Normal Paper ☒

No Fault Found or More Correctly, Fault NOT Found; its Causes, its Cost and its Correction

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Abstract

Entered into the maintenance log as "No Fault Found", its more accurate title is Fault NOT Found. No Fault Found is not a corrective repair but rather a delaying excuse leaving the real fault undiagnosed. All delays cost time, waste money and create availability holes: this paper examines Fault NOT Found, its causes, its costs and its solutions. Recognizing a problem then being able to cost its impact on the profit line are the first steps: nothing focuses the mind more than air weapons unserviceable on the ground or red numbers in the bank balance. Unknown unknowns can be dismissed as "a cost of doing business" but gathering data, analyzing it then targeting the "low hanging fruit" solves the problem. Faults not Found can be prevented using a management focus, appropriate test equipment and repair schemes. Losses can turn into profits and enemy advance into enemy defeated.

Keywords: intermittent fault, product life-cycle, electrical wiring, No Fault Found, avionic, quality assurance, electronic test equipment, reduce maintenance cost.

Why Would a Fault Cause be Mis-Named?

Whenever we travel we want every component on our transportation vehicle to work perfectly: we want to get safely to our destination. If faults occur we want them repaired as soon as the vehicle is available, and so maintenance organisations have been making big improvements in the effectiveness and efficiency of Maintenance, Repair and Overhaul (MRO) [1].

Figure 1. Catastrophic for 189 Souls

Digital technology is revolutionising predictive and prognostic maintenance however, there is one area where significant advances have NOT been made: *not all faults are repaired successfully on the FIRST attempt.* The problem is particularly widespread in avionics, electronics and electrical components, and goes by the misnomer of No Fault Found (NFF): "it was not there when I looked, I don't believe there was a fault, what you saw was a "one-off" and it will not occur again, just reboot the computer.". Concomitant technology to diagnosis and repair these faults is superior to an excuse in the maintenance log. If the name No Fault Found is found wanting then what? Call the fault what it is: Fault NOT Found.

Pilots, drivers and captains are not mischievous and report imaginary faults; a faulty system is stopping them doing their job: maintenance staff can be confident that a real fault occurred. If the fault is no longer there when the vehicle is available for maintenance, then Fault NOT Found is a more descriptive assessment; this name also sets the trust culture in organisations. This paper examines why intermittent faults are the leading cause of the Fault NOT Found (FNF) phenomenon, what assessment has been made of the cost of this phenomenon and at least one major user's strategy for tackling it.

Why call it No Fault Found?

NFF is an unsuccessful repair outcome where the fault symptom has disappeared. How do you repair a fault when you can't find it? Introduce an equivalent operating environment then repeat test the complete system for full integrity. In most cases repair organisations are not structured to duplicate environments so technicians will replace a 'box', the Line Replaceable Unit (LRU) based on the guidance of Hard Fault Isolation Manuals. Meanwhile, the vehicle is dispatched with the newly fitted Line Replaceable Unit…but the same fault comes back…and the process starts again [2].

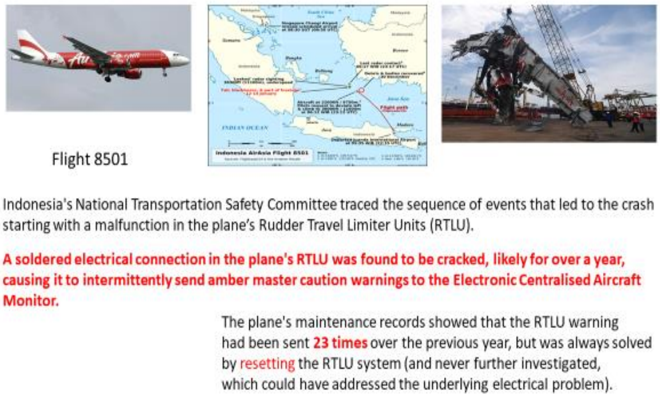


Figure 2. After 23 No Fault Found And Resets, the Aircraft Crashed

The Impact of Rogues

The maintenance impact of rogue Line Replaceable Units is best explained through scenarios.

The suspected Line Replaceable Unit IS the source of an aircraft fault.

