No Fault Found

A Platform Integrator’s View of the Problem

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Reliability department since 1993, working on programmes and projects such as Typhoon, Tornado, Hawk and future air systems.

Now the Reliability specialist on the Military & Technical Services group in Research & Technology (since 2000).

Before joining the company, served in the Royal Air Force for 25 years, working on Lightning, Jaguar and Harrier aircraft.

No Fault Found was an everyday occurrence during those 25 years.
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Definition (1)

- The maintenance problem known as ‘No Fault Found’ (NFF) is a widespread phenomenon in many sectors including Aerospace.

- Not defined in any of the standard reliability handbooks.

- ARINC 672 (Guidelines for the reduction of NFF) merely states: “Removals of equipment from service for reasons that cannot be verified by the maintenance process.”

- However, many faults classified as NFF do not result in equipment removal from the aircraft – many varied factors can cause this (e.g. operator policy, operational expediency etc.).
Definition (2)

• Different organisations (and different areas of those organisations) may have different ways of expressing this phenomenon*:

  • Fault Not Found (FNF)
  • Re-Test OK (RTOK)
  • Can Not Duplicate (CND)
  • And as many as 15 other descriptions

• Intention today is not to exhaustively cover all aspects of NFF, but to give an idea of the problem, some less well-known causes and some personal experience

* 'No Fault Found, Re-Test OK, Cannot Duplicate or Fault Not Found – Towards a standardised taxonomy' - S. Khan, P. Phillips, C. Hockley, I. Jennions.
Potential Extent & Cost of the Problem (1)

- In Aerospace products, NFF is not uncommon. Some systems and equipment have relatively low levels of occurrence, but others, principally avionic systems, may have as much as an 80% rate i.e. 8 out of every 10 reported faults are classified as NFF.

- Without going into the exact cost of any given system or equipment, let us take a theoretical scenario: An avionic equipment, fitted to a fleet of aircraft fails every 300 hours. The NFF rate is 50%. The fleet flies 30,000 hours per year and the cost to return one equipment through the supply chain for repair is £10,000.
  - Fault rate is therefore 30000/300 = 100 returns per year.
  - NFF occurrence is 50% of 100 = 50.
  - 50 returns classified NFF cost 50 x £10,000 = £500,000 per year.
Potential Extent & Cost of the Problem (2)

- That is for just one complex equipment – a fast jet combat aircraft has many items of equipment, a high number of which may be causing significant annual expenditure on NFF. The example above is a mid-range example, meaning that other systems or equipment may have higher (or, indeed, lower) occurrence rates and higher or lower repair costs.

- This does not include the cost of ‘at aircraft’ diagnosis and recovery.

- When added together, the NFF burden for a fleet becomes £millions per annum.
Effects on Customer

- Customers fall broadly into two categories: those that maintain their own fleet of aircraft without assistance and those who sub-contract their fleet maintenance wholly or partly to a maintenance contractor.

- NFF will cause a maintenance burden on both these: the former for the customer and the latter for the maintenance contractor.

- The effects are:
  - An increase in the fault arising rate (NFF is generally regarded as a fault for statistical purposes).
  - An increase in maintenance burden due to repeated investigation and equipment exchange.
  - An increase in supply chain costs due to potentially serviceable equipment being returned for repair.
  - A reduction in Availability of the fleet (dependent on Reliability [arising rate], Maintainability and logistics factors [supply chain]).
  - Increase in any costs associated with the above.
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Effects on Integrator

- Integrators also fall broadly into two categories: those that only make and provide a product (fleet of aircraft) and those who provide a maintenance service in addition to product manufacture and supply. Note that maintenance providers that do not manufacture a product would not be considered integrators.

- NFF will cause a burden on both these: the former for the design and manufacturing areas and the latter for the maintenance operation in addition to design and manufacturing. The burden on the maintenance operation is as stated on the previous slide.

- The effects on design and manufacturing are:
  - Investigation of underlying cause of NFF (including equipment supplier involvement)
  - Design change as necessary
  - Burden of proof that NFF cause mechanism / process has been eliminated
  - Cost associated with all the above for every NFF event investigated
Perceived Causes

- The REMM* project, some 10 years ago provided a comprehensive breakdown of potential reasons for NFF events:
  - Operator Policies (e.g. short turn round times, availability of spares, aircrew mission priorities)
  - Failure recording / reporting (e.g. quality of aircrew debrief, poor data coding)
  - Maintenance practice (e.g. training of maintainers, technical publications accuracy)
  - Repeat removals (e.g. little use of maintenance history, ‘rogue’ LRI’s)
  - Workshop effectiveness (e.g. pressure to produce throughput, staff training)
  - Test coverage (e.g. test philosophy across maintenance levels, comprehensiveness of test)
  - Interpretation of results (e.g. fault code interpretation, training of workshop staff)
  - Intermittent system connection (e.g. connector integrity, harness / loom integrity)
  - Product contains intermittent fault (e.g. solder joints, PCB weakness)
  - System design (e.g. BITE coverage, software tolerances)
Environmental Factors (1)

- Temperature – a known ‘avionics killer’. However, it is highly likely that the equipment will perform normally on ground test and display no indication that temperature was the cause of the recorded fault.

