Intermittent Fault Detection Technology Reduces No Fault Found (NFF) & Enables Cost Effective Readiness

Ken Anderson
Universal Synaptics
801.731.8508
www.USynaptics.com
@USynaptics

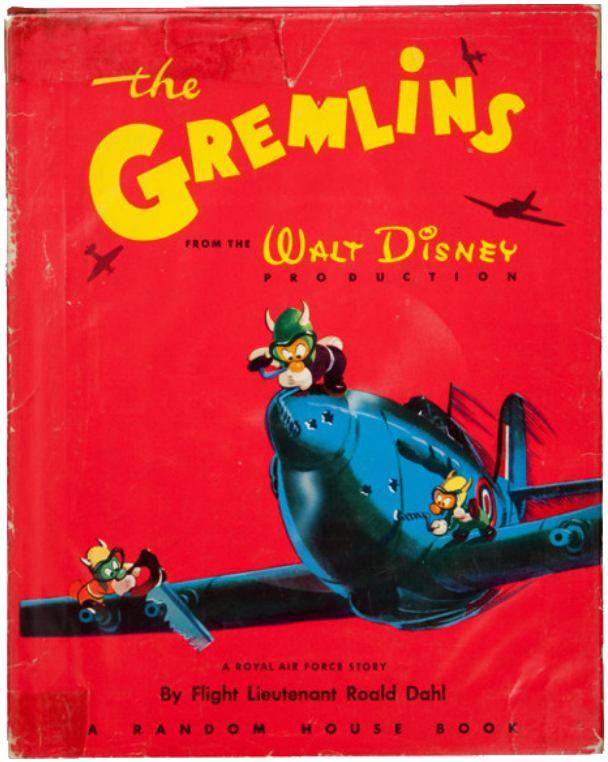
The Problem

- **Aircraft electronic LRUs test "No Fault Found" (NFF) approximately 50% of the time**
  - LRU malfunctions intermittently during flight, but tests good during subsequent ground testing
  - Intermittent activity also categorized as RTOK, CND, NTF, NEOF or even "Gremlins"
  - Intermittent discontinuity is also a significant problem in weapons system wiring interconnect systems

- **Intermittent faults are mechanical in nature**
  - Failures are in wiring, solder joints, wire wraps, connectors, via's etc.
  - Modern components are more reliable and capable – intermittent discontinuity between components is a major concern, readiness degrader and life cycle cost driver

No Fault Found costs the DoD between $2 and $10 Billion annually

The Problem



Pukka Gen on Gremlins

(Royal Air Force Slang for "the real low-down")

By Walt Disney

Disney to Go to England to Investigate Gremlins

BY FRANK P. GILL
Free Press Motion Picture Editor

THE GREMLINS, those interfering little people who were first brought to light, we're informed, by an Irishman in the RAF—it would be an Irishman, wouldn't it to get fairies and the Little People into war?—have became practically an international legend, and even Hollywood has caught the fever. Or, to be rather more specific, one studio in Hollywood—Walt Disney's—is interested.

That's why Walt is planning a trip to Britain very soon to beard the little six-inch personages in their lair, or kingdom, or wherever the flibbertigibbets, widgets, fifinellas and spandules congregate.

Disney has signed a deal with Flight Lieut. Roald Dahl, assistant air attache at the British Embassy, in Washington, whose real story about the Gremlins is paying royalties to the RAF, Benevolent Fund, and expects to turn this tale into one of his inimitable movies. But he wants to get all his material first-hand, hence the projected trip across the ocean.

The Filinella is a honey.

FROM ALL REPORTS, the Fifinella (that's the female Gremlin) is a honey. They tell us her face is *fizzing* and she has wizard curves, all in the proper places. Nothing *topsy* about this little *crumpet*. We gather from this that she's really an eye-full. The boys tell us that you'll never catch a Fifinella drilling holes in your wing, cutting your parachute straps or draining the alcohol from your compass. All a Fifinella has to do is hop aboard a plane for a joy-ride and the Gremlins will follow her in droves. (Statistics show one Fifinella to every twelve Gremlins.)

By the time they've chased her back and forth from one wing-tip to the other, wiggling your wing flaps, swinging on your aerial wire and playing see-saw on your elevators, you'll wish she'd stayed at home to mind the Widgets.

WIDGETS?—They're the new born Gremlins that appear in nests hidden in the dark corners of your aircraft. In every batch of Widgets you'll find a Flibbertygibbet. She's the one who eventually becomes a Fifinella. Before they're a day old, Widgets are up to mischief.

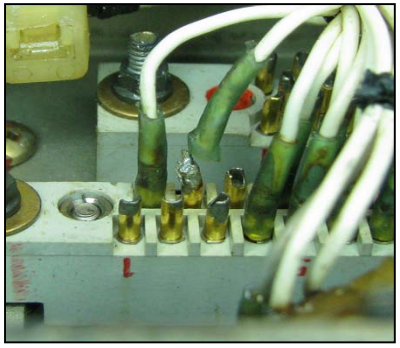
They have very high baby voices and chatter incessantly. Since they're not equipped with suction boots like older Gremlins, they usually concentrate on the instrument board and have a marvellous time putting all the gauges out of whack.

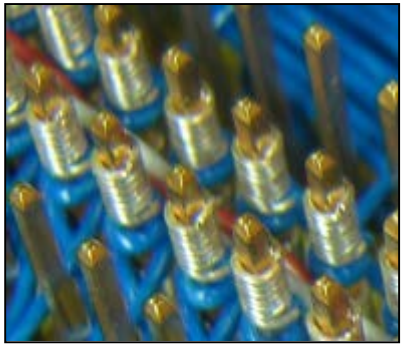
WIDGETS?—They're the new born Gremlins that appear in nests hidden in the dark corners of your aircraft. In every batch

No Fault Found "Gremlins" a Problem as early as WWII

Intermittent Faults, Physical Effects

- **Cracked solder joint**
- **Broken wire**
- **Loose crimp connection**
- **Loose or corroded wire wrap**
- **Corroded connector contact**
- **Sprung connector receptacle**
- **Deteriorated wire insulation**
- **Hairline crack in printed circuit trace**
- **Unsoldered connection**

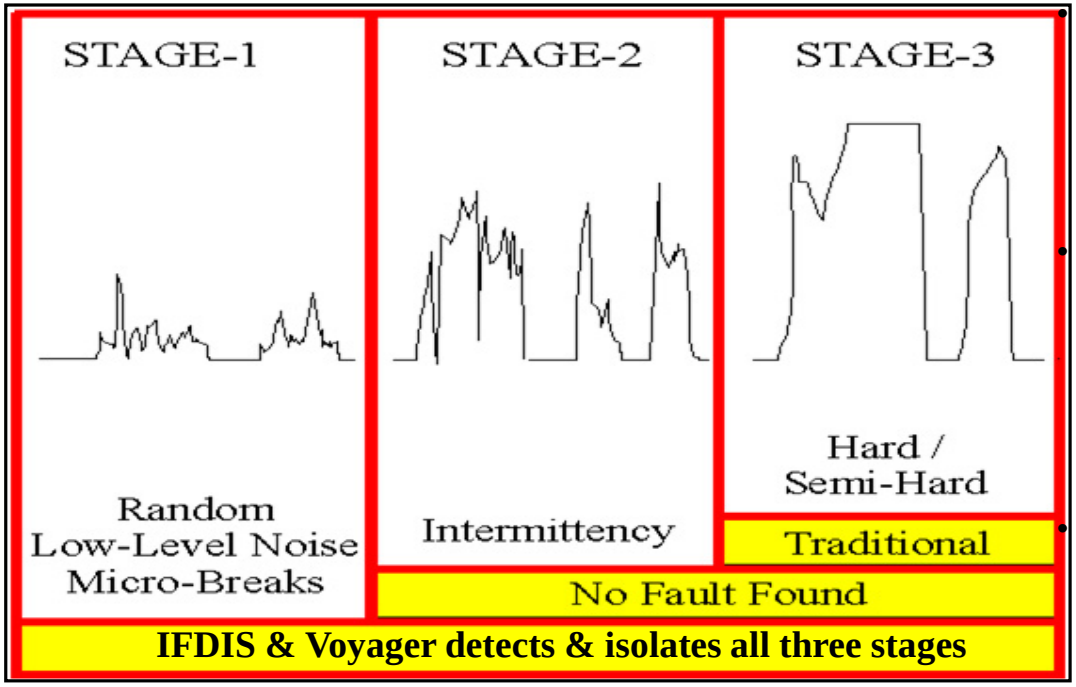




Physical Manifestations, Not Electronic Component Failures

Intermittent Faults

Three Stages to an intermittent fault:



Stage 1 – random low-level nanosecond micro-breaks, likely not operationally evident yet. However these faults are on the early curve of degradation and will become exacerbated over time based on Op Tempo and environmental conditions and will graduate to Stage 2.