A fault is reported and the cause is diagnosed to be inside Line Replaceable Unit 'A': Line Replaceable Unit 'A' is removed and replaced. The fault is cleared and the rejected Line Replaceable Unit 'A' is sent for Depot repair. The likely outcomes are:

a. The actual root cause is detected and a corresponding repair carried out.
b. An unrelated fault is detected, isolated and repaired. When fitted to another vehicle the original system fault will reappear.
c. No fault is detected as the repairer is not exhausting all possible fault causes so no repair is carried out: Fault NOT Found.

Individual Line Replaceable Units that repeatedly circulate round the Fault NOT Found cycle are called "Rogue Line Replaceable Units" [3].

The suspected Line Replaceable Unit IS NOT the source of an aircraft fault.

A fault is reported and the real cause is inside a wiring harness connected to Line Replaceable Unit ‘A’. However, Line Replaceable Unit ‘A’ is incorrectly diagnosed as the culprit and is removed and replaced. The fault reoccurs and at the next diagnosis, Line Replaceable Unit ‘B’ is replaced; this cycle continues until all the Line Replaceable Units in the system have been replaced and in desperation, the wiring [real cause], is investigated. The rejected Line Replaceable Units are sent for repair. The likely outcomes are:

a. An unrelated fault is detected, isolated and repaired. LRUs are returned through the supply chain, ready to be fitted to another aircraft.
b. No fault is detected so no repair is carried out: Fault NOT Found.

Individual vehicle system faults that cause repeated, erroneous Line Replaceable Unit rejections – which then repeatedly circulate round the Fault NOT Found cycle - are called “Rogue Systems” [3].

No Fault Found, the misnomer term, is often used as a catch-all phrase across both scenarios, resulting in wasted maintenance and effort and productivity loss. Repair and maintenance data can be analysed to distinguish between which Rogue Line Replaceable Units and Rogue Systems which are causing the biggest impact on Operational Reliability and on cost. Several years ago the United States of America Department of Defence (USDoD) conducted an analysis, and costed repeated repairs to Line Replaceable Units that didn’t have anything wrong with them (NFF) and concluded that these problems were a major driver of poor weapon system readiness and was costing them over US$2B in repair rework. *Every year* [4].

In a 2015 study, the cost of NFF to the mobile phone industry was estimated at US$10 billion, and for US civil aviation, the US Air Transportation Association estimates the NFF waste at US$2.2 billion per year; there is no reason to believe these figures have declined [4].

Intermittent Faults: the leading cause

The USDoD isolated the main reason for the NFF cost impact as *intermittent* faults caused by degradation in connectors, cables, circuit breakers and Line Replaceable Units because they are vulnerable to ageing especially in an adverse operating environment: vibration, temperature cycling, maintenance disturbance, ingress of dirt or fluids and hostile operations. When this happens the inter-connection integrity breaks down and the system begins to exhibit intermittent fault symptoms. Inducted into maintenance, technicians cannot reproduce the fault because the fault’s environment has changed and existing test equipment and procedures are designed to detect hard faults, not intermittent faults [5].

These faults begin as equivalent “noise” and systems are designed to ignore it but as the connection or wire fault deteriorates, the amplitude of the noise increases until it replicates an unwanted system signal at which point the system detects a fatal error and stops working [6].

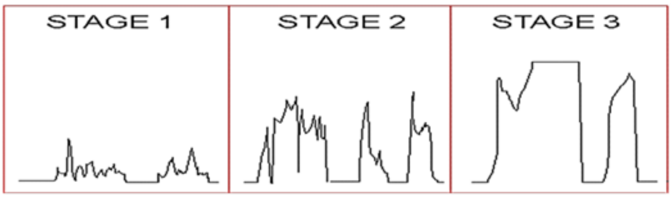


Figure 3. Growing an Intermittent Fault

The Difficulties in Detecting Intermittent Faults

Sample rates and digital averaging techniques have been used to improve numerical accuracy in circuit parameters eg Resistance, but in so doing, ignore "glitches". The combination of measuring at a single point-in-time, sampling rates and digital averaging result in intermittent faults being missed; it's the testing equivalent of trying to photograph lightning with a single shot camera: which part of the sky will it happen in and when do you press the shutter? To maximise the chance of capturing the lightening you would need to look at all of the sky all of the time. Similarly, to capture an intermittent fault requires monitoring all of the test points all of the time: the test equipment needed must be optimised to detecting changes on every test point simultaneously and continuously.

