CRANFIELD UNIVERSITY

LAURA LACEY

IS THERE A LINK BETWEEN NO FAULT FOUND AND AIRWORTHINESS?

DEFENCE AND SECURITY

PhD
Academic Year: 2022 - 2023

Supervisor: Dr Alistair Saddington
Associate Supervisor: Dr Simon Place
January 2023

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ABSTRACT

The no fault found phenomenon negatively impacts the aviation industry and an aircraft's airworthiness. Airworthiness and no fault found must be appreciated during the design, maintenance and subsequent operation. This research aimed to establish if a link between no fault found and airworthiness exists and to garner the aircrew's perception of any possible link. Semi-structured interviews and a questionnaire were conducted to generate primary data. Pilots and aircraft accident investigator interviews were conducted to establish a foundation of knowledge, experience and perspectives on no fault found and airworthiness to support the questionnaire. The questionnaire established predominately RAF aircrew views on the impact of no fault found on airworthiness, the key aircraft systems affected, communication methods and associated training completed. Secondary data from an aviation company's maintenance records were analysed for no fault found frequencies. The research analysis includes systems engineering, Bowtie, Functional Resonance Analysis Method and fuzzy logic inference.

The RAF aircrew canvassed perceives no fault found to negatively impact airworthiness causing missions to be cancelled, curtailed or replanned. Trust between RAF aircrew and engineers is diminished. This impacts the analysis and recording of no fault found and airworthiness. Training the aircrew and engineers on how to conduct the post-sortie engineering debrief, in a dedicated location, whilst using a dedicated proforma that focuses on no fault found and airworthiness, and reviewing the aircraft's no fault found history will decrease the occurrences of the phenomenon.

An iterative relationship between Bowtie and Functional Resonance Analysis Method established the key aspects that impact the link between no fault found and airworthiness. Based on mission success, the fuzzy logic inference of the aircrew and RAF engineers' linguistic variables, (negligible to severe), that described the aircraft's airworthiness level as a consequence of repeated no found faults, were combined to create 3-dimensional surface plots to represent the aircraft's overall airworthiness level. These combined confirmed that

airworthiness is not binary. These original 3-dimensional surface plots indicate the no fault found/airworthiness relationship varies over longer periods but is most pronounced in shorter periods with more no fault found occurrences. This indicates that the current methods for analysing and assessing the impact of no fault found on airworthiness require redefining and this research suggests that no fault found /Airworthiness working groups with key stakeholders are a means to achieve this. As the questionnaire participants were mainly RAF aircrew the external validity for them has been established. However, the wider validity of this research with other aviation organizations cannot be stated categorically unless further research is conducted.

Key Words

Aircrew, Bowtie, engineer, fault not found, FRAM, Functional Resonance Analysis Method, fuzzy logic, inference, NFF, post-sortie engineering debrief, surface plot, trust.

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LIST OF ABBREVIATIONS

AAI	Air Accident Investigator(s)
AAIB	Air Accidents Investigation Branch
AC	Alternating current
AFCS	Automatic flight control system
ALARP	As low as reasonably practicable
AMM	Aircraft maintenance manual
AP	*A priori*
ARINC	Aeronautical Radio, Incorporated
C	Control
CAA	Civil Aviation Authority
CAMO	Continuing airworthiness management organizations
CMM	Component maintenance manual
CURES	Cranfield University Research Ethics Committee
DAE	Defence Aviation Environment
DAEMS	Defence Aviation Error Management System
DAIB	Defence Accident Investigation Branch
DASOR	Defence Air Safety Occurrence Report
DH	Duty Holder
EASA	European Aviation Safety Agency/ European Union Aviation Safety Agency (from 2018)
EPSRC	Engineering and Physical Sciences Research Council
FAA	Federal Aviation Administration
FMECA	Failure Modes, Effects and Criticality Analysis
FNF	Fault(s) Not Found
FRAM	Functional Resonance Analysis Method
GPWS	Ground proximity warning system
HUMS	Health and Usage Management
I	Input
IDG	Integrated drive generator
IF	Intermittent fault
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IMRBPB	International Maintenance Review Board Policy Board
IOP	Input output processor
JEngO	Junior Engineering Officer

JSP	Joint Service Publication
LRU	Line replaceable unit
Ma	Major
MAA	Military Aviation Authority
MAAS	Military Air Accident Summary/Summaries
Mi	Minor
MOD	Ministry of Defence
n	Number
N	Negligible to none
NFF	No Fault Found
nk	Not known
O	Output
OED	Oxford English Dictionary
OEM	Original equipment manufacturer
P	Precondition
PAWE	Propulsion, airframe, weapon and electronic/electrical engineers
PC	Preliminary clustering
PSED	Post-sortie Engineering Debrief
QRH	Quick reference handbook
Q	Question
R	Resource
RA	Regulatory article
RAF	Royal Air Force
RtL	Risk-to-life
S	Severe
SEngO	Senior Engineering Officer
SI	Service Inquiry/Inquiries
SME	Subject matter expert
SQEP	Suitably Qualified and Experienced Person/Personnel
T	Time
TAA	Type Airworthiness Authority
Tested satis	Tested completed satisfactorily
UK	United Kingdom
US	United States

1 INTRODUCTION

1.1 Early Flight

Some myths and legends highlight the successes, failures and dangers of flying. The most well-known is probably that of Icarus who fell to the ocean after his wings, made of wax and feathers, melted when he flew too close to the sun. This was after his father, Daedalus, had successfully flown from Crete to Naples. Alexander the Great was alleged to have flown in a basket carried by Griffins, mystical winged animals (NASA, 2014). As early as 400 BC the Chinese invented kites and used them to test weather conditions (Song, 2021). There are claims that they considered them for human flight (Song, 2021). By the 15th century, Leonardo da Vinci drew many diagrams about flight and even proposed a machine for this purpose. Flight had been an aspiration of man for many centuries. Although the word may not have been used, *Airworthiness* may have been a consideration from the first flight, whether manned or otherwise. Early flight development was very mechanical with few avionic components. However, as developments advanced more electrical and avionic components and software have been introduced to aircraft. From this, the rise of No Fault Found (NFF) has grown. For current aircraft, the consideration of airworthiness and NFF must be incorporated during the design, maintenance and subsequent operation. Whilst aerodynamics and propulsion design will get the aircraft into the air, it should be safe or flown with a calculated degree of risk. The risk of NFF needs to be acknowledged and managed but first, an explanation of NFF is required.

A simple explanation of NFF is when a system develops a fault and when the engineers conduct fault diagnostics, including testing, and they are unable to reproduce the fault. It all works as expected. The fault may be intermittent, which makes it harder to fault diagnose and find. The NFF phenomenon is experienced across many disciplines, including the automotive, telecommunications, aviation and rail industries. Moreover, across and within these disciplines different terminology is associated with it and how it is abbreviated, such as Cannot Duplicate (CND), No Fault Apparent (NFA) or Re-test OK (RTOK) (Khan et al.,

2015). The impact of NFF can range from an inconvenience to a major safety hazard. Much depends upon the context of when the fault first occurred and then reappeared. To understand the problem caused by NFF and intermittent avionic faults some air incidents are presented.

1.1.1 Serious Incident AAIB: 6:2012 G-LSAI

The Air Accidents Investigation Branch's (AAIB) (2012a) investigation into the serious incident for Boeing 757-21B, G-LSAI on 7th September 2011, was raised following the failure of the left alternating current (AC) electrical bus losing power and the flight crew deciding to divert to Kavala Airport in Greece. The investigation concluded that there had been an intermittent failure caused by "corrosion within the crimp terminal" (see Figure 1-1 and Figure 1-2) and "Loss of electrical continuity at pin 12 caused the left IDG's [integrated drive generator] differential protection current transformer to erroneously sense that the 'A' output AC phase carried zero current, causing the left GCU, [generator control unit] via logic within the BPCU [bus power control unit], to disconnect the left IDG from the left AC bus".

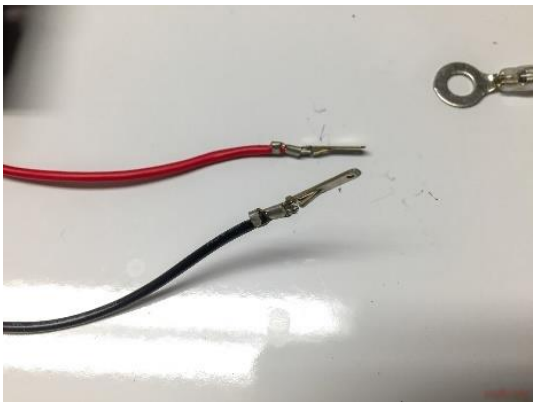


Figure 1-1: Example of a wire

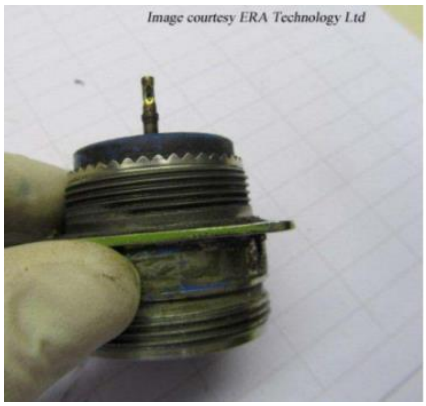


Figure 1-2: Detector showing detached crimp terminal (AAIB, 2012a)

Also, at another pin, loss of electrical continuity removed "the earth shield from the left IDG'S exciter field power supply" and reduced the AC voltage. This in turn with probable electromagnetic interference could cause electric motors and transformers to overheat and produce an electrical burning smell and some smoke.

It was stated that isolation of the defect was difficult to diagnose due to the intermittent nature of the fault and “the presence of an additional factor was required to cause electrical over heating fumes experienced.” This might not be seen as an obvious NFF but the intermittent nature of the fault meant that the true cause was undetected for a period of 13 flights and like other NFFs an additional factor was required to initiate the fault.

1.1.2 Serious Incident AAIB Bulletin: 6/2012 G-JECF.

The AAIB (2012b) investigated the Flybe aircraft DHC-8-402 Dash 8, G-JECF that flew below the selected altitude on approach to Exeter airport. The following details the accounts from that investigation (AAIB, 2012b).