Stage 2 – fails intermittently in operation, yet passes ground tests and labeled A-799 (CND or NFF). These in-flight failures are evident to the pilot and reported to the ground crew as “the radar lost lock”, “Heads up Display (HUD) blanked or blinked out”, “Gun Controls didn’t work”, etc. and will eventually become Stage 3.

Stage 3 – semi-hard or hard failures, all the currently fielded Automatic Test Systems (ATE) are designed to detect hard faults (open circuits or shorted circuits). According to the GAO, the DoD currently maintains $50B worth of ATE all designed to detect hard failures, “conventional” ATE was not designed to detect and is incapable of detecting momentary faults that cause A-799.

Operational Impact

- **High MICAP rates**
  - Missions canceled and postponed
  - Readiness is negatively impacted
- **High NFF / RTOK / CND rates**
  - Wasted maintenance resources and supply man-hours
  - Wasted time on supply documentation, transportation and troubleshooting
- **Supply chain becomes more expensive and less responsive**
  - Each LRU sent to the depot for a non-fix, unnecessarily wastes Combat and Support Commands millions of dollars each year
  - High availability (even a 100% production fill rate) does not equal high reliability or weapon system readiness

Change is required to reduce NFF & improve operational availability

MX and Supply Impact

- **Tools provided to maintainers are not sufficient:**
  - Just because a LRU passes BIT or ATE tests multiple times in a row, does NOT mean there isn't a lurking intermittent problem in the LRU
  - BIT / ATE testing does not check all circuits simultaneously or functional paths in an LRU or connection paths to SRAs
  - Conventional ATE does not test in an operationally relevant environment
  - Conventional ATE is incapable of detecting short duration intermittent faults that cause NFF

- **Flight Line "Blacklisting" of UUTs makes an expensive supply problem worse**
  - Creates availability issues / drives unnecessary acquisition
  - Masks the real problem / drives "swaptronics"
  - Recirculates "bad actors" to other operational units, thus perpetuating the problem

An Innovative Solution is Needed to Solve This Problem

No Fault Found

- **No Fault Found (NFF) is an annual multi-billion dollar non-value added expense to the DoD**
  - Intermittent discontinuity resulting in NFF is now recognized by the Department of Defense (DoD) as an operational readiness degrader and life-cycle cost driver
  - DoD estimates that 3 out of 4 (75%) of DoD weapons systems have undetected intermittent faults that manifest as operational failures
  - NFF costs the Department of Defense (DoD) between $2B - $10B annually
    (Source: Office of the Secretary of Defense (OSD) Maintenance, CTMA Partners Meeting)

- **What does NFF cost our FMS Partners?**
  - FMS Partners need innovative solutions to reduce No Fault Found and improve operational availability
  - DoD and FMS collaboration is required to ensure our FMS partners benefit from maintenance and sustainment innovations

Intermittent Fault Detection & Isolation = Cost Effective Readiness

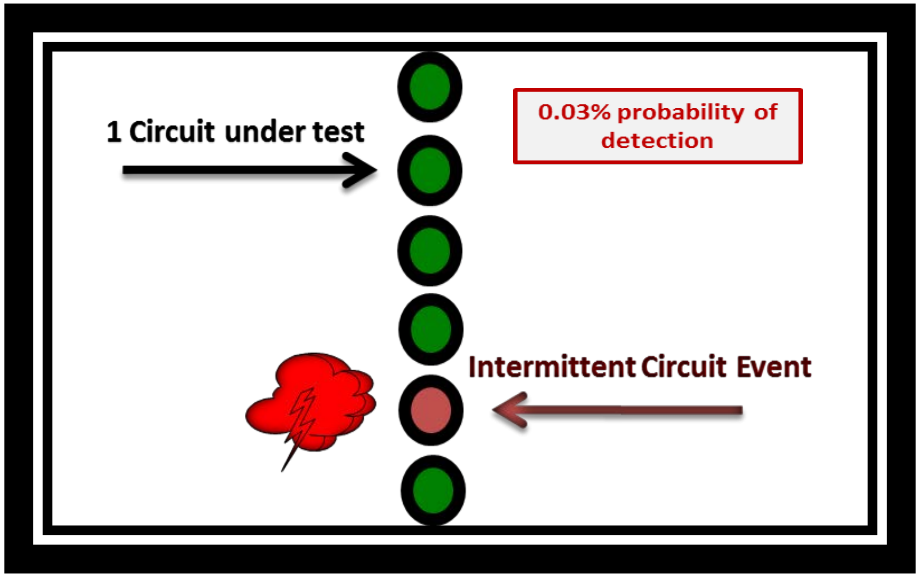
Conventional Approach

- **Functional ATE and Continuity testers cannot detect and isolate intermittent faults that cause NFF**
  - Test only one function at a time
  - Test only one circuit at a time, even when connected to multiple circuits
  - Digital averaging, scanning and sampling masks / misses the intermittent faults – a testing “blind spot” / “testing void” exists
  - LRUs are not typically tested in an operational environment which is where the failures occur, EWIS is also tested in static environment
  - Only designed to find functional failures, failed components and “hard” failures (opens circuits / short circuits)
  - Intermittent faults that cause NFF test results on the ground do not follow specific failure patterns

Conventional Approach = Conventional Results

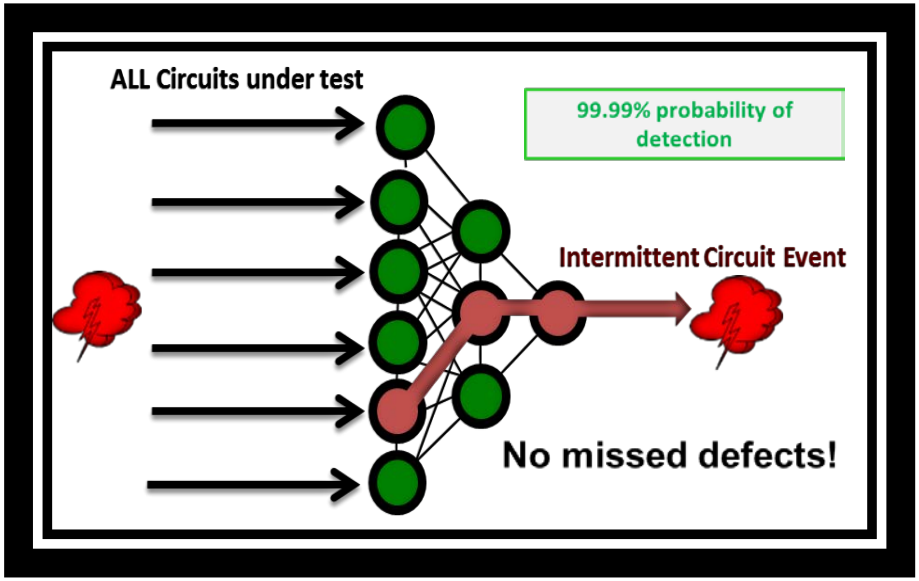
Intermittent Fault Detection Technology
Conventional Approach vs. IFDIS / VIFD

Conventional ATE



- Parametric testing (scanning one circuit or one function at a time)
- Makes assumptions based on set parameters (sampling or averaging test data and results)
- Tests component in static environment (does not simulate operational environment)

IFDIS / Voyager



- **Deterministic testing (all circuits under test monitored at the same time)**
- **Makes no assumptions, if a fault is present it is detected and isolated**
- **Similar to having an oscilloscope on every circuit under test**
- **Tests component in a simulated operational environment (3G, -20C to +70C temp range**

