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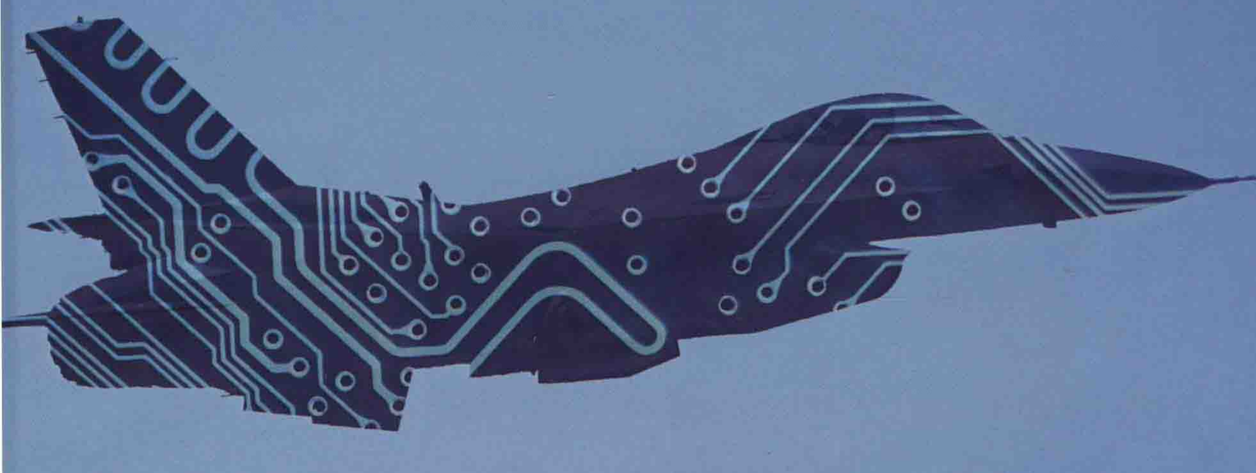
No Fault Found: The Search for the Root Cause



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Acknowledgments

The authors wish to acknowledge the support and opportunity provided by the EPSRC Centre for Innovative Manufacturing in Through-Life Engineering Services in the preparation of this book. The Centre was set up by the EPSRC in June 2011 as a partnership between Cranfield and Durham Universities with 5 main projects, research into NFF being one of those. Initial research established that there was very little knowledge and information available in the public domain about NFF. What information that did exist seemed to be in specialist publications or only readily available to limited groups or industries. An early aspiration of the project therefore was to redress this deficiency with a book that would provide a foundation in the subject for engineers and managers alike. The research and knowledge gained during the NFF project within the Centre has provided both the material, and certainly the inspiration, for this book.

We are most grateful to the Centre Director, Professor Raj Roy for his encouragement and to the SAE for the opportunity. In particular we would like to thank Monica Nogueira at SAE who has helped us achieve our aspirations. We trust that you the reader will find this a useful book in your efforts to understand and hopefully reduce the occurrence of NFF in your area of responsibility.

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Chapter 1
Introduction

1.1 Background

In today's society we are all strongly dependent on the correct functioning of technical systems, and this dependence has made us vulnerable to their failure. Any disruption, due to degradation or anomalous behavior, is of major concern, not only to us (the user) but also to the manufacturers, suppliers, operators, and maintainers of the equipment. It can have adverse effects on safety, operation, and brand name, and it can directly reduce the profitability of all elements of the value chain.

