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The contribution of maintenance human factors to no fault founds on aircraft systems engineering

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Abstract

In the context of aircraft engineering and maintenance, No Fault Found (NFF) is a chain of events that develops from a pilot experiencing a system malfunction with post-flight maintenance failing to reproduce the reported symptoms. Without any repair being undertaken, the malfunction may be experienced again on subsequent flights. This paper presents research into aircraft maintenance human factors that are prevalent when aircraft maintenance engineers interact with aircraft systems whilst undertaking fault diagnosis maintenance. The aim of the research is to develop a set of recommended guidelines that focus on mitigating human factors implications that arise from engineers interacting with complex systems when conducting maintenance tasks. This was achieved by undertaking an empirical study that involved a maintenance engineer survey and identification of a NFF case study where a structured interview was conducted. The study revealed that key resources such as aircraft test equipment, integrated onboard maintenance systems and technical maintenance manuals failed to support engineers when undertaking diagnosis tasks. The combined effect of the research findings is that aircraft maintenance personnel are unable to consistently undertake accurate and timely fault diagnosis tasks and this results in unwanted NFF occurrences.

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Keywords: No fault found; human factors; aircraft maintenance; fault diagnosis

1. Introduction

No Fault Found (NFF) is a phenomenon that affects technological equipment and leads to an adverse impact on business operations. In the context of aircraft maintenance, a NFF occurrence is a chain of events that typically develops from a pilot experiencing a system malfunction followed by post-flight maintenance failing to reproduce the reported symptoms. Quite often, the same fault situation is reported on a subsequent flight. The impact of NFF on the aviation industry is wide ranging. This includes increased maintenance time, wasted maintenance effort and increased utilisation of spare parts when not necessary. Aside from the financial life cycle cost impact, it can also have adverse effects on equipment availability and flight operations safety. This research concentrates on the human element of NFF, particularly focusing on the interaction between maintenance engineers and complex systems, and the associated human factors that may be prevalent. A limited amount of study into NFF phenomenon has introduced the possibility of aircraft maintenance human factors implications contributing to the NFF problem. The objectives of the research project were as follows:

1. Undertake a human factors focused investigation into current aircraft engineering maintenance practices.
2. Evaluate data and undertake human factors focused assessment to identify system failings and maintenance processes improvements to mitigate NFF impacts.
3. Identify 'good practice' methods and procedures within engineering maintenance organisations to mitigate NFF impacts.

All the above three will be discussed in this paper. The remainder of this paper is structured as follows: a succinct critical review of applicable literature is undertaken followed by presentation of findings from the empirical study leading to the research conclusions.

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2. Literature review

Definitions of NFF will differ depending on which aspect of the maintenance chain is experiencing the phenomenon. At the front line aircraft maintenance level NFF events originate from a fault condition that triggers a warning to alert the aircrew to possible system degradation [1]. The chain is initiated by the pilot experiencing a fault situation however subsequent diagnosis and maintenance intervention by the repair organisation may be ineffective as the same symptom occurs again on the next flight [2]. The reason engineers fail to accurately diagnose and repair reported faults could be attributed to a number of possibilities including the inability to reproduce the conditions under which the fault symptom first materialised, inadequate test procedures or human error [3].

An accepted categorisation emerging from recent studies propose the main reasons for NFF are grouped under: organisational and culture; technical deficiencies; procedural and human behaviour categories [3]. Although this approach appears strategic in nature it is the author's opinion that it offers the firmest foundations for identifying all applicable NFF origins linked to human factors implications experienced by aircraft maintenance engineers. Organisational and culture are expanded to include management influenced factors such as time pressure, poor communication, failure to adopt and share best practice, inadequate training and reluctance to change. There is a cause and effect relationship between the organisational and human behaviour categories. The adverse issues presented may foster a harmful environment that has a detrimental effect on the workforce behaviour. These are exposed as human factors implications that have a direct influence on the ability of the Aircraft Maintenance Engineer (AME) to undertake duties in a professional and diligent manner. Technical aspects of NFF address problems associated with the complexity of aircraft systems, functionality of Test and Measuring Equipment (TME) and aircraft Built-in Test Equipment (BITE) and equipment reliability. They are closely related to procedural issues that include discrepancies in manuals and incorrect reporting.