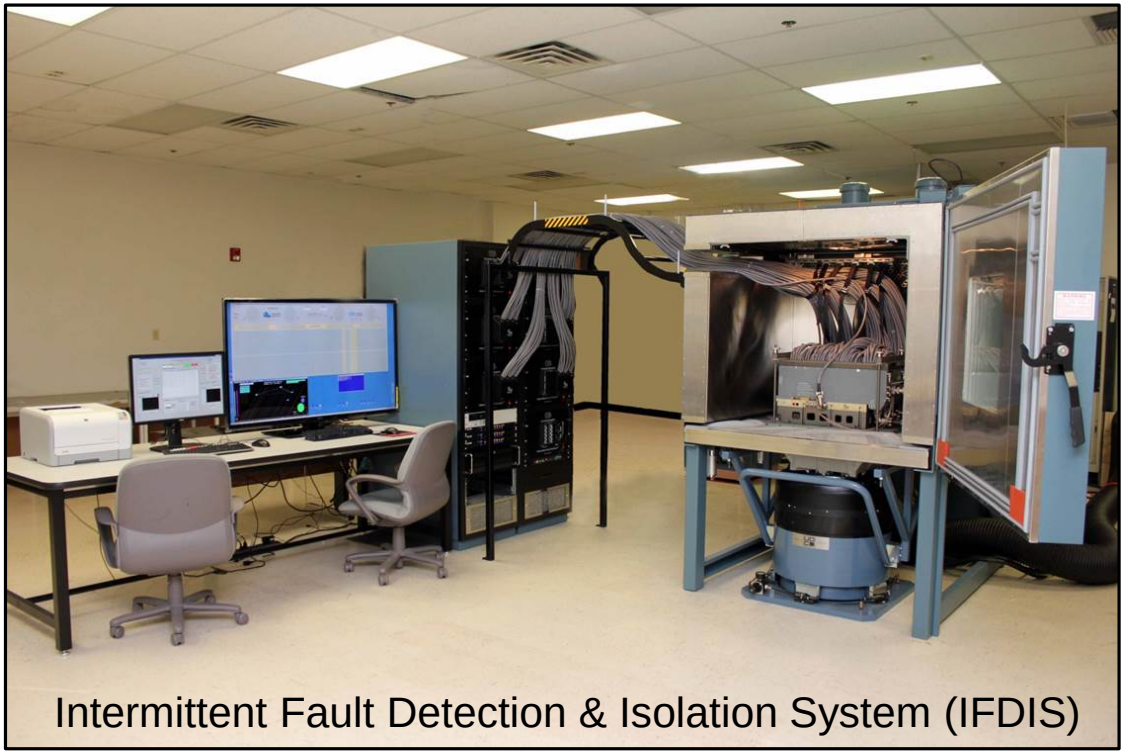
Universal Synaptics NFF Solutions

Voyager Intermittent Fault Detector (VIFD)

- MIL-PRF 32516 Compliant
- MIL-STD 202G Compliant
- Detects: intermittent faults, open circuit, shorted circuits, mis-wiring and distance to fault
- Includes: all lines all the time circuit monitoring (IFD), SSTDR, Huntron Tracker 30, DMM and
- AutoMap™ (No TPS development)
- 128, 256 & 512 test point variants
- TRL 9

DoD Mx Symposium “Great Ideas” Competition Finalist 2014

Universal Synaptics NFF Solutions



Intermittent Fault Detection & Isolation System (IFDIS)

IFDIS

- MIL-PRF 32516 Compliant
- Detects: intermittent faults, open circuit, shorted circuits and mis-wiring
- Includes: all lines all the time circuit monitoring (IFD), Picoscope, DMM and
- AutoMap™ (No TPS development)
- Easily expandable
- TRL 9

DoD Mx Symposium “Great Ideas” Competition Winner 2010 & 2012

Department of Defense Solution

- Office of the Secretary of Defense established the Joint Intermittence Testing (JIT) Working Integrated Product Team (WIPT) in 2012 – Joint Service effort to address the intermittent testing void
- DoD released Military Performance Specification (MIL-PRF) in March 2015, MIL-PRF 32516 *"Electronic Test Equipment, Intermittent Fault Detection & Isolation"*
- JIT Industry Week (04 – 07 Jan 2016), Universal Synaptics IFD technology passed all JIT Intermittent Fault Emulator (IFE) tests in compliance with MIL-PRF 32516
- Universal Synaptics has proven solutions that detect and isolate intermittent faults down to 50ns *TRL 9 technology solutions

Identifying Test Candidates

Analyze Maintenance Data

Identify:
- NFF's
- Poor performers
- Un-repairable
- System architecture
- Feasibility Study

Test Candidate?

No

Other Remediation Option

Test, Repair and Return to Service

Yes

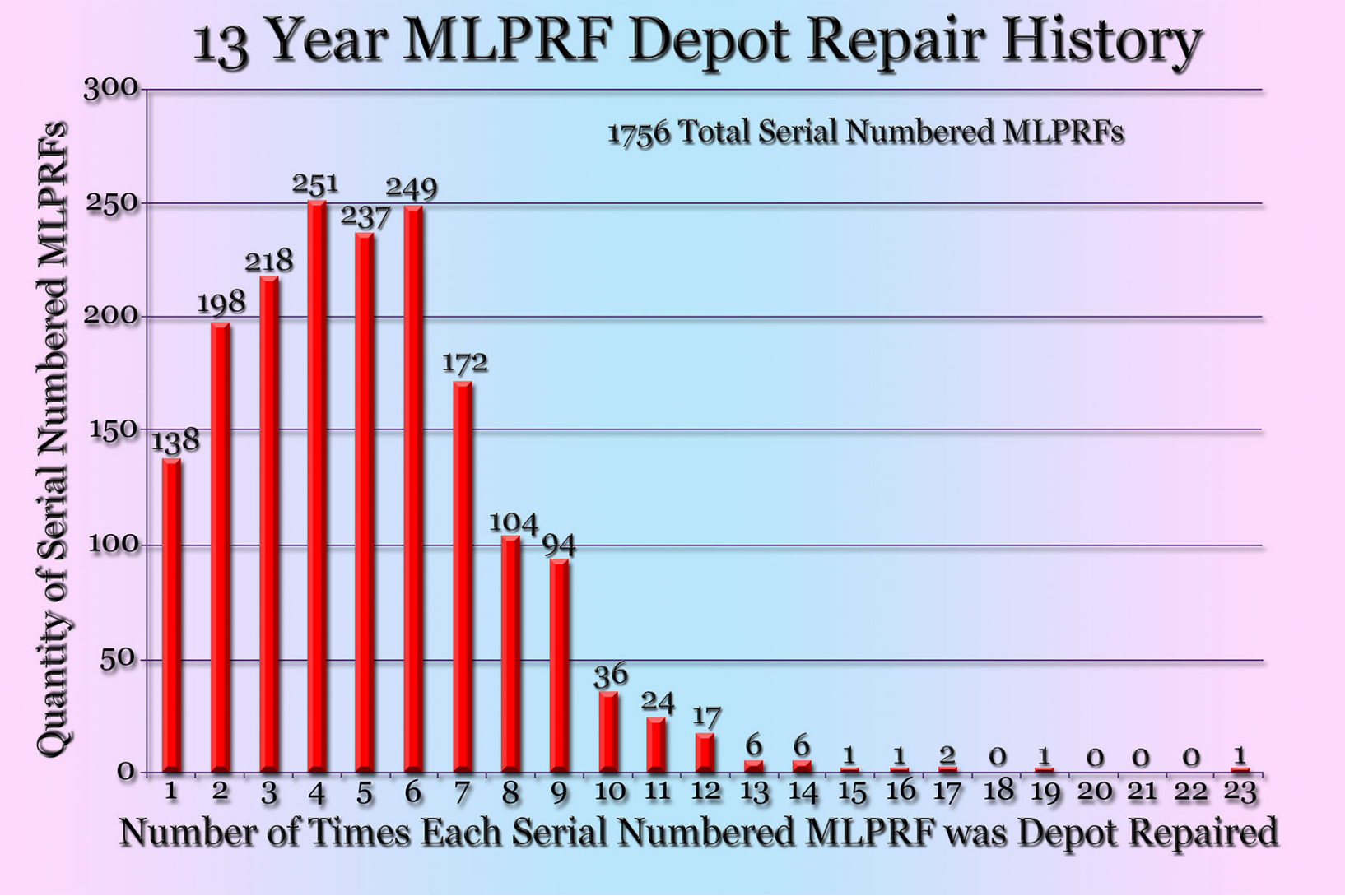
Perform IFD Diagnostics

Repair Chassis or wiring harness

Retest with IFD Technology

Collect Maintenance and Performance Data

MLPRF: 13 Year History



Source: USAF, Reliability and Maintainability Information System (REMIS) & Defense Repair Information Logistics System (DRILS)