The investigation found that the cause was the failure of the No. 1 input/output processor (IOP) and that this component had failed at least eight times over 61 days between 22nd August 2010 and 8th October 2010. The aircraft is fitted with two IOPs that form part of the flight data processing system, which receives data from various aircraft systems and sensors and sends it to other aircraft systems. Specifically, if the No 1 IOP fails the cockpit indications for fuel inlet temperature, oil pressure, and hydraulic quantity will be lost but, importantly, depending on the fault type there also may be a loss of indication for speed bugs, decision height and minimum descent altitude, erroneous aural warnings, CAT [category] 2 FAIL message and “MINIMUMS-MINIMUMS” callout during the approach. An IOP failure must be investigated before further flights are conducted. The resulting maintenance activity by the operator included testing the component per the maintenance manual and transposing the No 1 and No 2 IOPs; the intermittent fault now appeared in the No 2 position. The AAIB investigation concluded that the fault caused the flight crew to become distracted and the aircraft had descended a further 700 feet below the selected altitude before the ground proximity warning system (GPWS) alarm sounded. The investigation stated that there was insufficient guidance within the crew's quick reference handbook (QRH) to enable them to deal with the IOP failure. Additionally, the aircraft manufacturer’s maintenance procedures were insufficient to allow the operator’s maintainers to determine the actual fault. Furthermore, the manufacturer’s means

of testing, including the acceptance test procedures, were insufficient to identify the intermittent faults. Whilst it is acknowledged that the crew did not follow the correct GPWS procedures it was stated that the fault represented a "*significant distraction to the crew at a late stage in the approach*" (italics added). Following the investigation, the operating procedures have been amended and the IOP manufacturer was recommended to review the test procedures "to improve the detection of intermittent failures" to reduce the amount of NFF. Several components were given to the manufacturer for repair and were subsequently returned as NFF.

1.1.3 Serious incidents linked to civilian airworthiness

The implications of airworthiness were acknowledged when the Convention on International Civil Aviation was signed in Chicago on 7th December 1944. It was based upon agreed "certain principles and arrangements" so "that international civil aviation may be developed in a *safe* and *orderly manner"* and that the "international air transport services may be … operated soundly and economically" (ICAO, 2006). Specifically, Article 31 requires all aircraft involved with international navigation to be provided with a certificate of airworthiness (ICAO, 2006). These AAIB (2012a; 2012b) investigations had airworthiness implications for the aircrew and the passengers. It can be surmised that these aircraft were developed in "a safe and orderly manner" but there was a profound risk to those onboard. So, an airworthiness certificate may be insufficient.

1.2 United Kingdom Military Airworthiness (Problem Definition)

Haddon-Cave (2009) identified a large number of safety issues resulting in, among other things, the formation of the Military Aviation Authority (MAA). This was intended to bring about a better match between that of the Civil Aviation Authority (CAA) and the perceived Ministry of Defence (MOD) safety culture. Unsuccessful fault resolution does not yet appear though in the resulting MAA's area of responsibility or interest. Consequently, there is no recognition of airworthiness links to NFF or if indeed they exist. Nevertheless, anecdotal evidence in the military, together with research at the Cranfield University

Engineering and Physical Sciences Research Council (EPSRC) Centre for Through-Life Engineering Services (Khan et al., 2015), shows that the size and impact of NFF are underestimated in many areas. Linking NFF to the loss of aircraft availability and to the responsibility and accountability of 'managers' both in the military and civil air domain, however, seems to be a fundamental problem that is not being addressed. Evidence is sparse and proof appears to be non-existent. Whilst there is recognition of time and resources being wasted to find and resolve NFF, there appears to be little evidence to link NFF and airworthiness. What is clear is that there is a split in opinion from those within defence industries (Huby, 2012; Hockley, 2014).

The MOD (2015b; 2021) asserts that the "*Aviation DH* [Duty Holders] *have a personal duty of care to the personnel under their command*". Moreover, this is evident in its definition of air safety which the MAA defines as "*the state of freedom from unacceptable risk of injury to persons, or damage, throughout the life cycle of military Air System*", with a sub-definition for airworthiness namely, "*the ability of an aircraft or other airborne equipment or system to be operated in flight and on the ground without significant hazard to aircrew, ground crew, passengers or to third parties*" (MAA, 2015b; 2022c). The MAA also define flight safety as "A collective endeavour to operate in the Air environment safely, it embraces any activity that contributes to the safe operation of military *airworthy* systems in flight or on the ground" (MAA, 2015b). The italics on airworthy have been added to indicate the relationship of flight safety to airworthiness. Whilst the MAA (2021) has updated the regulatory principles the only definition to change is airworthiness, which has replaced aircraft with air systems. From these definitions, it could be deduced that a full investigation of NFF occurrences and the impact on aircrew safety, and hence airworthiness, should be undertaken. Otherwise, it is unclear how the Duty Holder can be confident that the aircrew is free from unacceptable risk or significant hazard.

The responsibility of each individual to uphold airworthiness is also unmistakable as "All individuals within the UK [United Kingdom] DAE [Defence Air Environment] have a duty to notify the MAA of any event that may jeopardize air safety and

which is not being addressed appropriately by the responsible command or management chain" (MAA, 2015b). This document has been updated and this definition has been changed to include "or Environmental Protection" but otherwise it remains unchanged (MAA, 2021). Nevertheless, whilst another regulation clearly states that "the MRP [MAA Regulatory Publications] do not absolve any person from using their best judgement to ensure the safety of aircraft and personnel" it goes on to provide a clause such that if "safety or operational imperatives demand, the Regulations may be deviated from provided that a convincing case can be offered in retrospect" (MAA, 2015a). This could be deemed that if the individual has managed to get away with the action, then all is well. So, if NFF has not led to an incident is this acceptable? The last quote has been removed from the latest edition of the publication (MAA, 2022a).

It might be asserted that any maintenance should keep the "aircraft and related equipment in a condition such that they are capable of fulfilling their declared purpose throughout their required life" (MAA, 2014). This specific regulation has been withdrawn and incorporated into other RAs (Regulatory Articles). However, the importance of analysing corrective maintenance trends is acknowledged (MAA, 2015a) and, therefore, it makes sense that this should certainly include trends for NFF. Nevertheless, evidence (Hockley, Lacey and Pelham, 2016) so far suggests that interest and acknowledgement of NFF and its contribution to airworthiness are superficial at best and this is also a finding of the author from lecturing MOD and industry students on the topics of maintenance trending, NFF and airworthiness.

So, when Lister (MOD, 2015), discussing the Lockheed Martin F-35, noted that to help future maintainers current aircraft engineering faults need to be investigated fully and not just rectified, it is hoped that this will include NFF.

A review of MOD and MAA documents has failed to show any link, definitive or otherwise, between NFF and airworthiness. Furthermore, whilst James et al. (2003) analyse NFF in aerospace, the focus is not on airworthiness but on improving reliability. The only document found to support a link between NFF and

airworthiness was written by Werner (2015) but this had input from Chris Hockley, a Cranfield University lecturer, who is a proponent of NFF.

A factor to be considered is whether the MOD procures its aircraft with a safe-life or with a fail-safe design philosophy. This distinction may also affect how NFF contributes to airworthiness. These terms will be examined within the context of airworthiness and NFF (Chapter 2).

Providing a clear link between NFF and airworthiness may focus the minds of those personally responsible and accountable within civilian and military aviation to ensure that each NFF is given due regard, investigated and monitored appropriately as research conducted indicates this is not the case (Hockley, Lacey and Pelham, 2016). When authors state that “A common rule-of-thumb for older aircraft is that 50% of all pilot-reported aircraft system malfunctions that occur in the air go undetected during follow-on ground testing” (Steadman et al., 2005) and that it could result in “potential mission abort or in-flight emergency consequences” (Steadman et al., 2005) it highlights the issue to show a link between airworthiness and NFF.

Therefore, this research will aim to establish what links there are and how these might be categorized according to impact, importance and criticality.

1.3 Research engineering field

Whilst the focus of this research is on aviation, safety and airworthiness the aspect of risk and safety are pertinent to other industries. An understanding of the cause of NFF, including the cost, the reporting process and the recording faults is applicable across numerous disciplines. From these, the impact of NFF on a business can be understood and managed. Processes can be implemented to reduce the effect of NFF and at the same time reduce the risk to the Duty Holder. This research will demonstrate the broad engineering field in which the research fits, before focusing on the link between NFF and airworthiness.

1.4 Structure

The thesis will adopt a traditional approach with a (systemic) literature review, research methodology to justify the approach adopted, analysis including air incident reports, a survey (with interviews) aimed at aircrew, analysis to draw together themes, and then a discussion to draw all the threads together. Conclusions and recommendations to highlight the key outcomes of the research along with originality will be stated. The thesis structure and linkages are shown in Figure 1-3.

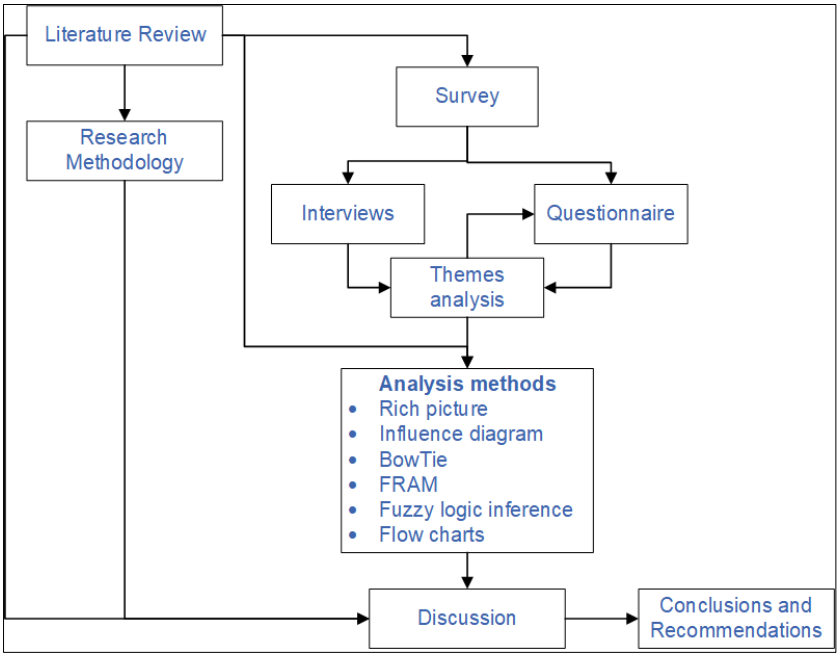


Figure 1-3: Thesis structure and linkages

1.4.1 Chapter 2 – Literature review

A review of the current literature will be presented, namely, to provide a clear link between NFF and airworthiness. The two objectives to support the research area are to:

A. To explore current theories for different definitions of airworthiness and NFF and provide ones to be used as the basis for this research.
B. To establish the current understanding of NFF across different industries and the perceived impact of NFF upon operations.

1.4.2 Chapter 3 – Research methodology

The research methodology and approach to the analysis are presented. It details the approach to the survey and explains how the primary data was analysed. Additionally, it covers the analysis methods chosen to address the research aim.

1.4.3 Chapter 4 – Interviews analysis

The requirement for the aircrew and air accident investigators interviews are presented along with the reason for the application of Template Analysis (King and Brooks, 2017) to corral the themes from the interviews. The themes progress from *a priori* to final themes. These themes are used to present the analysis of the interviews, with a focus on NFF and airworthiness.