3. Research Findings

The most comprehensive analysis relating human factors to the NFF phenomenon advocated the use of the SHELL* model as a tool to assess human factors implications [4]. The model presents a series of building blocks that illustrate human factors that may influence human behaviour [5]. At the heart of the model is the human being, depicted as Liveware, and is surrounded by Software, Hardware, the working Environment and other humans, which make up the key human factors components. The research methodology was primarily based upon extracting quantitative and qualitative data from a questionnaire. The questionnaire drew a significant response with a large number of returns received from all targeted sectors; the response count against sector is presented in Table 1.

Table 1. Survey response by sector

Sector	Distribution count	Response count
Commercial fixed wing	110	63
Commercial rotary wing	130	79
Military	~50	36
General aviation	Not known (online)	10

3.1. Survey demographics

The questionnaire identified respondents by their current employed maintenance role. The majority of responses came from certifying Category B (Cat B) licensed engineers. There are two sub-categories for Cat B License holders; B1 engineers are responsible for aircraft mechanical and propulsion systems and B2 engineers responsible for electronic and avionic systems. Figure 1 details response data by industry and current role within each sector. The chart also plots average industry experience by sector and shows that individuals have in excess of 9 years' experience in each of the three main industry groups.

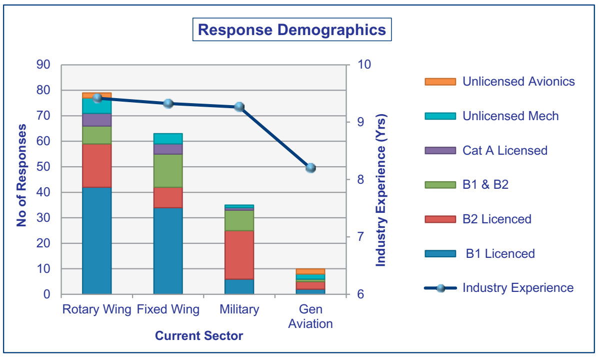

Figure 1. Survey response demographics.

3.2. Aircraft testing resources

This section of the survey posed questions surrounding AME interaction with off-aircraft testing equipment and aircraft integrated maintenance systems in order to identify human factors implications. With respect to TME, approximately 30% of aircraft reported faults require its use to aide diagnosis and repair. Further analysis revealed that 73% of respondents believed that TME was 'mostly available' when required and 11% stating that it is 'mostly unavailable'. The survey asked AMEs to state what percentage of TME used in support of fault diagnosis they are competent with. This data is presented in Figure 2 and is distinguished between aircraft trade and industry experience.

The percentage of TME that engineers believe they are competent with is plotted against experience for each trade on the secondary vertical axis. This shows a positive correlation between years of experience and competency. Overall, avionics engineers indicate they are competent in a wider

* Software; Hardware; Environment; Liveware; Liveware

range of TME than the mechanical respondents, particularly so for those who have 5 to 10 years experience in the industry.

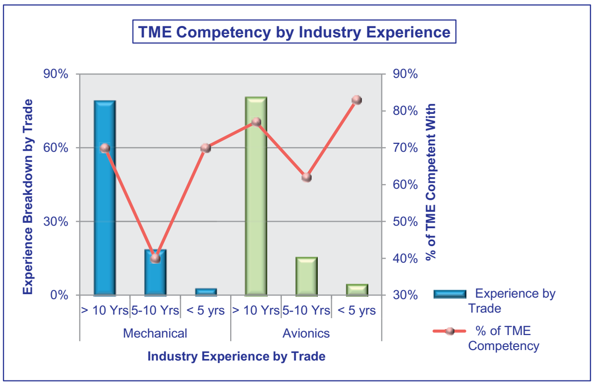

Figure 2. TME competency by aircraft trade and industry experience.

The sharp jump in competency levels for those with less than 5 years experiences can possibly be attributed to the low numbers of respondents who fall into this category. The main reason for lack of competency was due to infrequent use of equipment but a third of responses stated lack of training was the cause. Other reasons included equipment being too complicated to use and being unserviceable when required for use.

Numerous sources of data were used to ascertain the AMEs perception of Onboard Maintenance Systems (OMS) and BITE functionality when diagnosing faults, and their general confidence in its ability to support this. This information was correlated against AME perception of NFF occurrences on modern glass cockpit aircraft compared to platforms with ageing analogue based flight decks. This information is detailed in Figure 3.