Such disruption can come in various forms. Slow degradation, giving enough time to source and fit a new part, is a relatively minor inconvenience. A part that breaks (rapid degradation) is somewhat more annoying, as the ability of the equipment to perform its function is lost until the part is replaced. It is, nonetheless, tolerated, as the link between cause and effect can be understood and easily remedied. Neither of these is as troublesome as anomalous behavior, in which systems or subsystems do not act in accordance with design intent. In this category, one can include emergent behaviors in which, principally due to the complexity of subsystem interaction, a system can demonstrate a response with action that was unintended. Another area in the same category is that of faults where the root-cause diagnosis cannot be identified. In such cases, a suspect component is replaced only for it to be found that the fault has not gone away, and when the component is tested on a bench, it is found to be working normally. This area has been given the name No Fault Found (NFF) and is the subject of this book. When NFF occurs, other components are replaced until functionality returns, without a clear idea as to why. Due to our inability to diagnose such problems, the cost incurred, until recently, has become part of "the cost of doing business." However, with all companies now operating much more efficiently than one or two decades ago, this (large) overhead can no longer be tolerated, and the constituents of the problem have to be examined.

Figure 1.1 shows a generic operating environment that can be found across many different sectors (e.g., aerospace, rail, and energy), which operate expensive, complex equipment. The original equipment manufacturer (OEM) supplies an asset to an operator who is going to use it as part of a business to make a profit. The operator needs the equipment to be regularly maintained, and the maintainer will have access to the OEM's supply chain for spare parts. This is all done with a respect for standards, and certification in some industries. Altogether, this picture is much more complicated in real life, but it serves the purpose here of exposing all of the areas where NFF could have an effect, and that therefore have to be explored to reduce the (significant) cost of this effect. All of the areas shown are covered, to some degree, in this book.

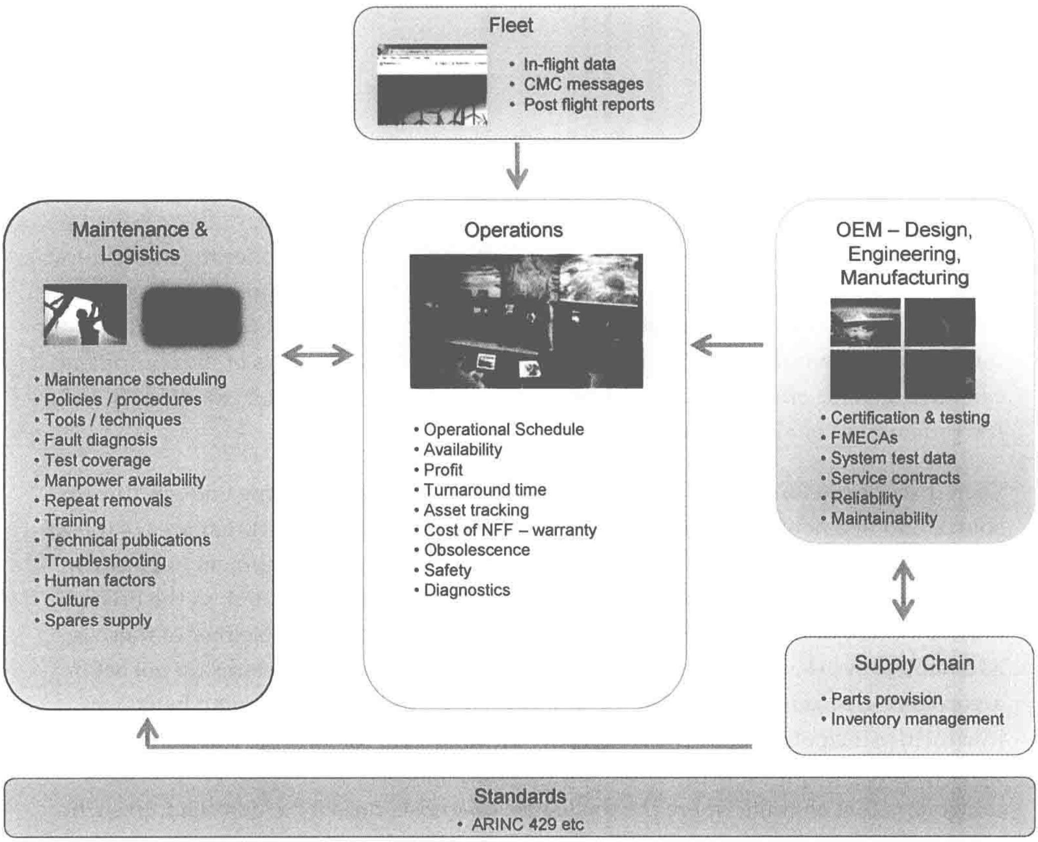

Figure 1.1 General operating environment.