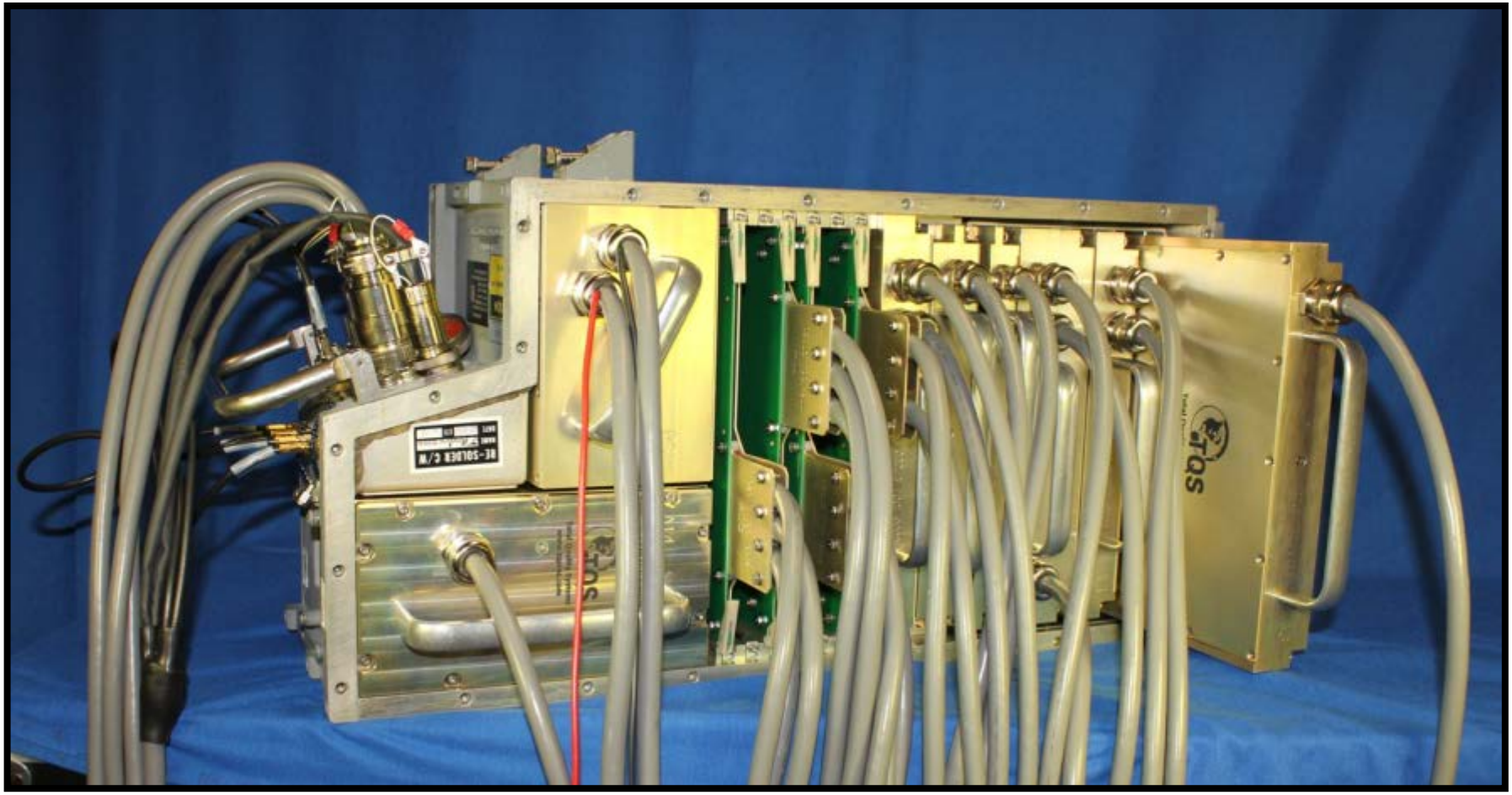
MLPRF: Example Serial # 10435

Date	Depot Level LRU Repairs	Depot Level SRU Repairs
31-Jul-98	No Fault Found	None
22-Mar-00	Reseat Circuit Card Assemblies (CCAs)	None
30-Aug-00	No Fault Found	None
5-Dec-01	Replace Frequency Synthesizer	Replace Guide Pin
	Replace Low Noise Assembly	Replace IF Assembly
5-Apr-02	No Fault Found	None
13-Aug-02	Resolder Ribbon Cable	None
19-Mar-03	Replace Low Noise Assembly	Replace Receiver Protector and FET Amp
7-Oct-05	Replace Low Noise Assembly and Micro-Switch	Replace Receiver Protector and FET Amp
15-Aug-06	Replace Frequency Synthesizer	RTOK
1-Feb-07	Replace Sample Data Assembly	Adjust R57 & R7 (Expected 90 +/-3, Measured 93.46)
11-Apr-07	Reseat Reference Oscillator Assembly	None
27-Aug-09	**IFDIS Tested - 1 Open & 11 Intermittent Circuits**	

Ref Des	Repair Activity	Intermittent Circuits
A14	Low Noise Assembly - Replaced 3 Times	A14-28 to A13-114
A2	Frequency Synthesizer - Replaced 2 Times	A2A2-3 to Ground
A8	Sample Data Card - Replaced 1 Time	A8-97 to A6-57
A3	Reference Oscillator Assembly - Reseated 1 Time	A3-9 to A13-50 & A3-12 to A13-139

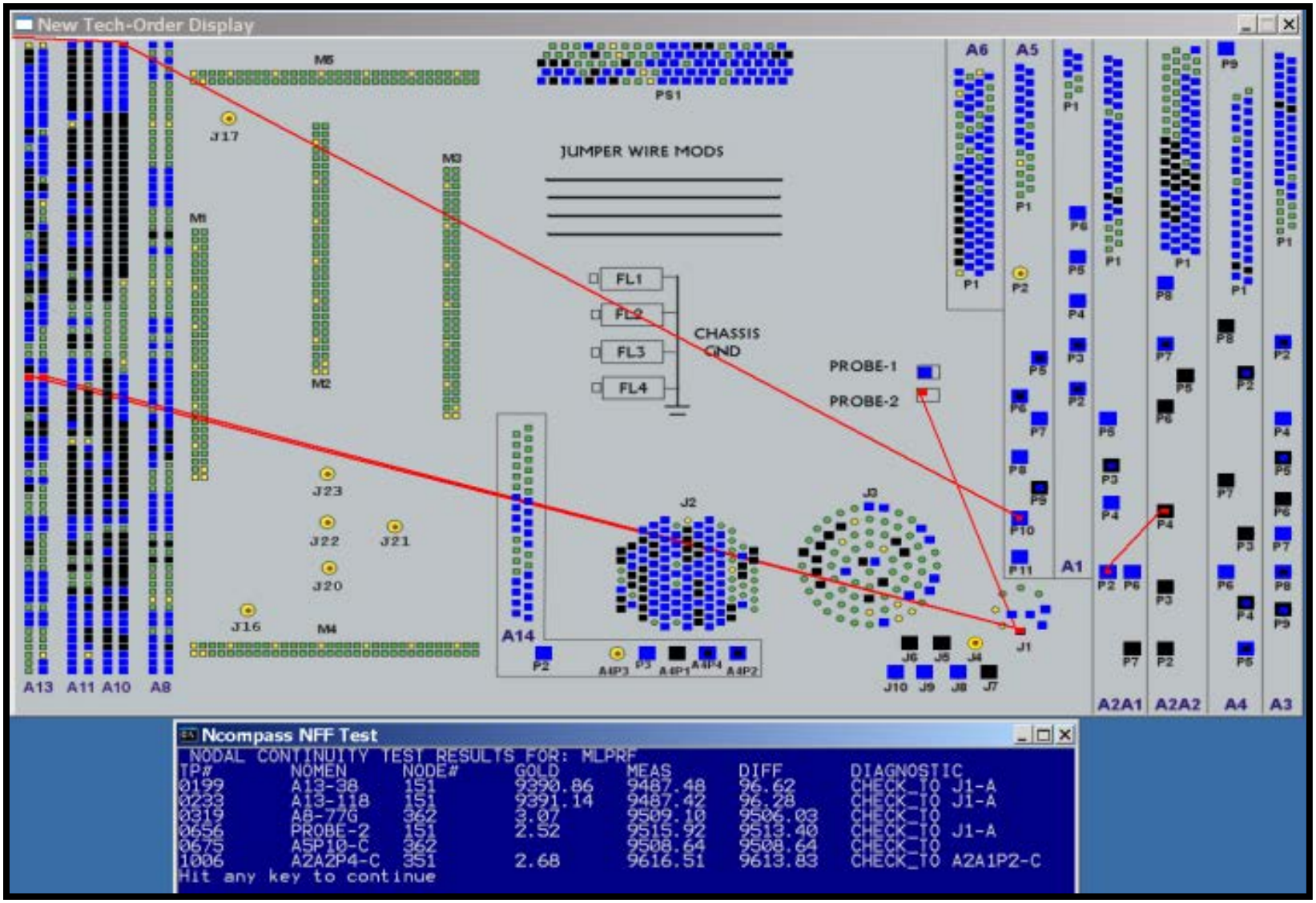
No Fault Found (NFF)
Quasi NFF Repair Activity