1.4.4 Chapter 5 – Questionnaire analysis

The requirement for the aircrew questionnaire is presented. To provide continuity for the analysis the template analysis and themes applied for the interviews are also applied to the questionnaire. An explanation is provided for where themes have been added or removed. Key themes that impact NFF and airworthiness are discussed.

1.4.5 Chapter 6 – Analysis

From the primary and secondary data, the analysis will address the '*as is situation*' using a rich picture and an influence diagram. The subsequent analysis, Bowtie diagram, Functional Analysis Resonance Method (FRAM) (Hollnagel, 2012), fuzzy logic inference and flow charts are used to present the strengths and weaknesses of the current situation to address a link between NFF and airworthiness. Further, these analyses indicate critical areas and present an approach to reduce the impact of NFF on airworthiness, from the aircrew and engineers' perspective. An explanation for the use of FNF instead of NFF is provided.

1.4.6 Chapter 7 – Discussion

A review of the thesis's aims, research questions and objectives is presented and indicates where and how these have been met. The Discussion will present the

‘original contribution’ and consider the wider implications of this research. It will include a reflection on the research method used.

1.4.7 Chapter 8 – Conclusion and recommendations

This re-states the aims, research questions, objectives and key findings, which asserts the aims and objectives have been met and the research questions have been answered. The applicability to other environments is stated along with recommendations and proposed further research.

1.5 Conclusion

This chapter has provided an introduction to the topic of NFF within the UK civil and military airworthiness environments and indicated that a link between the two has not been established. Advocates are evident to support either viewpoint. From the literature considered, it has been established that airworthiness is a tenet of the MOD and the recently, in military aviation lifespan, formed MAA. Moreover, whilst the Duty Holder has overall accountability and responsibility for the safety of those working on or around aircraft, members of the UK DAE likewise have a responsibility to highlight where aspects of air safety, of which airworthiness is a sub-element, are substandard and may jeopardize aircrew, engineers and the general public. Within the civil aviation environment, the safety of the crew and passengers is paramount. The AAIB investigations have shown a link between NFF and airworthiness. It is because of this aspect the association between NFF and airworthiness needs to be investigated and a link established, or not.

The Literature Review will consider key terms and definitions and establish the current viewpoint of NFF and airworthiness and identify any gaps or omissions within the resources available.

2 LITERATURE REVIEW

2.1 Introduction

Whilst from the MOD (2015c; 2022c) viewpoint the terms “air safety” and “airworthiness” are established and accepted, a wider view must be sought. So, before considering any link between airworthiness and NFF the terms need to be understood, critiqued and a common understanding proposed. Then any proposals for or against the linkage between the two terms will be reviewed. Incidents or accidents where NFF has been claimed or hinted at will be investigated. A link is defined as “a connection between two people, things, or ideas” (Cambridge Dictionary, 2023c).

Secondly, the literature review will consider the link between risk and airworthiness and any implications because of NFF. This will include analysis of topics such as cost, training, the operators and data recording, which are all contributors to understanding NFF and airworthiness. Aircraft safety and safe operation are required before a flight and key terms need to be explored and considered to determine how a NFF affects them, from the design through to the maintenance. Further, it will examine NFF across different disciplines. The Literature aims are as follows:

A. To explore current theories for different definitions of airworthiness and NFF and provide ones to be used as the basis for this research.
B. To establish the current understanding of NFF across different industries and the perceived impact of NFF upon operations.

The Literature Review will be structured as follows:

1. Explanation and definition of airworthiness. (or What is airworthiness?)
2. Explanation and definition of NFF. (Or what is NFF?)
3. Explanation of safe, safety, risks and links to airworthiness.
4. Requirement for training.
5. Data recording.

6. The operators (aircrew) and their workload and link to airworthiness and NFF.
7. Summary.
8. Research aims and objectives.

2.2 What is airworthiness?

Within many aviation standards, regulations and documents the term ‘airworthiness’ is used and yet few have provided a strong, precise and universally established definition so a common understanding can be formed. In 1956 Tye presented his philosophy of airworthiness and stated that he knew of “no satisfactory agreed definition of the word ‘airworthiness’” and declined to provide one (Tye, 1956, p.1). He proposed that chiefly it is a quality that enables an aircraft to contribute to a safe flight (Tye, 1956, p.1). Also, he suggested airworthiness was dependent on certain factors, including “controllability, stability, performance, structural strength and stiffness and reliability of moving parts” (Tye, 1956, p.1). He asserted that an aircraft described as airworthy has no unique significance—there is no absolute term as it is based on a person’s opinion of what is satisfactory (Tye, 1956, p.3). With relevance to NFF and this research, he stated the following:

> *“.. an airworthiness authority might disclaim responsibility for providing serviceability on the score that it was a matter for the operator to determine, I think that provision of serviceability might reasonably be considered as an aspect of airworthiness in the broadest sense.”* (Tye, 1956, p.1)

So, each person’s view of airworthiness will differ and the relevant authority (e.g., CAA, Federal Aviation Authority (FAA) or MAA nowadays) have a responsibility for providing airworthiness via their rules and regulation to ensure the aircraft is and can remain serviceable.

Some 50 years later, Kritzinger still acknowledges that variety exists but his viewpoint is that the designers need to adhere to certified design standards compliance, which he views as “rules and standards … considered necessary to

provide a safe product/system" (Kritzinger, 2006, p.24) Later he includes the requirement to "operate in a safe manner to accomplish its intended functions" and the requirement for the aircraft to be designed, managed, operated, maintained etc. by competent people within an approved organization and to the relevant standards (Kritzinger, 2006). However, without an agreed definition it could be argued that ambiguity, misunderstanding and omission can be allowed. Furthermore, the meaning of 'safe' needs to be established and this is addressed later.

A simple, dictionary definition for airworthy could be, "safe to fly" (Oxford Dictionaries, 2017). Again, the term safe is used. If considering crashworthy, a belief expounded by Masefield (Tye, 1952) was that no one wanted the aircraft to be "worthy of a crash". Using this as a basis, airworthy could simply be classified as something worthy of being in the air but this omits any context or consideration of those within the aircraft or the competence of the aircrew or engineers.

While the UK MOD had a definition of airworthiness provided in Joint Service Publication (JSP) 553 (MOD, no date, cited in Haddon-Cave, 2009, p.94), in his investigation into the loss of Royal Air Force (RAF) Nimrod MR2 XV230, Haddon-Cave stated that the definition provided was not understood. It has not been possible to view the original JSP 553 but the MOD (2008) Acquisition Operating Framework provided the same definition before the website was archived in November 2008 (MOD, 2008). A similar point was made by Richardson (2010) who maintains that national aviation standards use airworthy and airworthiness but the term airworthiness is not actually defined. The International Air Transport Association (IATA) describes airworthiness as "a term used to indicate when an aircraft conforms to its approved design and is in a condition for safe operation. This is indicated by the issue of an Airworthiness Certificate" (IATA, 2008, p.1). This could indicate that during the flight-test phase it may not be airworthy. IATA should have some credibility as it is a trade association, which represents 300 airlines and over 83% of worldwide air traffic, who contribute to the framing of aviation policy, especially those relating to critical issues (IATA 2022). The

International Council of Civil Aviation (ICAO) states that “Every aircraft engaged in international navigation shall be provided with a certificate of airworthiness issued or rendered valid by the State in which it is registered” (ICAO, 2006, Article 31). This is again focused on the whole aircraft and does not specifically address the systems, e.g., communication, radar, avionics, required to get the aircraft airborne or the aircrew who operate it, unless this is considered part of the “approved design”. It does, however, later state that:

> “… the International Civil Aviation Organization shall adopt and amend from time to time, as may be necessary, international standards and recommended practices and procedures dealing with: … d) Licensing of operating and mechanical personnel” (ICAO, 2006, Article 37).

Thereby, ICAO acknowledges the importance of qualified operators. This organization is a United Nations’ specialized agency and works with the Conventions, 193 Member States, and industry groups to gain accord on international aviation standards etc (ICAO, no date).

The MOD JSP 553 definition for airworthiness at the time of the Nimrod crash was as follows:

> “The ability of an aircraft or other airborne equipment or system to operate without significant hazard to aircrew, ground crew, passengers (where relevant) or to the general public over which such airborne systems are flown” (Haddon-Cave, 2009, p.164).

The 2015 MAA definition was as follows with the italics added to highlight the changes.

> Airworthiness “Is the ability of an aircraft or other airborne equipment or system to be operated *in flight and on the ground* without significant hazard to aircrew, ground crew, passengers or to third parties*; it is a technical attribute of materiel throughout its lifecycle*.” (MAA, 2015c).

The term “passengers” has been clarified and the definition now covers when the aircraft is on the ground. The 2022 definition (MAA, 2022c) has changed the

word aircraft for air system but otherwise remains unchanged. However, there is no clarification for the term attribute. Whilst attribute is defined as “A quality or feature regarded as a characteristic or inherent part of someone or something” (Oxford Dictionary, 2017), Finn (no date) clearly believed in a technical context the word needed expanding and clarifying for those involved with the Communication and Information Technologies. The crux of the attribute definition is the term ‘inherent’, which for technical equipment means something has been consciously or unconsciously designed in. It may be an emergent property. The critical aspect for Duty Holders is how they quantify a “significant risk” as this is a judgement call. It is questionable whether the final sentence of the current MAA definition is understood and as this is a vital term of the research topic, further investigation may be required to confirm this thought. However, following some ‘rough question analysis’ by the author of around 60 aviation engineers predominantly within the MOD who attended a Cranfield University Airworthiness of Military Aircraft Course in April 2017 the last phrase of the definition was not clearly understood. This then has similarities to Haddon-Cave’s (2009, p.164) assertion.

The Civil Aviation Authority’s (CAA, 2015a) airworthiness definition is succinct, namely “Information relating to the design, maintenance, repair and safe operation of aircraft.” By 2022 this had changed to include production but remove ‘safe operation of aircraft’ aspect (CAA, 2022a). However, a certificate of airworthiness is issued when the company “has demonstrated that the aircraft is in conformity with the design certified in accordance with Article 11, and that the aircraft is in condition for safe and environmentally compatible operation” (CAA, 2022b). Whilst the FAA has not published a definition for airworthiness it does state that two conditions from FAA case law must be met and these are that “the aircraft must conform to its type certificate” (which is the approval of the design of certain types of aircraft, engines and propellers (CAA, 2015b) and “the aircraft must be in a condition for safe operation” (FAA-Aircraft-Certification.com, 2007). Additionally, “the goal for those persons who operate and maintain aircraft is to keep them in an airworthy condition. The FAA refers to this condition as ‘continued airworthiness’” (Aviation Safety Bureau, 2007). So, the FAA

explanation is very similar to that of the CAA (2022b). Kritzinger (2006, pp.25-26) agrees with the FAA but adds that it includes being able to land safely and that *if* the aircraft configuration differs from the type certificate, then the airworthiness is compromised. So, if an NFF causes the aircraft type certification to be compromised it may provide a direct link to airworthiness. However, there would have to be a strong case that the apparent, or combination of apparent, faults did cause the aircraft to be unsafe. Again, this would ultimately be a judgement of the Duty Holder and those to whom they have delegated airworthiness responsibility. What aircrew would consider 'unsafe' would have to be established and this may be different for military and civilian pilots. Kritzinger (2006) makes a clear distinction between system safety and airworthiness and he is clear that system safety includes operational deployment. The distinction is made because he does not believe that hazards can always be resolved. The UK Health and Safety at Work Act (HSWA) requires that employees are provided with equipment and systems of work that are safe (Health and Safety at Work etc. Act 1974: Elizabeth II. Chapter 37, Part 1 General Duties, Section 2, 1974); the principle of as low as reasonably practicable (ALARP) is applied. Even for operational deployments, the risk should be ALARP. The safety case should be a living document that is continually reviewed to identify hazards and trends that may impact risks regarding the design and operational safety. It should allow the user to understand the combined and/or interconnected risks from using the system in question (Gov.UK, 2019).