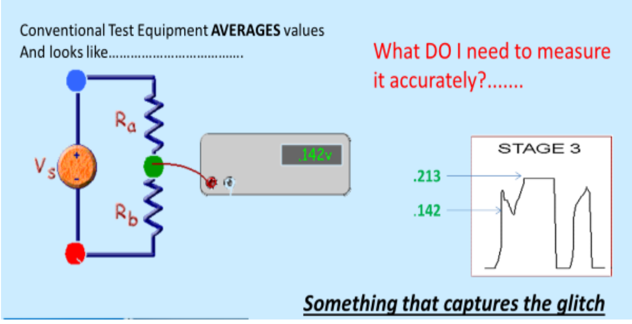


Figure 4. Averaging misses Critical Glitches

The USDoD recognised the relationship between Fault NOT Found, intermittent faults, the environmental factors and the intermittent fault detection shortcomings of conventional test equipment and concluded that test equipment which detects and locates intermittent faults would be the main weapon to tackle the problem. In 2012 the Joint Intermittence Testing Working Integrated Project Team (JITWIPT) was established to drive the initiative hosted by the US National Center for Manufacturing Sciences [7].

The JITWIPT introduced a test equipment performance specification for intermittence testers (MIL-PRF-32516) in 2015 and assessed a range of test equipment against that specification. The only test technology to meet the requirement – including detection of sub-100 nanosecond intermittent faults simultaneously across multiple test points - was the Intermittent Fault Detection (IFD) test equipment from Universal Synaptics Corporation (USC) [8].

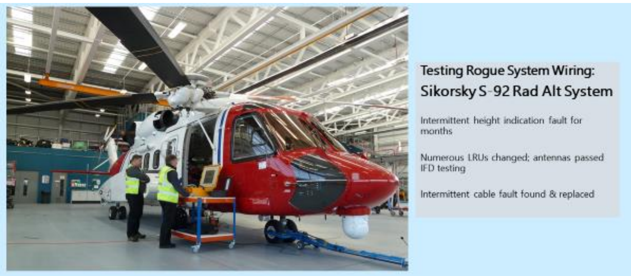
USC's IFD rack-mounted tester product (the IFD and Isolation System, or IFDIS™) can test for Intermittency, Shorts and Continuity faults on thousands of test points simultaneously, and is now used for Line Replaceable Unit testing on the US F-16 and F/A-18 fleets. Knowing that the wiring and interconnection components are also major factors in the Fault NOT Found problem, USC, and their Scottish-based partner Copernicus Technology Ltd, jointly developed a portable IFD tester for testing wiring and interconnection components both on and off the aircraft: the Voyager Intermittent Fault Detector (VIFD™). Both test systems have integral Spread-Spectrum Time Domain Reflectometry and Inductance, Capacitance and Resistance measuring functions.

Focused test equipment can reduce downtime and maintenance costs by tackling the No Fault Found and Fault NOT Found problems. Rogue Line Replaceable Units can be tested, repaired and qualified as fit for service. This process restores confidence that the system will remain serviceable and respective Mean Time Between Unscheduled Removals increased significantly. Rogue System wiring and interconnects can be tested to reduce the time taken to troubleshoot intermittent faults on aircraft and to prevent serviceable Line Replaceable Units from being incorrectly sent for repair. As well, scheduled IFD testing can be used for Prognostic & Health Management which "finger-prints" a harness whilst subsequent retesting detects deterioration for rectification before it precipitates a fault: "catching the thief before the crime is committed". Integrity faults can be dealt with or monitored as appropriate and the resulting data used to inform maintenance optimisation and life-extension. With all these reliability enhancement functions, then there must be successful case studies! [9]

Case Studies

Specific testing of Line Replaceable Unit back planes and printed circuit boards has tripled and quadrupled the meantime between failure for many USDoD avionic components. With the IFDIS ™ being qualified to Classification One testing status against MIL-SPEC-32516, this test equipment is now a key component of the USAF F-16 radar Line Replaceable Unit repair chain and subsequently has quadrupled the USN F/A-18 Classic Hornet Generator Control Unit time-on-wing. These programs began by focusing on testing Rogue Line Replaceable Units identified from maintenance data. The Rogues had undergone Automatic Test Equipment (ATE) testing on multiple repair visits for functionality but not for intermittent operation. Eventually they had been returned for repair so often they were quarantined as 'unrepairable'. IFDIS™ testing isolated intermittent faults in virtually all the Rogues: 70% of them were reclassified as repairable and were subsequently returned to use. The savings have been reinvested to duplicate the test capability across more weapon systems and to drive down the cost-of-operations.