F-16 MLPRF: Interface Test Adaptor

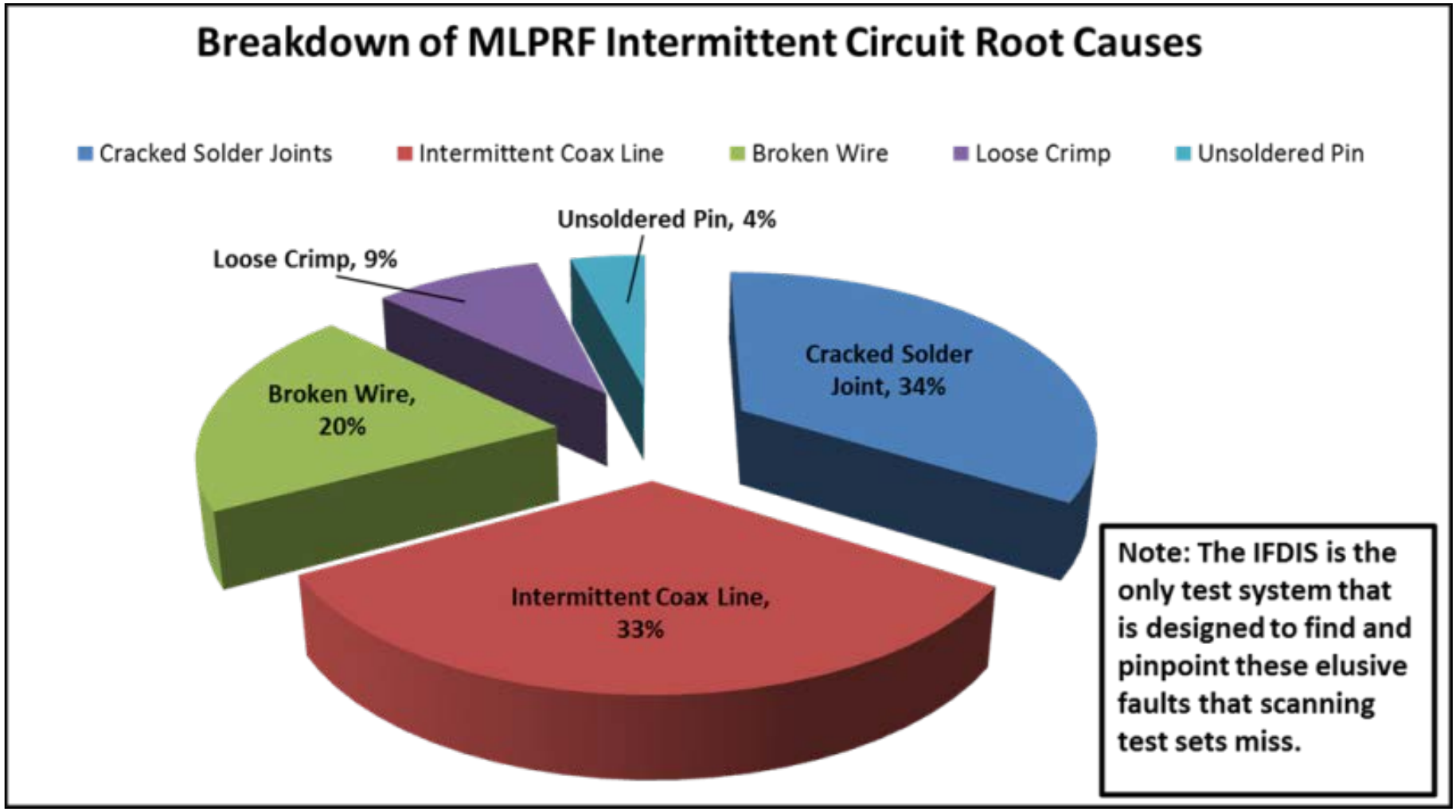


* Image courtesy of TQS

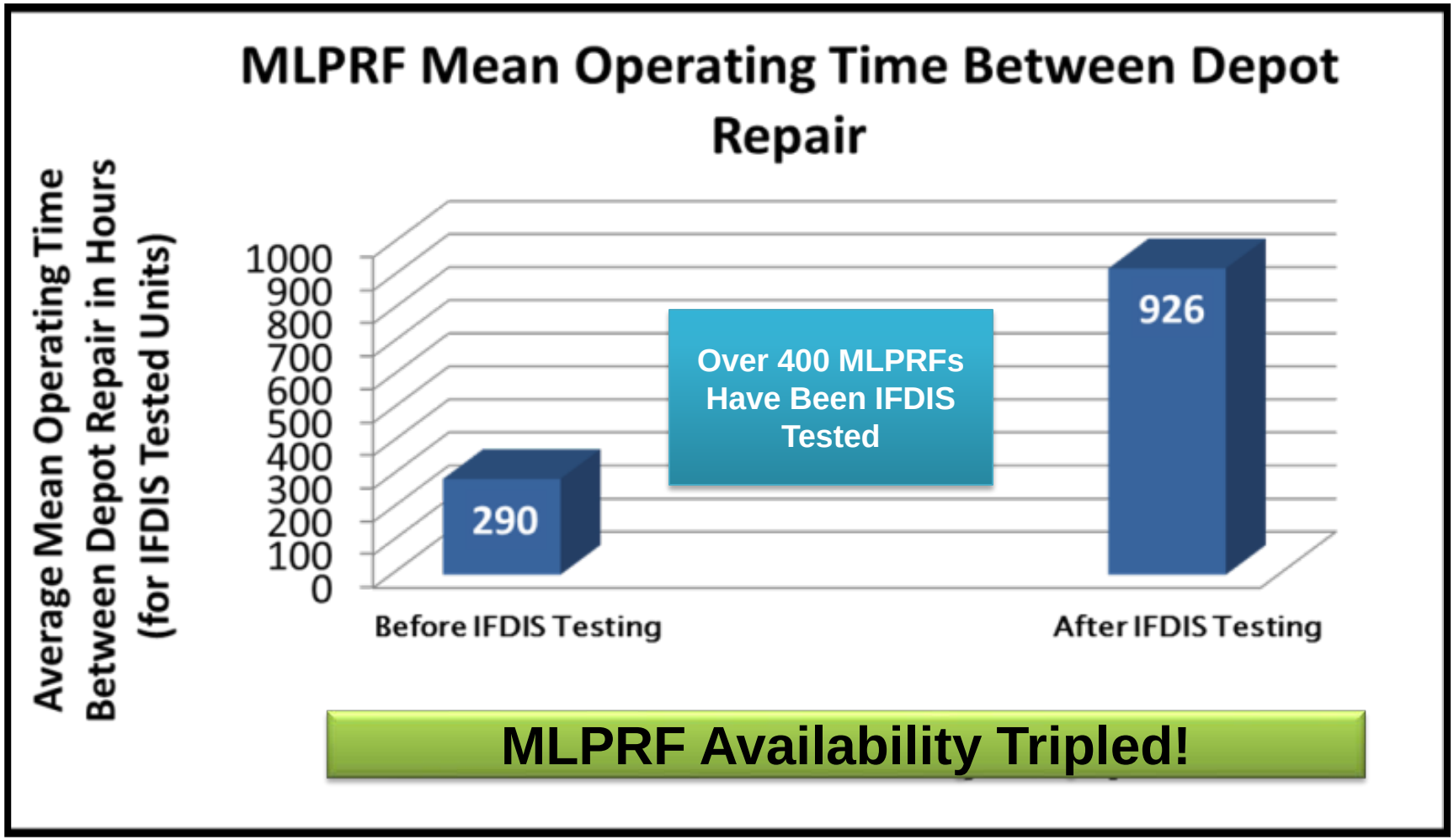
F-16 MLPRF Fault Isolation Graphic



F-16 MLPRF Results



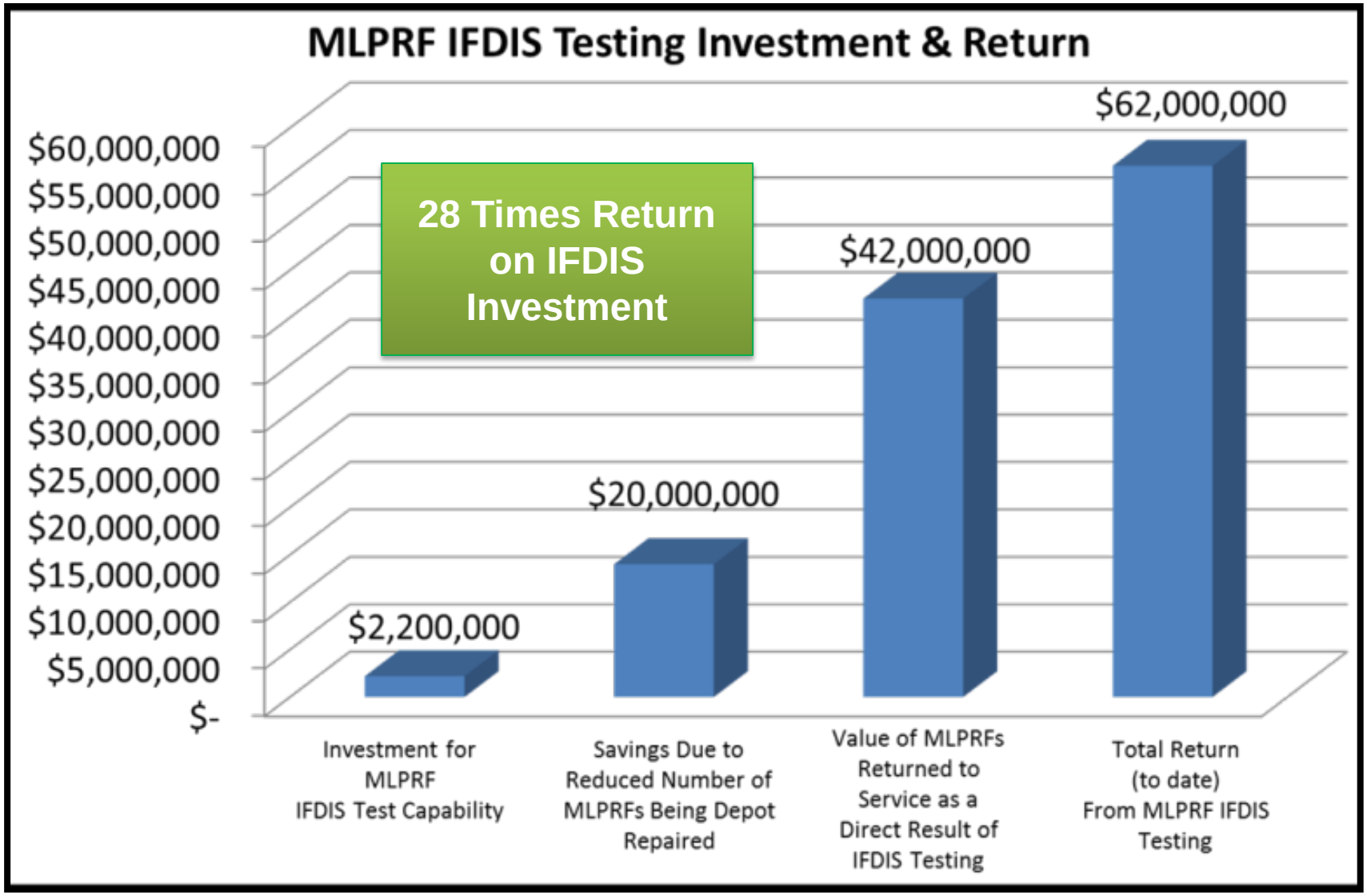
F-16 MLPRF Results



F-16 MLPRF Results

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

F-16 MLPRF Results



F/A-18 GCU: Overview

- NAVAIR F/A-18 Generator Converter Unit (GCU) is a Top Ten Fleet Degrader & number 1 cannibalized WRA at O-Level
- GCU Inductions have outpaced production for the last three years
- GCU inventory continues to increase due to aircraft production yet time on wing continues to decrease causing more GCU inductions each year
- BCM & I-Level AVDLR costs were $161.22M in FY14
- GCU G4 upgrade in process as well as multiple SRA modifications / upgrades
- An innovative solution was needed to improve time on wing, reduce BCM & AVDLR costs, reduce A-799 (NFF) and enable cost effective readiness – the solution now exists

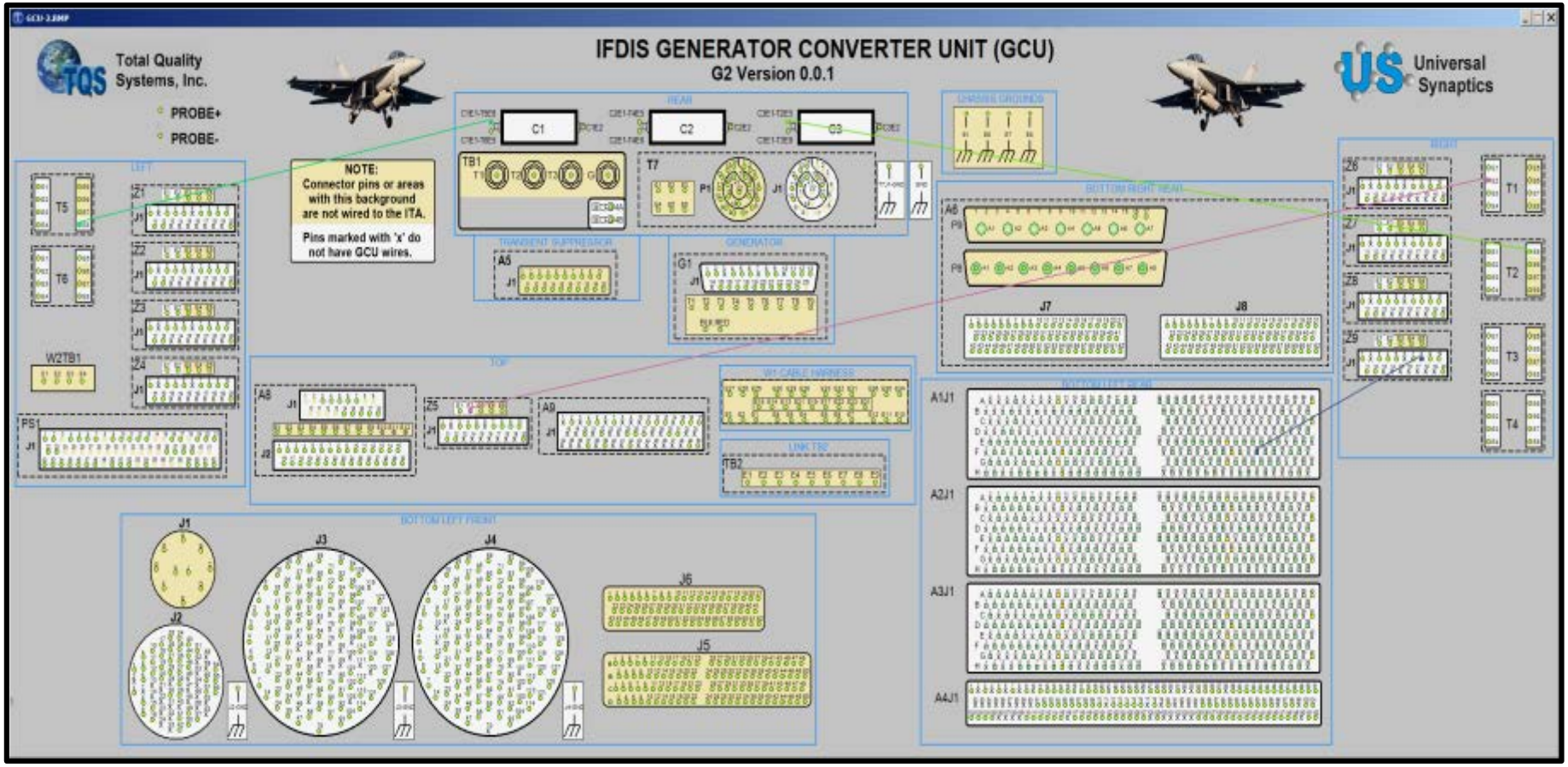
F/A-18 GCU IFDIS Delivered to FRC SW in January 2016

F/A-18 GCU: IFDIS Results

IFDIS testing identified chassis intermittent failures in the F/A-18 GCUs

GCU	IFDIS Testing Results & Causes for Intermittent Failures
1	Broken wire Z7-5
2	Motherboard ground wire damaged which caused massive open circuits