The Australian Government Department of Defence described airworthiness as a concept and it comprised two areas, Operational Airworthiness and Technical Airworthiness. The first relates to those operating the aircraft and includes the need for competent operators, the fitment of the correct equipment, and to be flown in accordance with procedures and training (Defence.gov.au, 2015). Moreover, a system of monitoring and supervising the operators must be in place (Defence.gov.au, 2015). The technical airworthiness concept relates to the fitness for, and sustainability of, flight of the aircraft based on design, build and maintenance standards implemented by competent and authorized persons (Defence.gov.au, 2015). In 2016 the Australian Defence Aviation Safety

Regulation (Defence Aviation Safety Authority, no date) was formed and the airworthiness definition was no longer split into two components but more closely resembles that of the MAA (2022c) but without mention of the technical attribute.

When writing his report Haddon-Cave used the Australian airworthiness definition which is:

> "to provide assurance that aircraft have been designed, constructed, maintained and expected to be operated to approved standards and limitations by competent individuals who are acting as members of an approved organisation and whose work is both certified as correct and accepted on behalf of the MOD". (Haddon-Cave, 2009, p.500)

This definition draws out the requirement for both engineers and aircrew to be competent, something that is missing from the CAA (2015a) and MAA (2015c and 2022c) definitions. So, it would be a valid requirement for aircrew to understand the engineering conducted on their aircraft (to a degree) and to have an appreciation of NFF and its implications.

According to the Aviation Safety Bureau (2010), "the goal for those persons who operate and maintain aircraft is to keep them in an airworthy condition", meaning "continued airworthiness" in FAA parlance.

Across different countries and organizations, different definitions of airworthiness are used. For completeness, these are presented in Table 2-1. Where they are from the same organization the change(s) have been highlighted using italics. This is not an exhaustive list but merely compiled to highlight that there are different definitions and the similarities and differences.

Table 2-1: Airworthiness Definitions from Different Organizations

Organization	Year	Definition
Oxford Dictionaries	2017	“Safe to fly.”
Australian Government - Department of Defence	2015	Is a concept, the application of which defines the condition of an aircraft and supplies the basis for judgement of the suitability for flight of that aircraft in that it has been designed, constructed, maintained and operated to approved standards and limitations, by competent and authorised individuals, who are acting as members of an approved organisation and whose work is both certified as correct and accepted on behalf of Defence. Airworthiness comprises the following elements: a. **Operational airworthiness**—Operational airworthiness is concerned with ensuring aircraft are operated in approved roles, with correct mission equipment, by competent and authorised individuals, according to approved procedures and instructions, under a system of supervision and monitoring. b. **Technical airworthiness**—A concept which defines the condition of an aircraft and supplies the basis for the judgement of its sustainability for flight in that it has been designed, constructed and maintained to approved standards by competent and authorised individuals, who are acting as members of either an approved or authorised organisation and whose work is certified as correct and accepted on behalf of the ADF.
CAA	2017	"...it is satisfied that the aircraft is fit to fly having regard to: “Information relating to the design, maintenance, repair and safe operation of aircraft.”
EASA	2017	EASA Part M Requirements – Article 2 Definitions (d) “‘continuing airworthiness’ means all of the processes ensuring that, at any time in its operating life, the aircraft complies with the airworthiness requirements in force and is in a condition for safe operation.”

EDA	2017	The ability of an aircraft, or other airborne equipment or system, to operate in flight and on ground without significant hazard to aircrew, ground-crew, passengers (where relevant) or to other third parties.
FAA		No definition provided but - “The definition is not published in the regulations, but FAA case law has identified two conditions that must be met for an aircraft to be considered airworthy.” (Aviation Safety Bureau, 2017
IATA	2008	“Airworthiness is a term used to indicate when an aircraft conforms to its approved design and is in a condition for safe operation. This is indicated by the issue of an Airworthiness Certificate”
MOD – JSP 553	n.d.	“The ability of an aircraft or other airborne equipment or system to operate without significant hazard to aircrew, ground crew, passengers (where relevant) or to the general public over which such airborne systems are flown.”
MOD MAA02	2020	“Is the ability of an aircraft or other airborne equipment or system to be operated *in flight and on the ground* without significant hazard to aircrew, ground crew, passengers or to third parties*; it is a technical attribute of materiel throughout its lifecycle*.”

2.3 Development following Haddon-Cave's report

Toy stated that "Regulatory (safety) decisions must be evidence based and proportionate to the Risk to Life" (Toy, 2014, p.13) and that those involved needed to "Be pragmatic, but … [to] not let ease of compliance or cost of compliance drive the argument" (Toy, 2014, p.13). A similar view could be afforded to NFF and airworthiness. The ease and timeliness of completing one maintenance task over another to make the aircraft available (as defined by Jones (2006)) should not drive the work completed if a better solution may be available following full or deeper analysis and consideration of the whole problem if a holistic manner was conducted. This links with Lister's (MOD, 2015) view on current maintenance aiding the diagnostics available for future aircraft. Toy additionally confirmed that "There is an impression that it is sometimes easier to risk manage rather than engineer a solution" and that those arguing for operational flexibility were usually the individual who would benefit from the flexibility (Toy, 2014). This applies at many levels including those who would benefit from having the maintenance completed in the shortest period possible, whether that is the engineer, the manager or the operator. The act of doing a test and declaring "test satis" (test completed satisfactorily) does not mean the fault is still not present but just that under those conditions and circumstances the fault could not be reproduced. Further testing or diagnostics may lead to a different solution or a better understanding of the conditions needed to reproduce the fault. A belief is that managers are managing the risk and not safety (Richardson, 2017) and for repeated NFF or intermittent failures this inability to view the complete picture may not just affect the risk but ultimately the safety of the aircraft and crew. As the airworthiness definition states "without significant hazard to aircrew …" etc. this may be jeopardized.

2.4 Airworthiness summary

In summary, it has been established that there is no agreed definition of airworthiness. However, it relates to the design of the aircraft and the maintenance practice to safeguard the aircraft type certification. Furthermore, the

competency of the operators, aircrew and engineers needs to be established, maintained and managed. Going forward, a revised airworthiness definition is proposed. The current MOD MAA airworthiness definition will be used, over that provided by the CAA, as it incorporates the significant hazard to aircrew and acknowledges the 'technical attribute' of the aircraft, even though this latter aspect is not fully understood by some engineers within the MOD. However, a weakness of the MOD definition is that it does not incorporate any requirement for competent engineers, aircrew or managers and, therefore, an adjunct to the MAA definitions was made to incorporate this aspect from the Australian Government airworthiness definition (defence.gov.au, 2015) and that by Kritzinger (2006), namely stating the need for competent engineers and aircrew. This revised airworthiness definition to be used for this research is shown below.

> 'Is the ability of an aircraft or other airborne equipment or system to be operated *in flight and on the ground* without significant hazard to aircrew, ground crew, passengers or to third parties*; it is a technical attribute of materiel throughout its lifecycle;'* ***it is to be undertaken*** **by competent and authorized individuals, according to approved procedures and instructions**. Adapted from: MAA (2015c)

That means all the activities (including design, operate, maintain) to achieve airworthiness are to be undertaken by competent and authorized individuals and as per approved standards, procedures and instructions.

2.5 What is NFF?

Within this section, the different definitions of NFF will be considered to ascertain a common understanding or agreed understanding of the terms and where there are alternatives. Additionally, an understanding of intermittent faults has to be established as they have a direct link to NFF events.

In 2001 the high number of NFF in electronic equipment had not been established but it was conjectured that software coding issues and transient effects contributed but more investigation was required (Jones and Hayes, 2001). Their view was that a NFF was an "occurrence of a failure without an identifiable root

cause" (Jones and Hayes, 2001, p.289). By 2002 Thomas, Ayers and Pecht (2002) had established that the phenomenon of NFF was known by different terminology under the banner of "trouble not identified." They confirm that it is the result of an equipment failure that engineers are unable to reproduce, prove existed or link to a type or site within the equipment (Thomas, Ayers and Pecht, 2002), which aligns with Jones and Hayes's simple explanation of a NFF.

Aeronautical Radio, Incorporated (ARINC) in their guidelines on NFF, regard it as a phenomenon that is the "removal of equipment from service for reasons that cannot be verified by the maintenance process (shop or elsewhere)" (ARINC, 2008, p.1), or within the glossary as "A result of testing when a unit is removed as faulty at one level of maintenance is found to be fault free when tested at the next lower level of maintenance" (ARINC, 2008, p.30), but emphasize that an interdisciplinary effort, including designers, operators and maintenance personnel, is needed to establish the real cause and to put in place sound solutions. The two ARINC descriptions of NFF are at odds as the first states it cannot be verified, meaning the truth cannot be established, and the second states 'fault free'. If the truth cannot be established then the opposite must also be true, it cannot be proved to be untrue. The ARINC (2008) report provides guidelines and general information that is found to be good practice for aviation organizations. Whilst an ARINC standard is for voluntary consensus-based use, the credibility of the document is that it is created by an international standards organization, Airline Electronic Engineering Committee (AEEC) (SAE ITC, 2022). The AEEC aims to "foster increased efficiency and reduce lifecycle cost for the aviation community" while representing "the technical position" of the aviation industry by the involvement of "over 4000 engineers and scientists", who represent almost "250 sponsoring organizations, participant in the development of ARINC standards" (SAE ITC, 2022). The ARINC standards should be reviewed every five years (SAE ITC, 2022). Additionally, there is a stringent process for their "development, adoption and publication" (SAE ITC, 2022). It should be noted that the ARINC report works from the viewpoint that the component is removed from the system/aircraft when in reality it may still be fitted to the system.

