintenance, further work is required to ensure these activities are closely aligned with DoD's technology insertion management and prioritization processes.

Improvements in this area could institutionalize the many successful aspects of the strategic intermittence approach described in this report and apply them more broadly to drive consistent, authoritative sustainment technology insertion across DoD. This would provide effective pathways to identify, scale, and implement emerging technology and temper the cultural resistance that comes with disruptive technological change.