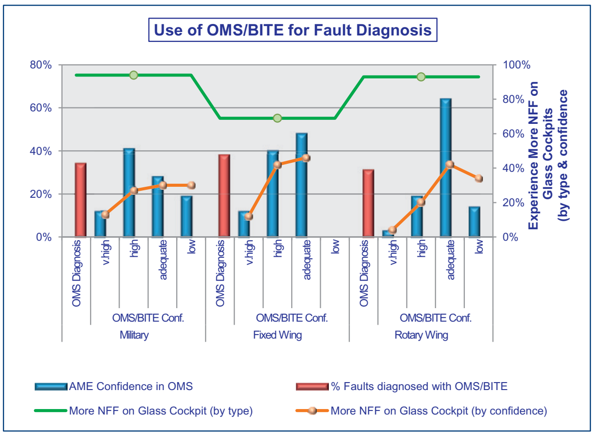

Figure 3. Use of OMS / BITE for fault diagnosis tasks. The primary axis plots AME confidence in OMS and the percentage of faults diagnosed with OMS whilst the secondary axis details response percentages from those who believe that more NFF occurrences are experienced on modern glass cockpit aircraft.

As detailed in figure 3 it is perceived across all industry sectors that approximately 35-40% of faults can be diagnosed using OMS and BITE alone. Within the military and fixed wing sectors there is a similar pattern of AME confidence in the ability of OMS, with the majority of respondents having high or adequate confidence in the system whilst confidence in the rotary wing sector appears to be slightly lower. The survey asked if NFFs were more apparent on modern computerised flight decks when compared to traditional analogue based systems. The reason for this was to ascertain if there is a complex technology factor that may lead to difficulties in diagnosing faults. The vast majority of respondents across all industry sectors believed that NFFs are more common on modern aircraft types. As detailed, the percentage of AMEs who believe NFFs are more common on modern aircraft types increases as their confidence in OMS falls.

When asked to describe their ability to use OMS, just less than half of respondents indicated they are not very confident in the use of system BITE and OMS. Although 32% are confident in its operation they were not aware of its full functionality. Approximately 10% believed they had limited knowledge and are unconfident in its use. These results are presented in figure 4.

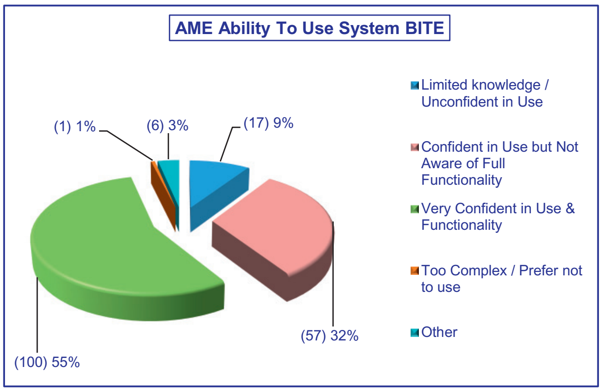

Figure 4. AME ability / confidence in the use of OMS.

3.3. Aircraft maintenance manuals

Questions in this area explored AME interaction with aircraft maintenance manuals to understand if human factors related issues are prevalent. An overwhelming majority stated they could not rely on manuals alone and use a combination of manuals and individual expertise when diagnosing faults. Failure to ensure accurate diagnosis, being difficult to follow and too time consuming to use are the significant reasons for AMEs preferring to use expertise instead of manuals when undertaking diagnostic tasks.

Data surrounding the availability of manuals and their ability to diagnose faults is presented in figure 5. The chart also details the average split between engineers use of experience versus manuals. In each of the four NFF boundaries the majority of respondents state that manuals 'mostly diagnose' faults with minimal responses stating they 'always' diagnose reported faults.