“No Fault Found (NFF) is a phenomenon that affects technological equipment and leads to an adverse impact on business operations” (Pickthall, 2014, p.59) and it is deemed to be a chain of events similar to that asserted by Avižienis, Laprie, and Randell (2001) for fault, error and failure. Pickthall (2014) also considers very briefly the safety of operations. His paper was focused on human factors and aviation safety but from the engineer’s perspective and not from the operators’/pilots’ perspective. Pickthall surveyed aviation engineers from civilian and military environments and found that a high percentage “believed that NFFs are more common on modern aircraft” (Pickthall, 2014, p.61) with digital flight decks.

Pickthall declares that “The adverse effect that lack of training has on the NFF phenomenon is clear but it also has a wider impact on the industry that includes negative consequences towards operational achievement, flight safety and organisational reputation” (Pickthall, 2014, p.64). The consideration of training is important as this could impact the aircrew’s understanding and need to report NFF. His focus was on aviation engineers and aligns with the finding of Hockley, Lacey and Pelham (2016). However, neither research undertaken by Pickthall nor Hockley, Lacey and Pelham surveyed or interviewed aircrew and, therefore, the aircrew could hold similar views regarding the need for training and the increase in NFF with digital flight decks. Moreover, it is unknown what pressures aircrew exert, either subliminally or openly, on engineers to complete the maintenance. Aircrew need serviceable aircraft if they are to maintain the requisite flying hours per year. Conversely, the impact of the NFF on the aircrew as a distraction has not been considered; this again, establishes a need to assess the area of NFF with aircrew. Khan et al. simply describe NFF as ‘‘a reported fault for which the root cause cannot be found’’ (Khan et al., 2015, p.30) and go on to state that “From a technical standpoint, a ‘No Fault Found’ tagged component is the result of an unsuccessful (or inefficient) troubleshooting regime of an unscheduled maintenance activity” (Khan et al., 2017, p.20). Khan et al. are clear that the fault existed at the time of reporting or during the flight. A problematic example of a NFF would be a computer ‘hang-up’. The normal practised procedure would be to reboot the computer as this would clear the fault

for the majority of occurrences. The fault existed at the time it was reported but the reboot effectively cleared the fault under the current conditions.

A computer hang-up could be deemed to be just an intermittent fault (IF) which "are defined as failures that can automatically recover once they have occurred" (Guanqian et al., 2014. p.390). The resetting or re-establishment of the 'normal operating' conditions (e.g., removing high g-loading) will remove the fault (Guanqian, G. et al., 2014). The differences and relationships between a fault, error and failure are explained by Avižienis, Laprie, and Randell (2001), with a fault being able to lead to a failure but this can be stopped at any time and, moreover, faults can be dormant until the conditions, such as the environment, change to activate the fault. However, intermittent faults are acknowledged to be responsible for the majority of errors and can happen more often than permanent faults by 10 to 30 times (Guanqian et al., 2014). Furthermore, Reason (1991) pointed out that dormant (latent) errors are not usually caused by the operator but by those removed from the operating environment, the designers, technicians and decision-makers and more effort to remove the dormant faults will have greater positive outcomes upon system safety than local efforts to manage the 'active' errors. This implies that addressing a NFF as just a local technical fault is insufficient and more effort should be placed into finding the source and removing that. This will lie with the designers and continuing airworthiness managers etc.

According to Copernicus, NFF is simply "a chain of events that typically commences with the pilot experiencing a fault symptom and then, after diagnostic and repair activities have been carried out by the maintenance organisation, the same symptom occurs again" (Copernicus Technology Ltd, 2012, p.3). It should be noted that Copernicus (2017b) is a commercial company that promotes the fact that they employ staff with military engineering and operational backgrounds. However, Huby, Managing Director of Copernicus Technology Ltd, was a member of the NFF working group created by ADS Group. Whilst Copernicus considers capability and missions there is no mention of airworthiness. They questioned the cost of NFF across the domains of air, land and sea and recognized that NFF was a distraction and that "When the distraction happens is

the important issue" (Copernicus Technology Ltd, 2017a). However, an extension to this question would be to ask about the cost in terms of airworthiness. Not only the financial cost but whether the inherent technical characteristic was tested for and approved with intermittent faults and NFF before the certificate of airworthiness was signed off. If so, maybe these are accepted costs in terms of delayed or lost flights as a result of NFF. However, as shown in Figure 2-1, research that has been conducted (Khan et al., 2015, p.104; Hockley, 2016), was focused on the operating companies, the manufacturers (the original equipment manufacturer (OEM)) and the engineers but it did not analyse the start of the information process—the input from the operators, so aircrew in the case of aircraft. It is the aircrew who experience the NFF first-hand. This valuable information does not appear to be examined in detail and is frequently just expressed as the reported fault but with no requirement or desire to examine this in any detail.

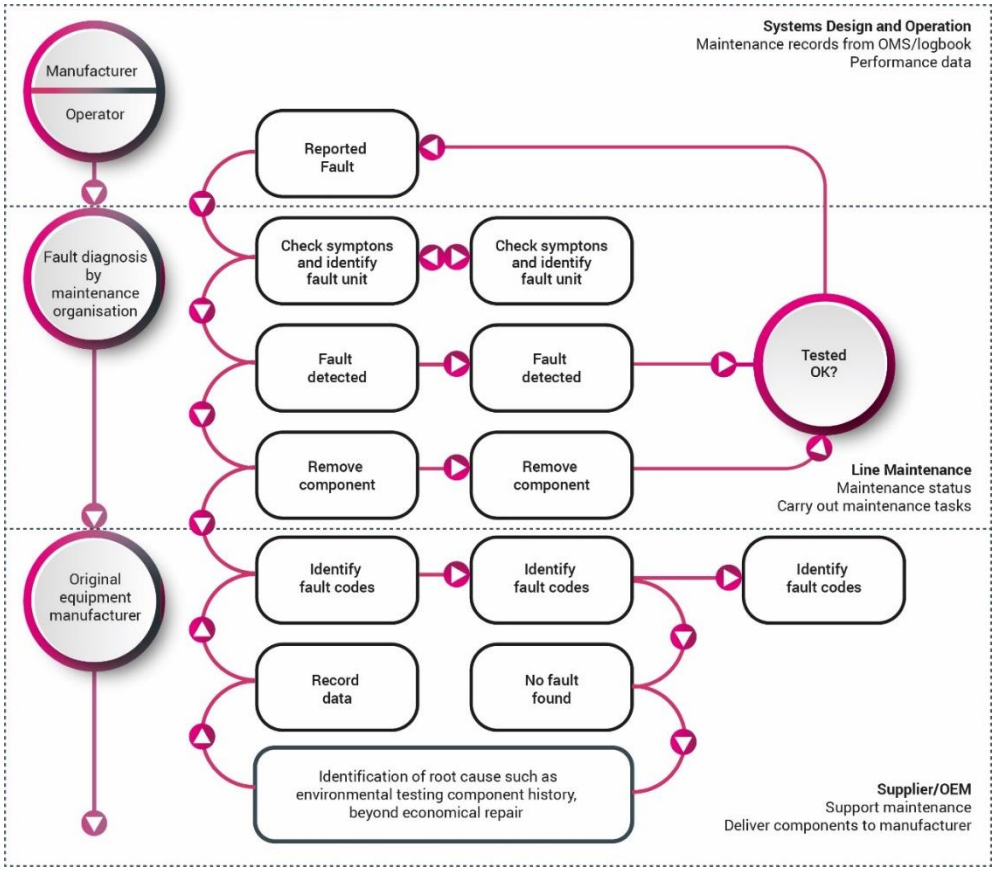


Figure 2-1: The stakeholders and their interaction at the component level (Khan et al., 2015, p.104)

Whilst, Qi, Ganesan and Pecht (2008) grant that operation and maintenance conditions may differ regarding the “temperature, humidity, vibration” and that the “loading conditions” play a part in any fault for an aircraft, this must also include the yaw, pitch and roll, or combination of, as many NFFs are attributable to wiring and circuitry, which may be affected by the aircraft’s orientation. A large percentage of NFF events or inconclusive test results are consequences of irregular wiring and connector connections, which are known as “intermittent circuits” (Steadman et al., 2005) and like Guanqian et al. (2014) conclude that the majority of NFF occurrences are caused by poor wiring connections.

The judgement of airworthiness varies across establishments and the Turkish Air Force does not tolerate repeat failures or those that lead to abortive missions (Ilarslan and Ungar, 2016). This contrasts with that observed by Hockley, Lacey and Pelham (2016) where the RAF had no clear approach to managing NFF. It is acknowledged that those in management positions do not appreciate the seriousness of the NFF situation and this is because suitable metrics to quantify the problem do not exist (Khan, Farnsworth and Erkoyuncu, 2017). From their research, it is not apparent whether this view was held by aircrew as well, as this is not evident from the key and sub-themes for NFF in industry they proposed (Figure 2-2). The key NFF themes in industry are fault diagnostics, data management, processes/procedures/human factors and system design, with associated sub-themes.

As their research was for NFF in industry, it is proposed they did not consider the aviation industry. However, it is suggested that the aircrew input may be included under ‘operational feedback’ or ‘communication’. From an airworthiness viewpoint, this may be important as both the MOD and the Australian Government include the operator within the definition of airworthiness and, thus, are the first-hand recipients of a NFF event. It is worthwhile noting the inclusion of accountability and training within Figure 2-2 as these are considered later.



Figure 2-2: NFF Themes in Industry (Khan, Farnsworth and Erkoyuncu, 2017)

From analysing the literature on NFF it is concluded that much is written about what it is, the phenomenon, what can be done to make financial savings and improve the availability of the aircraft. Nevertheless, there is no agreed simple definition of NFF. Mostly it is described (Table 2-2). Thus, going forward the following description of NFF will be used:

> "NFF is therefore described as the output of a diagnostic process where the root cause of a reported fault cannot be verified." (Erkoyuncu et al., 2016, p.208)

Table 2-2: NFF definition and or description

Definition / Description	Source
“Removals of equipment from service for reasons that cannot be verified by the maintenance process (shop or elsewhere)”	ARINC (2008 cited in Khan, et al., 2012, p.187)
“A result of testing when a unit is removed as faulty at one level of maintenance is found to be fault free when tested at the next lower level of maintenance”	ARINC (2008, p.31)
NFF is “a chain of events that typically commences with the pilot experiencing a fault symptom and then, after diagnostic and repair activities have been carried out by the maintenance organisation, the same symptom occurs again”	Copernicus Technology Ltd (2012, p.3).
“NFF is therefore described as the output of a diagnostic process where the root case of a reported fault cannot be verified’”	Erkoyuncu et al., (2016, p.208).
‘‘A reported fault for which the root cause cannot be found’’ “From a technical standpoint, a ‘No Fault Found’ tagged component is the result of an unsuccessful (or inefficient) troubleshooting regime of an unscheduled maintenance activity”.	Khan et al. (2015, p.26)
“The inability to replicate field failure during repair shop test/diagnosis”	Kirkland (2011 cited in Khan et al., 2012, p.4)
“No Fault Found (NFF) is a phenomenon that affects technological equipment and leads to an adverse impact on business operations”	Pickthall (2014, p.59)
“A failure that may have occurred but cannot be verified, or replicated at will, or attributed to a specific root cause, failure site, or failure mode”	(Qi et al., 2008) Also cited in Khan, et al., 2012, p.4)
“No Fault Found is a reported failure that cannot be confirmed, recognised or localised during diagnosis and therefore cannot be repaired”	(Roke, 2009, cited in Khan, et al., 2012, p.4)
The result of an equipment failure that engineers are unable to reproduce, prove existed or link to a type or site within the equipment	(Thomas, Ayers and Pecht, 2002).