3	*No intermittence detected*
4	*No intermittence detected*
5	Broken wire J5-C3
6	No intermittence detected
7	Broken wire: A8H1-19; Motherboard: Intermittent circuits between J3-127, J5-B4, & J4-28
8	*No intermittence detected*
9	Broken wire: J5-D42
10	Broken wires: Z7-20, J5-All, & A5-A13
11	Broken wire: PS1-39
12	Broken wiresA8J1-19, T7J1-14, & T7J1-20
13	Broken wires: Z2-20, PS1-42, & four open circuits; motherboard: several intermittent and one open circuit, damaged, new motherboard required
14	Recorded 617 open circuits due to missing screws at the circuit board receptacle mounting plate; motherboard damaged, new motherboard required
15	Broken wire: J6-21; bad solder joint J5-D6
16	*No intermittence detected*

F/A-18 GCU: Fault Isolation Graphic



F/A-18 GCU: IFDIS Results

- F/A-18 GCU: IFDIS Results to date:

"Collaboration, innovation and forward thinking were key words used to describe the amazing work taking place across the FRC landscape in support of the Naval Aviation Enterprise Vision.

At FRC West, Sailors teamed with artisans to interdict repairs for Generator Control Units—or GCU—using the Intermittent Fault Detection and Isolation System. This resulted in the GCU time on wing to more than double, providing what was a top ten degrader asset, to be readily available for longer periods of time in support of flight operations."