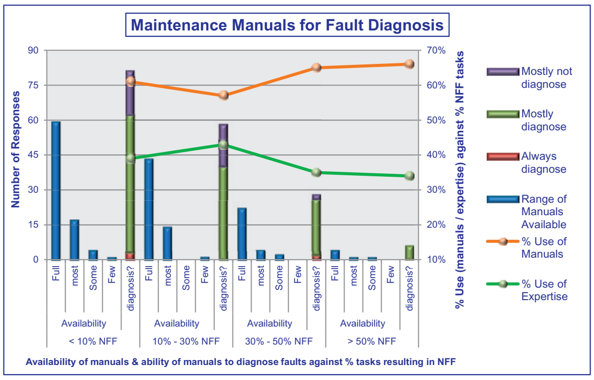

Figure 5. Use of maintenance manuals for fault diagnosis. The primary vertical axis details the availability of manuals when required for use and their ability to diagnose the faults against AME perception of the percentage of reported faults that result in NFF.

It is also noted of those AMEs who perceive that up to 30% of tasks result in NFF (<10% and 10%-30% range), approximately a third of these believe that manuals 'mostly not diagnose' reported faults. With regard to availability of manuals, approximately 25% of respondents' state that a full range of manuals are not always available. The secondary vertical axis plots the percentage weighting of use of manuals against use of expertise in each NFF boundary. On average this is shown as a 60% bias towards use of manuals and 40% towards the use of expertise.

3.4. Organisational pressures

Lack of time and organisational pressures are important human factors that impact upon the AME in many ways. Analyses of these findings that focus on the effects of time and pressure on AMEs when conducting corrective maintenance are presented in Figure 6.

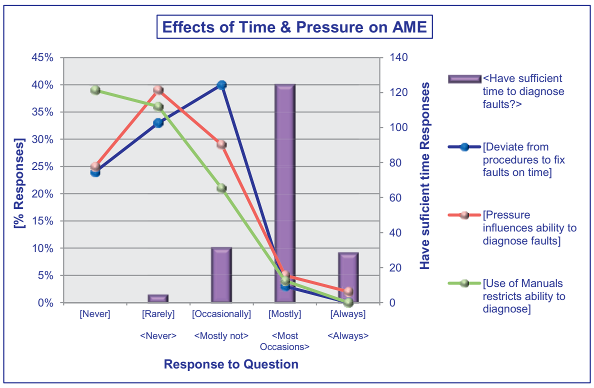

Figure 6. Effects of time and pressure on AMEs. Organisational pressures that may adversely affect behavior are plotted on the primary vertical and upper row of the horizontal axis. AME perception of time available plotted on secondary vertical and lower row of horizontal axis.

Approximately 65% (124 responses) of engineers believe that on most occasions they have sufficient time but 16% (31 responses) believe they mostly do not. With regard to other pressure related characteristics the data shows that 40% of AMEs occasionally deviate from procedures to fix faults on time, 30% occasionally feel pressured that influences their ability to diagnose faults and 20% state the need to use manuals occasionally restricts their ability to undertake accurate diagnosis.

AMEs were also asked to select the most significant factors that lead a lack of time to accurately diagnose reported faults. Most individuals quote manpower shortages to meet the workload and unavailability of equipment as the primary reasons. Other recurring themes that lead to lack of time to diagnose faults and include the shortage of replacement parts and the lack of training on all aircraft systems and related testing equipment.

3.5. Maintenance engineer training

To complete the human factors assessment, the level of training and professional development undertaken by AMEs with respect to aircraft systems and testing resources was analysed through a series of targeted questions. The survey also explored if maintainers would benefit from additional training and what type of training this should be. Figure 7 presents analysis of the data received from the survey.

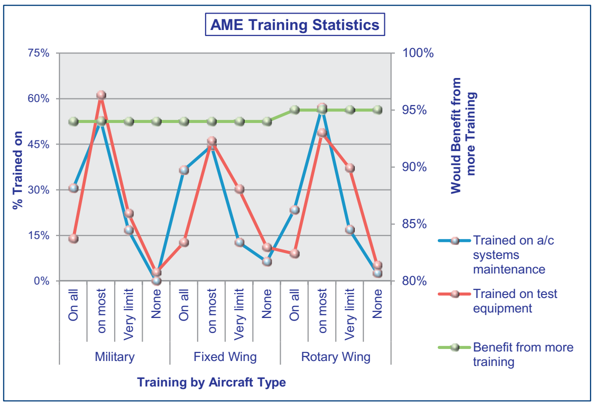

Figure 7. Training data overview. The range of training received is categorized and presented by sector on the primary axis.