The advantage of the description being used over that provided by ARINC (2008) and Kirkland (2011 cited in Khan et al., 2012) is that it does not require the unit

to be removed from the platform, whether that be an aircraft, train or car. A NFF can be recorded on an aircraft after diagnostics and this was supported by BAE Systems (Murray, 2013) citing also operator policy and operational expediency.

It is evident that no consideration has been given to what the aircrew can do to assist with NFF. How their input can help with the understanding and experience of NFF and its impact. If agreeing with ARINC (2008) that is it interdisciplinary, then their involvement is important and may even be crucial. Additionally, the need to understand how much of a distraction a NFF can be to the aircrew, as evidenced by the Flybe aircraft DHC-8-402 Dash 8, G-JECF (AAIB, 2012b), is important in implementing it within an organization's risk management strategy.

2.5.1 Cost of NFF

If the cost of NFF can be established, then a commercial reason exists to reduce it as much as possible. This may help drive the need for more operator input. Evidence on the true cost of NFF is hard to establish as many companies do not record the actual time spent undertaking NFF diagnostics and maintenance. This is compounded by the terms used to record NFF events, such as No Fault Found, Retest OK, Cannot Duplicate, Fault Not Found (Khan et at., 2012) and no fault indications, reseated ok and assessed serviceable (Hockley, Lacey and Pelham, 2016).

The cost values are imprecise; most are estimates. For some companies, this is because they do not know the true value or from where within the supply chain it should be calculated. Companies do not consider all the buried costs such as handling, transportation, maintenance, testing time and physical resources, including manpower. As an example, in 2005, within the mobile telephone industry, it was established that of the telephones returned to the manufacturer, 63% were classified NFF and for the UK this equated to approximately £54 million and a value of $4.5 billion was estimated to be the worldwide cost (Ungar, 2015). The estimated cost for 2010 was $10 billion (Ungar, 2015). What this figure does not reveal is that many were returned as the customer did not know how to use the telephone correctly—human error. This supports the notion that training is a key requirement to reduce NFF. As the cost of NFF is unknown it is proposed

that the hidden costs to the OEM, operator and supply chain need to be incorporated into any commercial contract that involves NFF equipment (Singh and Ganguly, 2021).

Within the aviation world, values are again imprecise. However, indicative values have been stated and these range from millions to billions (Table 2-3).

Table 2-3: Cost of NFF

Source	Year	Cost
British Airways	1990	£20M (Copernicus Technology Ltd, 2014)
United States (US) Air Transport Association	1997 2014 adjusted figure	$100,000 per aircraft per year or $20M for an airline operating 200 aircraft. $140,000 per aircraft per year = a global cost of $2.2 billion every year (Söderholm, 2007; Khan et al., 2015)
RAND Corporation	2000	At $800 per component removal, NFF costs commercial aviation £300,000 per annum. (Mark et al., 2000)
US Air Force	2001	$10,000,000 spent by F-16 customers exchanging NFF Line Replaceable Units (LRU) (Steadman et al., 2002).
	2002	F-16 LRU exchanges had a 67% NFF rate (Steadman et al., 2002)
	2014	$2,000,000 per year for this one modular low-power radio frequency component (Copernicus Technology Ltd, 2015)
Air Transport Association	2002	4500 NFF events cost Air Transport Association members $100,000,000 annually (Beniaminy and Joseph, 2002)
BAE Systems	2013	The theoretical rate for one avionic component for a fleet - £500 k per annum (Murray, 2013)
US Department of Defense		Annual NFF cost exceeds $2 billion per year (Copernicus Technology Ltd, 2015)
US Naval Air Command (NAVAIR		$94M on NFF equipment removals which have actually resulted from wiring problems (Copernicus Technology Ltd, 2015) (Khan et al., 2015)
UK Royal Air Force	2016	NFF rate is 28-58% higher than quoted within RAF maintenance databases. For only four aircraft fleets maintenance man-hours costs

		£1.9M per annum and for all RAF fixed-wing fleets, this equates to greater than £7.4M per annum. (Hockley, Lacey and Pelham, 2016)

The introduction of the Boeing 787 Dreamliner was marred by a NFF of the lithium-ion batteries that overheated resulting in the Dreamliner deliveries being halted (BBC, 2013). The head of research at the Royal Aeronautical Society stated that it may result in a major redesign of the aircraft if the fault was not caused by the battery (Hayward, no date, cited in BBC, 2013); an analyst put the cost of the redesign between $250 million and $625 million and that was prior to the root cause being established (BBC, 2013).

For the NFF themes, (Khan, Farnsworth and Erkoyuncu, 2017) operational feedback is an input to the system design and it is speculated that it may also be included in the processes/procedures/human factors theme via the communication sub-theme (Figure 2-2). By improving the quality and precision of operator feedback the engineers may better understand the fault conditions and location and, notwithstanding the technical issues also included in Figure 2-2, they can direct the diagnostics to the correct area quicker. Doing so should hopefully reduce the maintenance, supply and transportation costs and the NFF occurrences. The operator's (aircrew) and engineers' feedback can be used by the designer to enable the publications, e.g., engineering manuals and aircrew flight reference cards, to be amended and improved. However, it must be accepted that on modern digital aircraft with Health and Usage Management Systems (HUMS) and flight-data recorders the input of the operator may be reduced as much information can be extracted from these sources. However, their feedback on the impact to airworthiness and their safety, are important considerations that need to be voiced and acknowledged.

2.6 NFF and airworthiness

The following will specifically look at links between examples of NFF and airworthiness with aircraft accident investigations.

2.6.1 UK military air accident investigations

The UK Government has made available MOD Service Inquiries (SI), Board of Inquiries (BOIs) and Military Aircraft Accident Summaries (MAAS) with more to be added as they become available following the presentation to Parliament (Gov.UK, 2017). Within these, there are over 320 UK Military Air Accident Summary (MAAS) from the period 1979 to the present date, 27 aviation-related Service Inquiries and three Boards of Inquiries. Each serves a slightly different purpose. A SI is held to comprehend the circumstances that caused a military incident where there was a death or serious injury and to state changes to avert a repetition (Gov.UK, 2017). Within the context of military aviation, a Board of Inquiry is raised following a serious military aircraft accident and the subsequent MAAS is the document presented to Parliament, written in layman's terms (Gov.UK, 2017). For this analysis, a MAAS has its limitations in that it is just a précis of the full investigation, usually limited to approximately four pages, and does not provide the depth of technical information required for full analysis. However, analysis of these has indicated that the cause of three accidents may have been due to a NFF—the explicit wording, NFF, has not been used. Each will be discussed to explain the deduction.

1. RAF Jaguar GR1 XX963 – 1982

   The scenario for this accident was that during a simulated war-conditions exercise, a Phantom aircraft released a live air-to-air missile that hit Jaguar XX963, which was on a routine exercise and not part of the war-condition exercise (MOD, 1984). "The cause of the accident was the inadvertent firing of the missile by the Phantom crew who, when airborne, followed the procedure applicable to an unarmed aircraft … despite carrying live weapons" (MOD, 1984, p.2). However, the report goes on to state the accident was caused by an amalgamation of failures where:

   "a circuit breaker in the rear cockpit, which was normally used to isolate the firing system, was unreliable in that it was possible to depress the circuit stalk just sufficiently to make electrical contact and render the circuit live, without pushing the circuit breaker fully home" (MOD, 1984, p.2).

It is reasoned that as the aircraft maintenance records, included as part of the investigation, must have recorded the unreliability of the circuit breaker and that this was either a known problem and/or one that had been recorded more than once. As the report does not state anything regarding poor maintenance practices (as per other MAAS), it must be surmised that the engineers investigated the cause of the unreliability and were unable to find the root cause. The report neither indicates whether this was raised as a limitation with the aircraft's F700[1] nor indicates over what period the unreliability had been evident. As the full investigation report is not available these assertions cannot be verified; however, the unreliable circuit breaker was of sufficient concern for the investigators to recognize it as contributing to the cause of the accident. Based on the above, the opinion is that this is indicative of a NFF, a fault for which the root cause has not been established (Khan et al., 2015).

This probably NFF impacted the air safety of another aircraft and resulted in a significant hazard to a third party, namely the pilot in the second Jaguar aircraft (See airworthiness definition Section 2.4). This builds on the concept of a NFF being linked to airworthiness.

2. Harrier ZD377 – 1997

   The scenario for this accident was that the aircraft experienced a nose drop soon after take-off, whilst still at a low level, before flying into the ground (MOD, 1999). Whilst the pilot's flap check on the ground did not indicate a fault, once airborne the aircraft rose higher than expected, the pilot took corrective action to lower the nose and adjust the rear engine hot nozzles but he realized the flaps control was not working (MOD, 1999). The report states that an intermittent electrical fault "could have caused

[1] "The MAA recognize the MOD Form 700 as a method of recording Maintenance activity and Airworthiness data. The MOD Form 700 is an omnibus title given to a collection of MOD Forms in the 700 numerical series. When assembled and allocated to a specific Air System ►or◄ Products, Parts and Appliances, the MOD Form 700 provides a history of the associated Air System ►or◄ Products, Parts and Appliances and a statement of its current condition." (MOD, 2022b)

the flaps to malfunction" (MOD, 1999, p.2). This aligns with the findings by Guanqian et al., (2014) who showed that intermittent faults are linked to most errors and, thus, if they cannot be detected are linked to NFF events.

3. Canberra T4 WJ866 - 2004

The scenario for this MAAS was a Canberra night-time flight check that incorporated a simulated engine overshoot, roll and land manoeuvre when during the third circuit the aircraft landed, swerved left, which was corrected by the pilot's yaw input, and the aircraft became airborne before hitting the ground and stopping 1000 m away (MOD, 2006). "The Inquiry concluded the accident was caused by the aircraft becoming airborne in an asymmetric power configuration below a safe speed" (MOD, 2006, p.1).

However, the MAAS goes on to state that:

"The aircraft was found to be serviceable apart from a *propensity* for the left-hand engine to 'hang' in the 4000 rpm range *during testing*. It is most probable that as power was applied to commence the roll, the left hand engine stagnated at around 4200 rpm, which meant that the aircraft was unbalanced, with more power coming from the right hand engine, causing the aircraft to yaw left" (MOD, 2006, p.4).