Two aligned fields that deserve mention at this point, as they add complexity and richness to Figure 1.1, are Product Service Systems (PSS) and Integrated Vehicle Health Management (IVHM). PSS [1-1], or servitization [1-2], arose from some OEMs transforming their business model from selling a product to selling a service. In the product scenario, income is derived from the original sale, and future income is dependent on the sale of spare parts. In the service scenario, a maintenance contract is sold at the same time as the asset, and hence a steady monthly income is derived in return for effective maintenance; the OEM has become the maintainer, captured more of the value chain, and assumed more of the NFF "cost of doing business." IVHM [1-3] arose to better inform the OEMs of the behavior of their assets in service. It provides data from sensors on the asset and processes it, via diagnostic or prognostic algorithms, into actionable information. With the aim of improved fault isolation, IVHM provides the vital signal as to the component degradation that Operations and Maintenance need to begin their respective jobs.

1.1.1 Maintenance and NFF–Historical Perspective

To understand the role that NFF plays in today's maintenance practices, it is helpful to examine some of the historical developments over the years. Although a complete chronology of the use of the term No Fault Found is beyond the scope of this text, an early reference to NFF for a maintenance-related theme can be identified from 1954 [1-4]. Even though the article was discussing a maintenance plan for airborne radio equipment, it made note of the implications of unscheduled removals whose faults could not be confirmed during bench testing:

> "Item 1 includes instances in which malfunctioning was reported to aircrew or maintenance personnel, but could not be confirmed on test. There are four possible causes for such removals: (1) Erroneous reporting: i.e., no fault existed, (2) Wrong diagnosis: i.e., the fault was in a unit other than that was removed, (3) Incorrect or wrongly applied test procedures: i.e., the wrong tests were applied, or the right tests were incorrectly applied, or (4) Invalid tests: i.e., the prescribed tests do not disclose the fault."

All of the four factors listed are still applicable in today's systems, where the level of NFF has certainly proven to be an issue that can throw any modern maintenance policy into disarray.

Figure 1.2 captures the natural evolution of maintenance systems since the 1950s, showing the trend toward increasing component complexity and system integration, and hence system maintenance requirements. To address these challenges, the discipline of system engineering has been promoted to accommodate the development of interacting systems. From a NFF point-of-view, this means that systems have become more intricate and complicated, and any reported failures may require an even more sophisticated and rigorous testing procedure to elicit reliable and dependable results.

Across industry, the aerospace sector has reported the major share of NFF failures, primarily within aircraft avionics, and hence the next section is devoted to NFFs in that sector. These avionics' problems not only indicate the correlation between increasing electronic components within modern systems and the NFF rate, but also demonstrate how a non-issue can develop into a strategic concern for an organization within a competitive environment over time.