Rear Adm Zarkowski
Commander FRCs
USN
"Holiday Message to the Fleet December 2016"

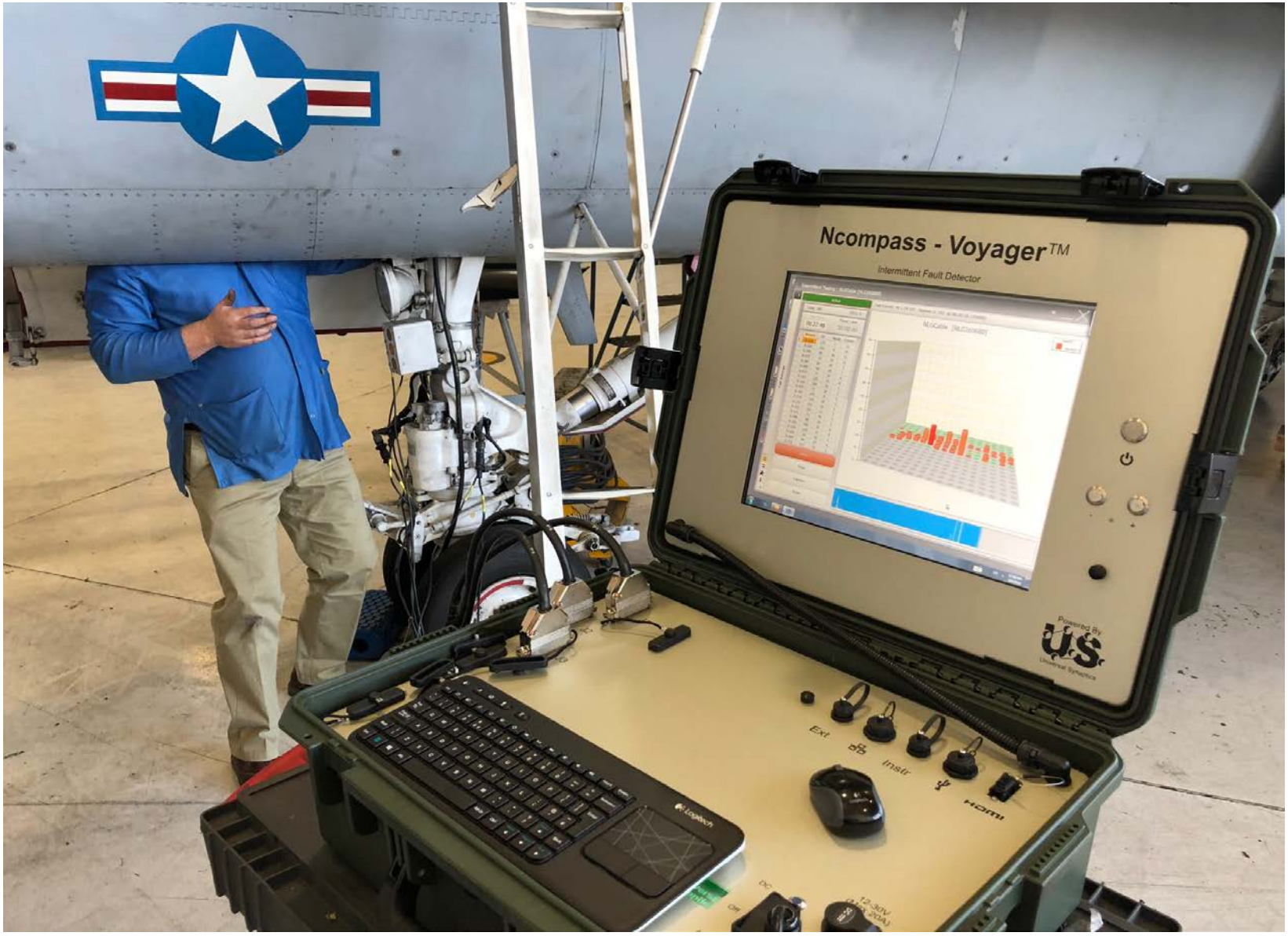
NAVAIR Solution

- PMA-260 procured two additional IFDIS to address the F/A-18 GCU readiness problem
- NAS Oceana and NAS Lemoore (I-Level) locations will utilize these systems
- NSWC Crane procured a 10,240 channel IFDIS and two VIFDs to address the EA-18G AEA Suite
- Navy has issued “F/A-18 GCU A-D Overhaul and Repair LES NI F-18-010-05 REC C” which mandates IFDIS testing of all F/A-18 A-D block aircraft GCUs.
- LP-CRADA with FRCSW utilizing the VIFD to troubleshoot F/A-18 NLG wiring harnesses via an AWTS ID patch cable

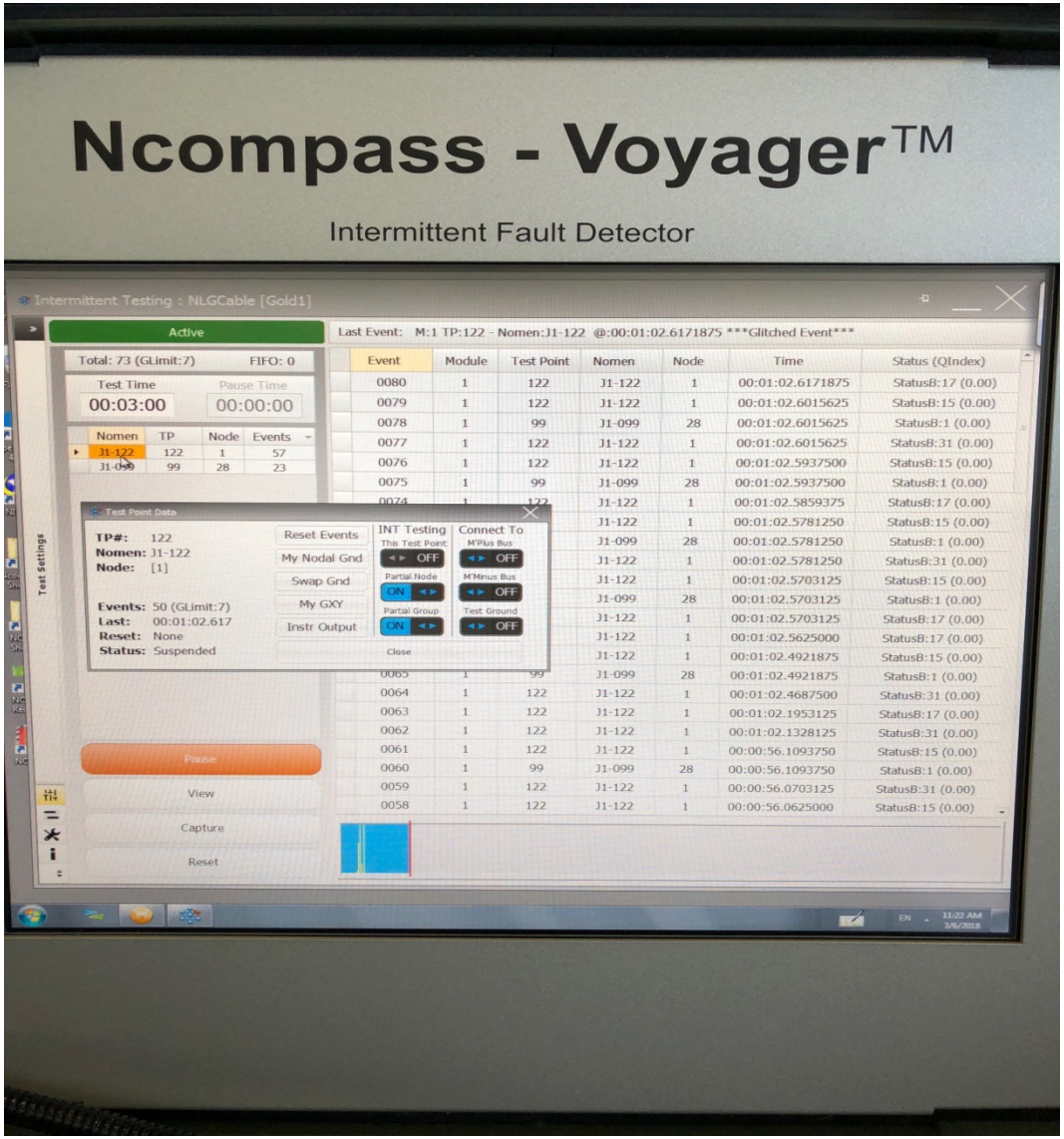
FRCSW LP-CRADA

- Initial results: AWTS NLG ID passes VIFD continuity test, failed VIFD intermittent test
- F/A-18 NLG “Gold” wiring harness passes VIFD continuity test, failed VIFD intermittent test
- F/A-18 NLG in-situ harnesses pass VIFD continuity, failed VIFD intermittent test in both F/A-18s tested
- AWTS GCU Harness ID passes VIFD continuity test, failed VIFD intermittent test

FRCSW LP-CRADA



FRCSW LP-CRADA



IFDIS & Voyager Proven Results

- F-16 Fighting Falcon
- F/A-18 Hornet & Super Hornet
- EA-18G Growler
- EA-6B Prowler
- A-10 Thunderbolt II
- UH-60 Blackhawk Helicopter
- AH-64 Apache Helicopter
- CH-47 Chinook Helicopter
- C-130J Super Hercules
- Eurofighter Typhoon
- Tornado GR4
- M1A1 Abrams / FV 4034 Challenger 2
- Boeing 757, Airbus A320 & MD11

Technology Partners

Technology Recognition

“Create the Future” Contest – “Top 100 Finalist” 2015

Best of State, Applied Science & Technology Category – Winner 2014

DoD Maintenance Symposium, “Great Ideas” Competition – Winner 2010 & 2012, “Top 5 Finalist” 2014