The VIFD™ has been successfully used on a multitude of aircraft types - from the Sikorsky S-92 helicopter to Eurofighter – as well as on trains and armoured vehicles. An early customer of VIFD™ testing was the RAF's Chinook helicopter fleet where system wiring and interconnects for a critical flight safety investigation revealed the presence of intermittent circuit breakers and switches along with EMC vulnerability. Furthermore, analysis of the Chinook fleet's MRO data had identified other systems which were impacting on fleet mission success rates. These systems were tested, faults pin-pointed and repaired. Several other aircraft types with Rogue Systems and multiple Line Replaceable Unit replacements were then targeted and VIFD™ testing of system wiring revealed system wiring integrity issues, with multiple test points affected by excessively high resistances and/or intermittence. The VIFD™ test duration per aircraft was documented as being only 25% of the time needed for the standard test of the entire system's wiring (over 400 test points) for continuity alone, whilst repair of the VIFD™-detected faults resulted in an overall fault rate reduction of 40%.



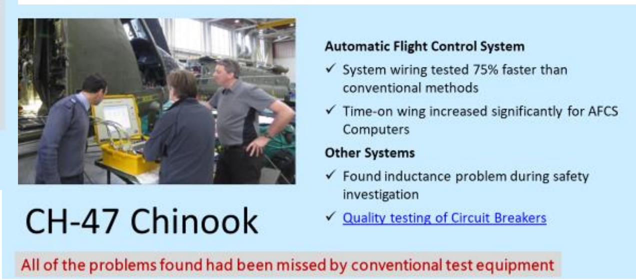


Figure 5. S-92 & CH-47 Application

As with all of these examples, in every case, the faults detected using VIFD™ had been missed when using standard test methods.

The Future…

Intermittence has become a recognised failure mode in the USDoD and IFD testing is becoming an integral part of their Avionics and aircraft maintenance capabilities. The JITWIPT's IFD testing strategy aims to make large Readiness Improvements and Maintenance cost savings across multiple fleets that will be impossible to ignore. It remains to be seen how quickly the global aviation, defence and transport sectors will follow the USDoD's example in adopting test solutions to tackle intermittent faults?

Conclusions

Entered in the maintenance log as No Fault Found, its rightful title is Fault NOT Found: to call it otherwise is deception. No Fault Found is not a corrective repair but rather a delaying tactic until the underlying fault reappears. All delays incur expenditure waste and create availability holes: gaps on the mission or schedule report. Recognition of a problem and being able to cost its impact on the profit line is the first step. Nothing focuses the mind as much as air weapons on the ground or red numbers in the bank balance. Unknown unknowns can be quantified by gathering data, analysing that data then targeting the "low hanging fruit".

Fault NOT Founds can be prevented using a proven management focus and then the appropriate test equipment and repair schemes. Losses can turn into profits and enemy infiltration into enemy defeated.

References

1. Hockley, C.J. etal (2016) No-Fault-Found A Best Practice Guide, ISBN 978-0-9955405.
2. Cockram, J. Huby, G. No fault found (NFF) Occurrences and Intermittent Faults Improving Availability of Aerospace Platforms CEAS 2009 Conference proceedings.
3. Huby, G. No Fault Found: aerospace survey results. Copernicus Technology Ltd 2012.
4. Ungar, L (2015) Causes and Costs of No Fault Found Events, Advanced Test Engineering Solutions, Inc. El Segundo, CA.
5. Aerospace/Defence/Security No Fault Found Working Group Best Practice Guide, Cranfield Press, 2016.
6. Khan S Phillip P Jennions I Hockley C No fault found events in maintenance engineering part 1 current trends implications and organizational practices reliability engineering and system safety 123 (2014) pp183-195.
7. USDoD CBM+ Joint Intermittence Working Integrated Product Team, 25 February 2012.
8. MIL-PRF-32516, 23 March 2015, Performance Specification Electronic Test Equipment, Intermittent Fault Detection and Isolation for Chassis and Backplane Conductive Paths.
9. An Introduction to Prognostic Fingerprint Technology©, AIAC16, Cockram, J. Baker J.W.C., 10 October 2014