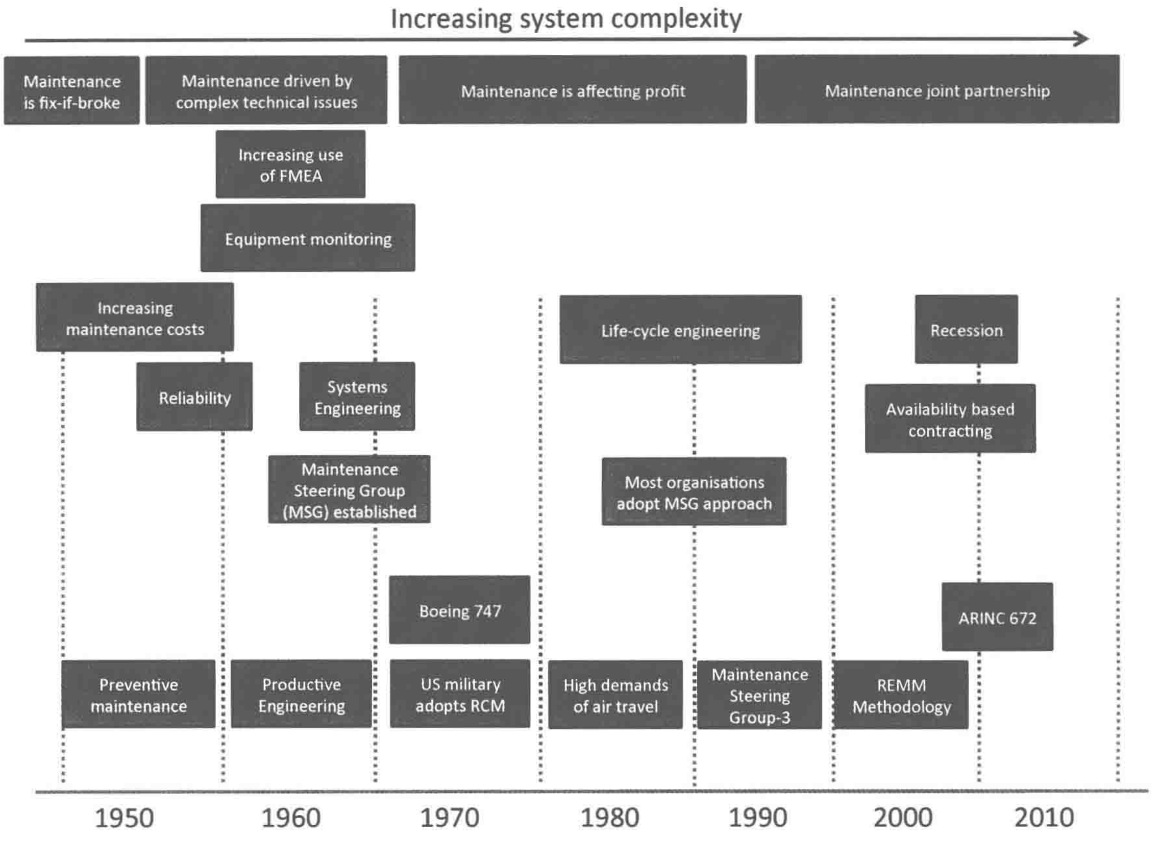

Figure 1.2 Maintenance evolution over time.

1.1.2 The Growth of NFF within Aerospace

By the late 1960s, a much more competitive marketplace had developed, with an increasing intolerance of downtime. Coupled with rising system complexities and maintenance requirements, the civil aviation industry recognized that overhaul activities were not only costly but were also failing to reach acceptable levels of safety. It was hence recognized that business and management practices, which had worked well for smaller aircraft, were simply inadequate for large, complex, high-value assets. During the development of the Boeing 747, the aviation industry started to search for improved reliability, questioning maintenance strategies and disregarding the long-established rule that old components are "the most likely culprits."

As a consequence, a Maintenance Steering Group (MSG) was commissioned comprised of aerospace manufacturers, operators, and the Federal Aviation Authority to analyze current practices. This initiative led to the invention of reliability centered maintenance (RCM) concepts that had an emphasis on reliability improvements, cost reduction, and good maintenance practices [1-5]. Work continued from this on specific standards, introduced over the years, to improve system maintenance and overall scheduling costs [1-6], [1-7]. These documents recognize NFF events as hidden failures. These are functional failures that do not become evident to the operating personnel under normal circumstances (e.g., the immediate overall operation of the system remains unaffected) (see Figure 1.3). If the functional failure is not hidden, then the failure is considered as evident.