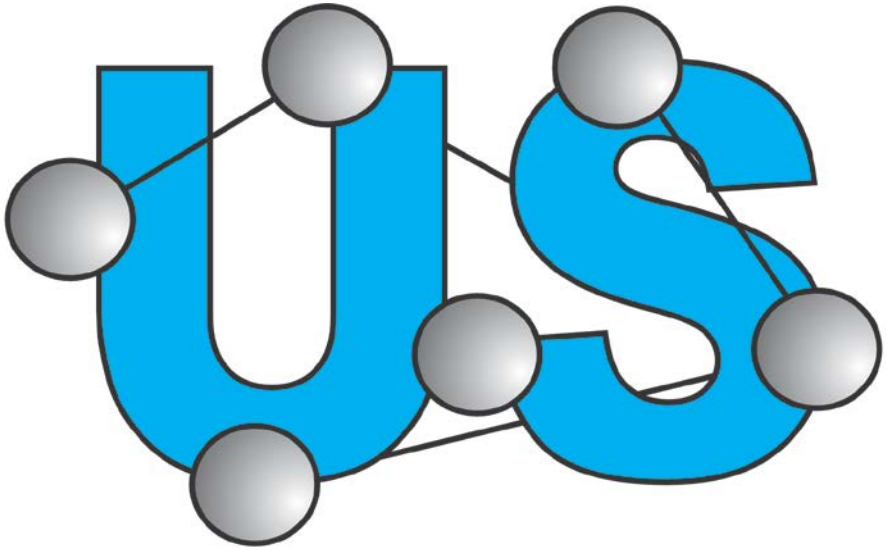
CTMA Symposium, OSD MX Technology Challenge – “Top 5 Finalist” 2012 & 2013

Conclusion

- Undetected intermittent faults are a systemic issue – a testing void exists
- Advanced IFD diagnostic solutions are available to detect and isolate intermittent faults that cause NFF in compliance with US DoD MIL-PRF 32516
- Intermittent fault detection and isolation capability has proven to reduce NFF, reduce life cycle costs, reduce repair cycle times, improve Time on Wing (TOW) and improve operational availability
- IFDIS™ & VIFD™ are proven solutions making a positive impact today and can be utilized on any platform

It's Time to Stop Admiring the Problem

Questions?



Universal Synaptics

Contact: Ken Anderson - 801.731.8508 – Contact@Usynaptics.com – www.USynaptics.com - @USynaptics

Contact: Nate Johnson - 801.731.8508 – Contact@Usynaptics.com – www.USynaptics.com - @USynaptics

DoD Intermittent Fault Definition

JIT Team Definition of "Environmentally Induced Intermittent Fault"

- A discontinuity that occurs in LRU/WRA chassis and backplane conductive paths 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 tin whiskers, metal migration and delamination of materials. These faults can occur individually and/or in rapid succession on any chassis or backplane circuit.

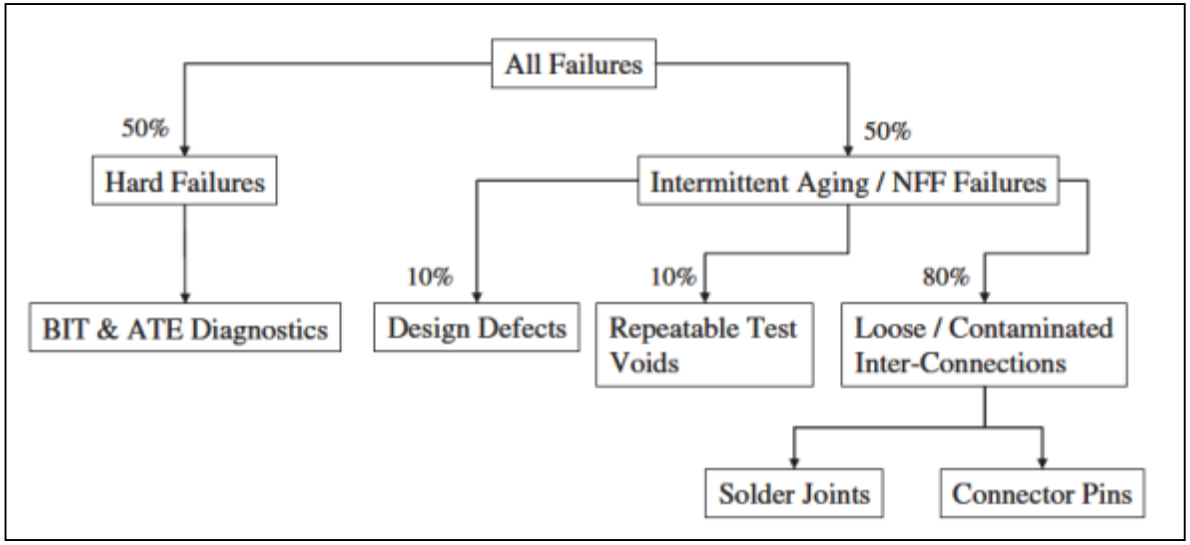


Figure Source: B. Sorensen, "Digital-Averaging-The-Smoking-Gun-Behind-No-Fault-Found", http://www.aviationtoday.com/asw/categories/commercial/Digital-Averaging-The-Smoking-Gun-Behind-No-Fault-Found_2120.html, Air Safety Week, February 24, 2003.

DoD MIL-PRF 32516

MIL-PRF 32516 ***"Electronic Test Equipment, Intermittent Fault Detection & Isolation"***

- Covers the "minimum performance requirements for equipment to detect and isolate nanosecond, microsecond and millisecond conductive path intermittent faults"
- "Intermittent faults can occur in any and all of the hundreds to thousands of LRU / WRA chassis and backplane circuits and their wire harnesses"
- Establishes performance requirements framework for intermittent fault detection test equipment to detect and isolate nanosecond, microsecond and millisecond intermittent faults
- "Not intended to address hard opens, shorts or constant function failures found in routine electronics repair"

Intermittent Faults

- **Hi-Pot testers** rely on the breakdown of the insulation to show if there is a fault. It is well known that this technique stresses the cable under test and in some cases can actually damage the insulation on sites that would otherwise have not caused a problem. Some recognized military forces have banned high voltage insulation testing following the NTSB report into the cause of the loss of TWA Flight 800 in 1996. In addition, Hi-Pot testing can actually mask intermittent faults and can result in a false negative result.
- **Low Energy High Voltage** testers are a better solution for finding some intermittent faults than Hi-Pot testers because they use a low energy pulse. However, depending on the type of intermittent they then need to use higher voltages to expose the fault, which can then lead to the same disadvantages as Hi-Pot testers. On commencing testing it is not possible to know the type of the intermittent being dealt with so it is difficult to determine what voltage level to use. This method also assumes that intermittent faults have an adjacent escape path for the pulse ie the airframe, or another adjacent cable with exposed conducting material; this is not always the case and so detection probabilities are low and scenario driven.

Intermittent Faults

- **Spread-Spectrum Time Domain Reflectometry** (SSTDR) technology is very advanced at detecting cable changes using complex signals, reading reflections and carrying out post analysis. However, the detection rate is limited to approximately 50 millisecond changes, which means that not all intermittent faults below this threshold can be detected. Furthermore, as a stand-alone tool, SSTDR can be applied to just one wire per cable loom at any given time and this 'switching' approach between wires in the loom introduces more opportunities to miss the intermittent fault than it does to find it.
- **Oscilloscopes** can be set up to have a latching trigger and defined trigger parameters to detect and latch a particular condition. Generally they do not have a self-stimulus and so this needs to be provided as a 3rd party aspect of the test when using an oscilloscope in this mode. Importantly, setting up the triggers and releasing the latching trigger in time for capturing subsequent fault(s) is an extremely complex technique and it would only be applicable for a single line-at-a-time. These approaches could be used on I or D-level applications but it would be extremely time consuming to apply to each of the suspect lines during fault investigations.

EA-6B Prowler Results

EA-6B Prowler Intercommunication System (AIC-45) Weapon Replaceable Assembly (WRA)

- High Mission Incapable (MICAP) rate
- High NFF / CND rates
- Conventional test equipment unable to identify intermittent issues or improve reliability
- IFDIS identified and isolated one or more intermittent circuits in **83%** of the AIC-45s tested

CH-47 Chinook Results

CH-47 Chinook Wiring Harnesses

- High NFF rates, costly to support and sustain
- Conventional ONE circuit at a time wire testers unable to identify and isolate intermittent wiring problems, reduce NFF or improve readiness
- Voyager IFD is detecting and isolating intermittent wiring issues that cause NFF and drive high sustainment costs
- 75% reduction in test time achieved with Voyager

Tornado GR4 Results

- Intermittent / NFF Cross-Drive Clutch wiring problems since 2006
- On just one aircraft:
  - 35 maintenance repeats
  - 30+ components replaced
  - 500+ man-hours of investigation
  - Conventional ATE ineffective
- Voyager IFD testing of wiring found:
  - Intermittent faults that went undetected by continuity testers
  - Root cause of the faults located in minutes