The range of training received is categorised and plotted for each industry sector. The chart also displays the response of engineers when asked if they would benefit from additional training. Approximately 95% of AMEs across all three sectors indicated they would benefit from additional training. The range of training received on aircraft systems maintenance and testing resources follows a similar pattern across all sectors. The range of training received peaks at 'on most' for both aircraft systems and test equipment in each sector with responses in the region of 45% to 60%. A significant proportion of AMEs indicated they had received 'very limited' training, particularly on test equipment that peaked at 37% in the rotary wing sector to 22% in the Military environment.

Figure 8 summarises the preferred options for additional training and professional development. A large number of engineers revealed they would benefit from training on testing aspects - 69 opting for OMS / BITE and 105 on the use of TME, whilst over 100 individuals believed they would benefit from system operation and functionality training.

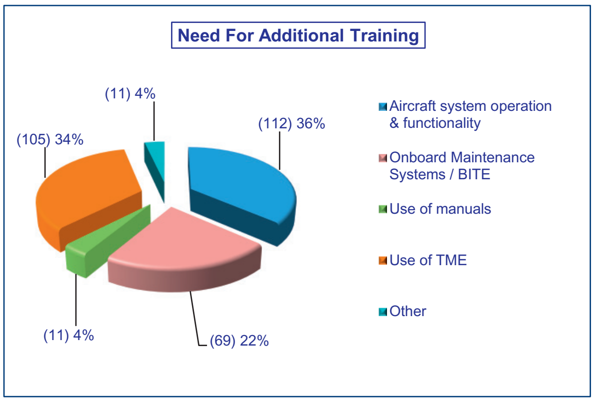

Figure 8. Common preferences for additional training and professional development.

4. Conclusions

NFF is a challenge faced by most technology dependent industries and particularly so in the aviation industry where it has plagued aircraft operators for many years. The consequences of NFF to the operator are hugely significant and include direct financial cost, delayed and cancelled flights and flight safety implications. A comprehensive review of theoretical literature revealed that the human factors domain was rarely addressed as an NFF causal factor. Further to this the limited literature that tackled this aspect fails to examine a key chain of events; that is human factors issues adversely effects aircraft maintenance engineers that may lead to an increase in NFF arisings. The aim of this project was to develop a set of recommended best practice guidelines, centred on human factors interfaces, to help mitigate the negative impact that NFF has on aircraft maintenance operations. Conclusions for each of the human factors interactions are detailed in the remainder of this section and are summarised as follows:

- Engineers are not competent in the use of the full range of testing resources made available to them
- Onboard Maintenance Systems are incapable of diagnosing a full range of faults
- Maintenance manuals fail to provide sufficient information to support accurate fault diagnosis
- Fault isolation manuals to not address all fault scenarios
- Lack of time and organisational pressures inhibit accurate and efficient fault diagnosis
- Engineers receive insufficient training on the operation of testing hardware

4.1. Testing Resources

Off aircraft test and measuring equipment (TME) and aircraft integrated onboard maintenance systems (OMS) are an integral part of diagnostic maintenance and should ensure that AMEs accurately and quickly diagnose reported faults. The study revealed this is not the case as shortcomings in this area prevent AMEs from doing so. Off aircraft TME is often unavailable and engineers indicate they are not fully competent in its use. It seems that OMS is incapable of diagnosing all reported faults and as such AMEs have limited confidence in its functionality. There is also an interactive complexity factor as data shows that AMEs experience more NFF occurrences on modern aircraft types with complex flight deck interfaces. Lack of training is frequently quoted as a reason for deficiencies in this area.

If the AME has no confidence in the OMS they may be reluctant to use it, instead drawing on individual system experience and knowledge that may lead to unauthorised practices being adopted. The same can be said with TME; if AMEs are not fully competent in its effective use they will be unlikely to use it even though it may lead them to the fault root cause in a timely fashion. It can only be concluded that the identified issues surrounding the use of TME and OMS contributes to the NFF problem. The inability of testing resources to support accurate fault diagnosis not only restricts the AME but also prevents organisations from achieving maintenance objectives.

Mitigating these problems will have practical implications on this aspect of the aircraft maintenance chain. AME training philosophies will need to be reviewed to ensure individuals are competent with the use of testing resources, particularly when using complex aircraft systems that aid fault diagnosis. A practical suggestion is that aircraft operators could do more to share fault related best practice to assist engineers when faced with complex faults.