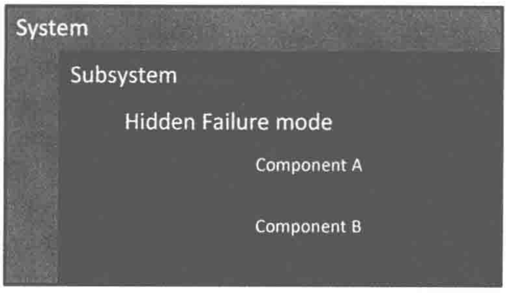

Figure 1.3 Failure in only Component B will not affect the functionality of the overall system. Components A and B must fail simultaneously for a functional failure to become evident. Such redundant paths may not always have failure warnings for each component, and hence such failures will remain hidden.

For modern industry, however, NFF has been an area in which huge sums of money can be wasted through increasingly high levels of unscheduled removals. As mentioned, this is due to the continued trend in increasing system complexities and the resulting cost implications on maintenance programs. Additionally, business culture within civil airlines has changed, with a stronger desire to reduce costs while increasing the availability of their aircraft. Recognizing the lack of any NFF standards or procedures, these organizations adjusted their practices according to their own understanding and requirements. This also meant that each organization started using their own terminology to describe NFF, which continues to grow (See chapter 2 on Terminology). The lack of a single common descriptive and standard term also indicated that NFF was not well understood, and hence led to confusion from a technical and nontechnical standpoint. These developments will be traced more completely in later chapters of this book.

Work published throughout the 1980s and 1990s [1-8], [1-9], [1-10], indicates the demand for greater system reliability, availability, and maintainability at lower cost. This also created awareness of new failure processes, improvements in management practices, and new technologies that could improve the understanding of system, subsystem, and component level health. As maintenance, reliability, and risk became more significant for design engineers, environmental and safety issues became paramount through legislation [1-11], [1-12], and hence maintenance procedures had to be refined. This led to advancements in a number of maintenance and health-monitoring techniques, including condition monitoring, quality standards, expert systems, and reliability centered maintenance, to name but a few. Many aircraft were being used well beyond the years envisioned by their design, which created serious concerns about maintaining airworthiness/safety matters. Increasing demands for air travel promoted various safety studies and thus established the requirements for upgrading existing systems while accommodating advances in avionics at reduced costs. Given the growing total cost of ownership, tight maintenance budgets, and attempts to remain competitive, organizations were looking to maximize the return on their contracts rather than enhance their maintenance practices. This period witnessed a rise in the number of unscheduled removals. Commercial contracts did not acknowledge NFF as an issue, and no mechanisms were placed to calculate its true costs. With no defined metrics or responsibility, NFF continued to cause a wasting of resources and unproductive time utilization—adding to maintenance costs, downtime, and unavailability of systems.

The continued increase in avionic complexity led to an increase in the NFF rate. Practitioners realized that the issue was affecting their reputation (and relationships within the supply chain) and hence required a solution. In 1998, a Reliability Enhancement Methodology and Modeling (REMM) project was initiated to support the reliability enhancement of electronic systems. Within it, a statistical model to facilitate the assessment of reliability throughout the product life cycle was included [1-13], [1-14]. One of the major deliverables was to investigate the root cause of NFF events within the aerospace industry and provide a comprehensive breakdown of potential reasons for these. This list included:

- Operator policies (e.g., short turnaround 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, accuracy of technical publications)
- Repeat removals (e.g., minimal use of maintenance history)
- 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 containing intermittent fault (e.g., solder joints, PCB weakness)
- System design (e.g., built-in test equipment—BITE—coverage, software tolerances)

Much of this work, which was never openly published, emphasized the importance of developing practical guidance for system designers to facilitate reducing NFFs in both current and future products. With continuously evolving reliability requirements, and contract types in the commercial world, it seemed that guaranteeing a fixed failure rate, for high-value products, may not satisfy end user objectives and government regulations, especially if these products suffer from a high number of NFF events.

In 2008, fundamental to advances made in NFF, a set of procedures was introduced in the form of the ARINC 672 Report [1-15]. This report was directly aimed at providing a basis for a structured process to address NFF within the aviation industry. It also introduced a definition of NFF:

> "Removal of equipment from service for reasons that cannot be verified by the maintenance process (shop or elsewhere)."