The italic emphasis has been added to highlight important words concerning a possible NFF event. *Propensity* indicates that this was a known phenomenon and accepted. It is deduced that this would have been investigated, on more than one occasion, to establish the cause and to try to remedy a solution. It is unlikely that it would have been accepted or tolerated without investigation and this links to the "*during testing"* element of the MOD statement. As the complete investigation report is not available the engineers' work record cards cannot be analysed to establish the duration of this *propensity,* what remedial work had been undertaken and if it occurred only when the engine was fitted to this aircraft. However, this is indicative of a NFF, as described by Khan et al. (2015). Moreover,

it was a probable NFF that impacted the airworthiness of the aircraft and culminated in a significant hazard to the aircrew. The three crew ejected but only one survived. This builds on the concept of a link between NFF and airworthiness.

Of the 27 aviation-related Service Inquiries only one used the phrase NFF and no others gave any indication that a NFF may have been present or investigated. The one incident was for Tucano ZF349 at RAF Linton-on-Ouse (MAA, 2013).

4. Tucano ZF349 at RAF Linton-on-Ouse

The following is a précis of the key points relevant to this analysis from the SI (MAA, 2013). To appreciate the internal working of the fuel control unit torque motor, see Figure 2-3.

Following maintenance work to rectify a previous engine exhaust gas over-temperature reading, a partial-test flight was conducted that included checking the engine control and performance in the engine electronic control normal and manual modes. As abnormal torque readings were noted during the manual mode the aircrew chose to end the flight test. However, when switching from manual to normal mode a loss of thrust was felt and an emergency landing was conducted.

The investigation panel hypothesized that when the selection was made for the Engine Electronic Control to switch from manual to normal mode there was a change in the ram recovery air. That resulted in a fast pressure change within the fuel control unit torque motor unit and, consequently, the bellows became displaced from the housing, due to a failure of the adhesive - probably due to age and environmental conditions. This meant the pressure differential between the flapper and the nozzle could not adjust automatically to manage the pressure differential. This resulted in a decrease in fuel flow to the engine and a resulting reduction in engine rotational speed and, therefore, thrust that the crew felt.

Whilst the fuel control units were tested following the manufacturer's procedures it was noted that routine bench testing of the fuel control unit

resulted in some control units being classified as NFF and returned as serviceable, only to fail upon refit to an aircraft. The torque motors do not have a lifing policy and are not tested individually unless the fuel control unit failed a test. Consequently, the maintenance company undertook testing of the torque motor by applying a current test procedure. However, the torque motor on ZF349 had *not* been tested. The investigating panel concluded that as the fuel control unit had been fitted to the aircraft for 69 flying hours without any anomaly, a failure within the torque motor 'would' not have been evident. The investigating panel decided that the failure of the fuel control unit test procedure to identify faulty components was not a contributing factor to the incident but the limitations of the standard test meant that faulty torque motors were returned to service. (MAA, 2013)

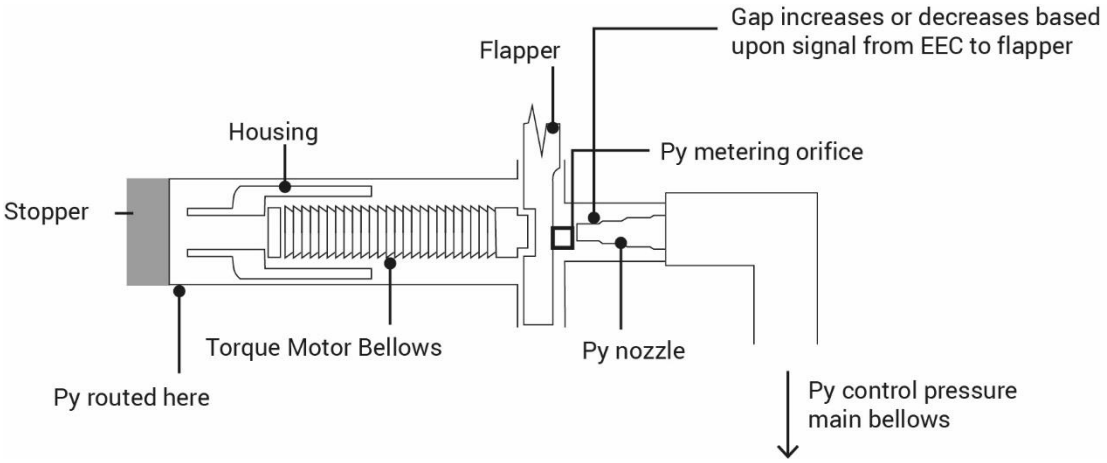


Figure 2-3: Internal section of the Tucano fuel control unit torque motor, identifying the bellows and flapper value (MAA, 2013, pp.1.4-10)

However, what the SI does not indicate is the sensitivity of the torque motor test and how much age and environmental factors affect the test and the likelihood that it will indicate a failure. Moreover, the temperature and pressure at which the testing was conducted would probably impact any results (Söderholm, 2007) and it is unknown if these parameters were indicative of the normal usage conditions for the torque motor and bellows. Additionally, of the torque motors that had been tested, there was no indication of how many had passed and how many hours elapsed before failure was evident. It would have been useful to know if any Failure Modes, Effects and Criticality Analysis (FMECA) or highly

accelerated life testing or highly accelerated stress screening had been conducted on the torque motor. All this indicates that the NFF may have contributed more to the incident than was first apparent.

This builds the concept that there is a link between NFF and airworthiness. It was a technical attribute of the systems that posed a ‘significant’ hazard to the aircrew, culminating with a controlled emergency landing and smoke coming from the front and rear cockpits. the aircraft.

2.6.2 Civilian air accident investigation

In addition to the two AAIB investigations covered in Chapter 1, this section will highlight another civilian incident investigated by the AAIB that had a clear link with NFF and impacted airworthiness.

1. Report on the serious incident to Airbus A319-111, registration G-EZAC near Nantes, France on 15 September 2006 AAIB 9/2009

   The following is a précis of the key points relevant to this analysis from the AAIB Report (AAIB, 2009).

   Whilst flying between Alicante and Bristol the aircraft, G-EZAC, suffered an electrical failure that caused many aircraft systems to be degraded or inoperative. Consequently, the aircraft could only be flown manually, the captain’s electronic flight instrument display went blank and the radios did not work so no contact could be made with air traffic control for the remainder of the flight. Efforts to reconfigure the electrical system were unsuccessful so the crew flew and successfully landed the aircraft in the degraded condition: the operation of the aircraft was significantly harder for the crew.

   Of note, during the previous flight, the aircraft had experienced an electrical fault that affected the No 1 (left) electrical generator and so for the Bristol flight the generator was selected off and the Auxiliary Power Unit generator supplied power to the left electrical network.

The investigation found that there were “Inadequate measures for identifying Generator Control Units repeatedly rejected from service due to repetition of the same intermittent fault” (AAIB, 2009, p.2). As a result, the following recommendation was made within the report.

“It is recommended that the EASA [European Aviation Safety Agency] and the FAA require that approved component repair organisations have procedures in place to identify units with an excessive service rejection rate or recurrent faults. (Safety Recommendation 2008-89)” (AAIB, 2009).

The FAA did not respond to this recommendation. EASA were to update EC 2042/2003 with a requirement for maintenance organizations to establish “procedures for the identification and control of components with recurrent faults” (AAIB, 2012c, p.40). Consequently, the recommendation was closed by the AAIB. Of concern, a search of EC 2042/2003 (EASA, 2003) found no evidence of this recommendation being implemented. The search included the following terms from the AAIB recommendation and the EASA response to the recommendation: control, identif*, recur, rej* and repeat. EC 2042/2003 was repealed by Commission Regulation (EU) No 1321/2014 (EASA, 2014) and a search of this document and later versions of EC2042/2003 also found no inclusion of the AAIB recommendation.

This incident clearly builds on the concept of a link between NFF and airworthiness and resulted in the AAIB recommendation. Implementation of Recommendation 2008-89 would have connected more closely the regulation of the operators, engineers and logisticians in addressing the problem. This opportunity appears to have been lost. However, it cements the requirement to involve the design organization logisticians.

2.6.3 NFF summary

NFF is a phenomenon that has been evident for decades but became more prominent with the advent of electronics and software. The cost of NFF for businesses has not been fully established but the evidence provided clearly

shows that it is millions if not billions of pounds per year. The cost is also in terms of the time and effort of the transport system, logisticians and engineers. It is argued that the service inquiries considered that intermittent faults and NFF certainly contributed to the accidents, even though the term NFF was not used. However, the term and effect of an intermittent fault and NFF were linked to an air incident by the AAIB and then recognized by EASA. This finding is important to acknowledge as the NFF impacted the airworthiness of the aircraft and effected the aircrews' ability to fly the aircraft without distraction. As covered in Section 2.4, airworthiness should not cause signification hazard to the aircrew. The NFF occurrences did cause a hazard for the aircrew and passengers. Thereby supporting the concept of a link between NFF and airworthiness.

2.7 Safe

Believing oneself or society to be safe is a perception that can be coloured by different experiences within a person's life. However, "it is generally accepted that attitudes and perceptions affect … behavior which, in turn, affects … [the] propensity to have "accidents" (Heinrich (1931), Suchman, (1961), Wigglesworth (1978) cited in Coyle, Sleeman and Adams, 1995, p.247). This is endorsed by Kritzinger (2006, pp.17-18) who lists many factors that will affect that perception of being safe, including ignorance, frequency and the suddenness of consequence. The quicker the effect of an event is felt the less likely one is to agree to the risk. So, a pilot who is ignorant of repeated NFFs or engineering faults may feel safer when compared with one who has experienced repeated NFFs and within a short period—the suddenness of consequence factor. Probably not measurable but maybe the pilots' perceptions of a NFF risk and airworthiness are linked to their belief that there will be a perceived benefit. These perceptions and beliefs may be connected to whether they assume themselves to be or are deemed to be an alpha male or female. Whilst not an out-and-out violation, accepting the risk, or being ignorant of a risk, may be beneficial to the pilot or the organization but it may also highlight trust issues resulting from inappropriate procedures and processes (Reason, 2013). Though this is outside the scope of this research the question as to whether a pilot identifies with being

an alpha may link with their perception of being safe when encountering NFF. So, from this, it could be deduced that the aircrew's attitude to and perception of NFF could affect the approach taken towards NFF and airworthiness and from this air safety, as the latter two are interlinked. The safe aspect aligns with the MOD (2008; 2017) definitions of airworthiness in that the people affected by the aircraft should have minimal impact from a hazard and this would link with the HSE (2018a) view of a system being ALARP. The latest version from the MOD (2020b) Knowledge in Defence portal reflects the wording from the MAA glossary but does now state that airworthiness is underpinned by competence and recognised standards.

2.7.1 Safety

To be safe a safety system needs to be implemented. Kritzinger (2006, p.19) proposes the terms "sufficiently safe" and "safe enough" and that management is responsible for achieving this via procedures and processes. The proposed airworthiness definition includes 'approved procedures' so should aid in achieving a safe system, if they are complete, accurate and followed.