4.2. Maintenance Manuals

The use of maintenance manuals is an essential and mandatory requirement and engineers heavily rely on troubleshooting guides located within the manuals to expediently diagnose reported faults. It is of strong belief that the availability of manuals and their technical content, to an extent, restricts the ability of AMEs to accurately and quickly diagnose reported faults. Worryingly, the vast majority of AMEs revealed they are compelled to use personal experience to supplement maintenance manual provision when undertaking fault diagnosis. Many state that manuals fail to provide sufficient information to diagnose faults as a reason for this. The evidence also indicates that manuals are not always available when required.

Given the regulatory requirement that all aircraft maintenance work is conducted in accordance with specific manuals, the evidence presented poses significant issues. If engineers fail to use fault isolation manuals and draw upon individual expertise instead, it is possible that unauthorised maintenance practices will be adopted leading to a range of adverse implications; this may include flight safety issues. Less experienced AMEs who lack expert system knowledge rely more heavily on manuals to guide them when undertaking corrective tasks. In this case, the deficiencies of manuals may lead to prolonged maintenance time and an increase in NFF arisings. Practical implications to mitigate the problems exposed in these findings are potentially significant. Aircraft manufacturers may need to review their approach to the design and production of maintenance manuals. They would need to ensure that documents provide sufficient information that allows maintainers to diagnose all fault symptoms that are generated by systems. At a local level, operators must ensure that a full range of manuals are available when required for use.

4.3. Organisational Pressure

Organisational influences are a major issue, partly brought about by the need for airlines to adhere to passenger rights and maintain strict flight schedules. The maintenance environment is not immune from these forces. It was evident from the study that AMEs believe they have insufficient time to overcome the maintenance burden. It was also accepted that this is commonplace throughout the industry and is generally acknowledged as the nature of the environment they are employed in. As such, the impact this has on the NFF problem is indicative of the problem it presents to industry as a whole. Alarmingly, a large number of AMEs reveal they may deviate from procedures in order to complete maintenance on time and a significant proportion believe that management pressures adversely affects their ability to diagnose faults.

Even though organisational pressures, particularly lack of time, are an accepted industry problem, their impact on the NFF phenomenon should not be ignored. When faced with lack of time, AMEs may be inclined to go for a 'quick fix' that involves replacing a component that is most likely to clear the reported fault as opposed to following a course of action that involves the use all available resources to undertake thorough fault diagnosis. In many cases this shortcut approach may cure the reported problem but when it fails to do so it results in an additional NFF arising and the documented consequences associated with this. It is the responsibility of line management and other support functions within an organisation to manage this and implement strategies to ensure negative impacts are minimised.

4.4. Training

The final human factors domain explored by the empirical study addressed the range and quality of job-specific training received by AMEs. An overwhelming majority revealed they would benefit from additional training to support them in the execution of their maintenance duties. Many AMEs indicated they had received very limited training on off-aircraft TME and integrated aircraft OMS and thus inhibits their ability to undertake diagnosis tasks. It was accepted that the quality of training received was of a high standard. Lack of training was revealed as a major reason for the lack of competency and confidence in testing resources addressed earlier in this chapter.

When required to use equipment they are not trained on, AMEs may opt to undertake tasks without it and embark on a course of action that may deviate from approved procedures. Alternatively, they may attempt to use the resource but not with the confidence and competency that allows them to exploit its full functionality in diagnosing the reported fault. Either way, the outcome is likely to result in the failure to accurately and expediently diagnose the reported fault and therefore compounding the NFF problem. There is a link between lack of training and organisational pressures. Training courses may be available but rigid work schedules and lack of spare time prevents individuals from attending courses. The adverse effect that lack of training has on the NFF phenomenon is clear but it also has wider impact on the industry that includes negative consequences towards, operational achievement, flight safety and organisational reputation.

4.5. Final remarks

In spite of the increasing research being undertaken into the NFF phenomenon, the complex nature of aircraft maintenance has resulted in theoretical and empirical study failing to address all causal factors in significant detail. The human factors focussed study at the maintenance engineer level presented in this research project has identified numerous factors that compound the wider NFF problem. The work undertaken should make a positive contribution to wider research into the phenomenon and should complement other research avenues being explored by the project.

Acknowledgements

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