- Vibration – the second of the ‘big three’. Amongst a general tendency to cause deterioration in many areas of the platform, is likely to cause poor solder joints to deteriorate and subsequently show no (or intermittent) signs of failure, until the vibration eventually causes complete failure and the fault can be detected.
Environmental Factors (2)

- Humidity – again, a known problem. In theory, conditioning systems should keep this problem from occurring. However, incidents have been recorded where faults due to humidity effects have occurred in flight. Once the aircraft is on the ground, any evidence of moisture will tend to have evaporated and therefore give no clue as to the cause of any fault reported by aircrew. Moisture precipitates corrosion!
Intermittence (1)

- High proportion is in the Electrical Wiring Interconnect System (EWIS) which includes the connectors as well as the wiring.

- Some potential causes, all not necessarily manifesting permanently, but under flight ‘G’ forces or other maneuvering:
  - Open / Short circuit
  - Chafing / Insulation damage
  - Excessive bending
  - Arcing
  - Corrosion
Intermittence (2)

• Example incidents:

  • Lightning XM135 (1966) – Invertor cut out on take-off. Traced to a redundant ground test wire, which was shorted by the radio mounting tray as it moved on its AV mountings under acceleration. Detection took several weeks and a famous incident!

  • Jaguar Undercarriage ‘Red’ (1980) – A persistent fault that re-occurred over a period of weeks. Eventually carried out full wiring checks and found an internally corroded bulkhead connector. The corrosion occurred due to moisture ingress through a missing core blanking plug.

  • Jaguar Engine Temperature ‘overswing’ (approx 1983) – another persistent fault that occurred over a period of months. I have only recently discovered that this was only resolved when the aircraft went away for major servicing – but I still do not know what the fault was!
Less well-known Factors (1)

• Lead Free Solder
  • The most likely cause of NFF from lead-free solder is tin whisker short circuits. Tin whisker growth is much more likely in unleaded solder than in leaded. Tin whiskers can demonstrate high growth rates and if they short to another track on a PCB can cause a fault. The whisker melts due to the short and therefore the evidence of the cause is removed. If the equipment can be re-set, the result of any investigation is likely to be NFF

• Protection of equipment stored during maintenance
  • During recovery testing post maintenance, it is usual to have a significantly high number of faults, including NFF, which may even continue as the aircraft returns to flying status
  • Maintenance facilities vary from operator to operator. Some are a controlled environment, others are not. When undergoing maintenance, much equipment is removed from the aircraft and stored nearby, to be re-fitted on completion of the maintenance
  • Fuel and hydraulic mist from testing and ambient atmospheric conditions (in an uncontrolled environment) can contaminate stored equipment, if no protection has been provided
  • Possible electro-static damage during handling
Less well-known Factors (2)

- Atmospheric Neutron Radiation

  - A known phenomenon for nearly a century. In the days of valve electronics, this did not pose much of a problem. However, the current trend for electronics to be increasingly miniaturised and to operate at much lower voltages than previously, has exposed avionics to potential failures due to this naturally occurring radiation.

  - The following list provides to lower level detail the kind of effects ANR has on devices. At the operational level on air platforms, the result may be either a ‘hard’ failure that requires an equipment change to rectify the failure, or a transient failure that may not be repeatable during ground testing (i.e. a NFF).

Currently these modes are defined:

- SEU - Single Event Upset or “soft error” - caused by charge deposition turning a logic 1 into a logic 0 or vice versa
- MBU - Multiple Bit Upset (not all in the same Word)
- SMU - Single Multiple Upset (all in the same Word)
- SET - Single Effect Transients - spurious signals
- SHE - Single Hard Error (permanent damaged bit)
- SEGR - Single Event Gate Rupture (destroys gate insulation)
- SEL - Single Event Latch Up (freezes state until power cycled, may lead to SEB)
- SEFI - Single Event Functional Interrupt (an upset in a complex device e.g. processor leading to "lockup" or "crash")
- SEB - Single Event Burn Out (triggered by an individual radiation particle - usually preceded by latch up)

New modes are being discovered!
Summary

- NFF is not a new problem – long before I joined the RAF in 1965, NFF was a known area of concern

- Annual costs to both customer and integrator are in the millions of pounds

- There are multiple causes of NFF:
  - Some are not very obvious
  - Organisational and environmental as well as procedural and technical

- Solutions reside not only in maintenance, but also in design, manufacturing, testing, organisational imperatives, operator priorities etc.
Questions?

Thank you for your attention
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