However, as highlighted by Khan et al. (2015) research was ongoing to establish if there was a link between NFF and air safety. Latterly from the research conducted it was apparent that the process for looking for NFF trends was not conducted or at least not across all depths of maintenance (Hockley, Lacey and Pelham, 2016) and the engineers were unsure if the project teams were informed of any repeated NFF occurrences. This indicates that suitable processes and procedures are either not in place or not being implemented. The lack of processes and procedures is questionable as the MAA provided the MAP-01, Manual of Maintenance and Airworthiness Processes (MAA, 2015a), now the MAP-P (MAA, 2022a), and this stipulates the need to analyse for maintenance and fault trends. Conversely, Richardson states that "'safety' does not actually exist; it is a condition that is created wherein the chance of safety harm is reduced to and maintained at an acceptable level" (Richardson, 2017, p.1). The establishment and continuation of this "condition" is a result of numerous "activities" (undefined by Richardson) and the success of these "activities"

governs the level of safety achieved (Richardson, 2017). Moreover, it is the management of risk and not the management of safety that is conducted but as companies fail to appreciate the failure and the reason for the failure, they cannot accurately establish the amount of risk present (Richardson, 2017). Strong words, especially as many companies use risk registers to quantify their risks.

For a military aircraft part of this process should, therefore, be the periodic checking of the MOD Form 700; however, this is undertaken at the flying establishment and there is a requirement for it to be conducted by the Continuing Airworthiness Management Organization (CAMO) or the Type Airworthiness Authority (TAA) as they aid the management of the risk (MAA, 2015a; 2022a).

What has not clearly been established is whether a safety system is in place if the aircraft has repeated intermittent faults and NFF. It is assumed that the maintenance manuals will be sufficiently detailed to enable accurate diagnostics and that there is a process for monitoring them but as noted by Hockley, Lacey and Pelham (2016) this is not the case. Therefore, it could be argued that the NFF environment does not imply a safety system is being maintained following the signing of the airworthiness certificate. Moreover, the risk should be reduced to ALARP and is about a balance of risk and sacrifice but should be balanced in favour of health and safety and it is presumed the duty holders will execute a risk reduction measure (Health and Safety Executive, 2018a). The problem arises when the risk reduction measures, manuals, people, and test equipment are not at the appropriate standard. Then the question of what is 'grossly disproportionate' needs to be raised and answered.

Richardson goes on to state that "Risk should only be accepted and signed for once it has been determined that the proposed effort is indeed reasonably practicable i.e., you have done enough to reduce risk taking into account all reasonable steps and only discarding those that are grossly disproportionate." (Richardson, 2017, p.5). The 'reasonably practical' aspect aligns with the HSE terminology (Health and Safety Executive, 2022) whilst the 'grossly disproportionate' description aligns with the MOD ALARP definition (MOD, 2020a). Additionally, those who accept the risk need to be certain they know what

they are signing for and that looking at risk registers is not the whole story of safety and risk (Richardson, 2017); the behaviours of all involved contribute to it. This latter aspect endorses the view of Coyle, Sleeman and Adams (1995). Within the MOD this responsibility lies with the aviation duty holder (MAA, 2015b; 2021). What is unclear from the literature is whether the risk of NFF is known, or whether it is just assumed knowledge.

2.8 Safe life and fail safe

To understand safety and risk within aviation some key terms need to be understood, specifically the difference between ‘safe life’ and ‘fail safe’. The design philosophy will be different. In simple terms ‘safe life’ means that the equipment has been designed such that it will not fail within a set period and that period is determined by methods, such as FMECA and testing. At the end of the period, the equipment is disposed of. The FAA considers ‘safe life’ from the viewpoint of the structure and how many functions (e.g., landings, flight cycles) the structural strength of the aircraft can withstand fatigue cracking before it falls below the design ultimate value (FAA, 2011).

In contrast, a ‘fail-safe’ system has been designed to automatically return to a state acknowledged to be safe, such as a back-up mode, and as a consequence, the functionality will be limited (Kritzinger, 2006). A more specific definition is provided by the FAA who similar to ‘safe life’ attribute it to the structure and residual strength being designed in such that the aircraft can operate with a complete or partial failure of primary structure in an unrepaired condition for a period (FAA, 2011).

Kritzinger (2006) points out that an aircraft designed for a ‘safe life’ should benefit from a reduced probability of both unplanned maintenance and failure, whereas if designed for ‘fail safe’ unforeseen aspects, e.g., an unexpected failure, can be managed better along with alleviating damage from the failure. The design philosophy implemented will have implications for how a NFF and airworthiness can be managed and the procedures put in place for managing the risk such that it is ALARP, tolerable and still airworthy. However, as Khan (2015) states, before

fully understanding NFF the real operating environment has to be captured so that relevant tests and diagnostics can be developed. This needs to be considered before declaring an aircraft is airworthy, so the Risk to Life (RtL) must be known.

2.9 Failure, error and fault

To appreciate how an aircraft is designed, whether fail safe or safe life, the terms fault, error and failure have to be explained as they will contribute to the risk to life of the operators and passengers (Section 2.4) and the in-flight events a pilot will experience.

Avižienis, Laprie and Randell succinctly state how the three terms are defined and importantly linked. The emphasis has been added to highlight the keywords.

> "A system may fail either because it does not comply with the specification, or because the specification did not adequately describe its function. An **error** is that part of the system state that may cause a subsequent *failure*: a **failure** occurs when an *error* reaches the service interface and alters the service. A **fault** is the adjudged or hypothesized cause of an *error.* A **fault** is active when it produces an *error*; otherwise it is dormant". (Avižienis, Laprie and Randell, 2001, p.3)

Whilst their paper was about computing systems the fault, error and failure explanation were concerning the actual components that make up the computer hardware. This is the same as for any avionics components used within an aircraft: they are made up of smaller components such as printed circuit boards.

The first sentence clearly links the aircraft design to the designer's interpretation of the specification and how this is translated into the final aircraft. The designer should have this in mind when conducting the FMECA, with the C, *criticality*, foremost when designing for safe-life or fail-safe aircraft. This may introduce redundancy to meet the design. With NFF in mind the final word of the definition, *dormant*, is important and needs to be considered by the designers and also the maintainers when assessing a fault. O'Connor and Kleyner (2012. p.6) use the

term “sneak” to classify a system that may have been designed correctly, and all the individual components all work correctly, but when assembled can cause failure under certain conditions, as they explain this caused the Apollo 1 spacecraft crew capsule fire. The subsequent error or failure may not be evident when the aircraft lands but during the flight, the pilot's workload may have increased to manage the error or failure. Moreover, the dormant fault will impact the choice of diagnostics conducted; it will be difficult to depict an unknown dormant within a fault tree analysis. This is why fault-trend monitoring is important and as EASA (2017) stipulate within the regulation Part 21A and 1321/2014 that as part of a company’s internal occurrence reporting system the procedures shall recognize adverse trends and the actions implemented or to be implemented to address deficiencies, which includes an assessment of all known applicable information about these occurrences (Figure 2-4). Pilot reports and technical reports are primary sources that contribute to the trending analysis, or individual events that need examining (EASA, 2017). Figure 2-4 shows the suggested harmonization of EASA and FAA regulations by LOTAR and how EASA Part 21A should align with FAA 14 CFR part 21B (LOTAR International Consortium, 2016).

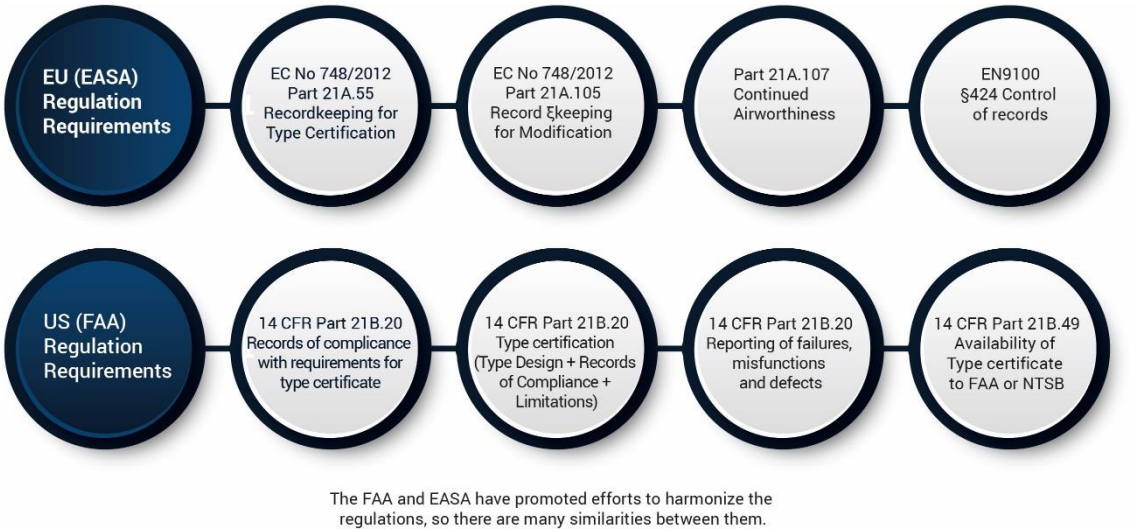


Figure 2-4: Harmonization of FAA and EASA regulations (LOTAR International Consortium, 2016)

An important point to remember is that an error may have more than one cause and each may not necessarily result in a failure due to operator intervention

(Jones and Randall, 2004). The failure is evident when the error has not been averted, or the initiating conditions removed, so the “fundamental chain” is followed “. . . → failure → fault → error → failure → fault → . . .” (Jones and Randall, 2004) and the originating fault can be caused by the human either through design, intervention, attacks or mistakes (Avižienis, Laprie and Randell, 2001, p.5).

Designs during the 1940s and 1950s were acknowledged to use unreliable components so “duplexing with comparison” and “triplication with voting” to assist diagnostics were incorporated (Avižienis, Laprie and Randell, 2001, p.1). Incorporation of some redundancy within a system is recognized as one method to resolve a critical failure (following FMECA) that would result in a hazard (Moubray, 1992, p.192; Kritzinger, 2006). However, this redundancy will increase complexity and if software related, and specifically avionics, will according to Khan et al. (2015, p.6) result in an increased possibility of a NFF. So, the overall design to achieve a safe-life or fail-safe aircraft design per the standards may inevitably increase the NFF rate. Considering the airworthiness definition (Section 2.4) includes the statement “i*s a technical attribute of materiel throughout its lifecycle*” this supports the concept of a link between NFF and airworthiness.

Khan et al.’s (2015) aircraft de-icing system example includes many of the issues with understanding a fault and that it could be dormant. There was an impact on flight safety, an association between the environment and the aircraft systems and the result is an unidentified fault. Regrettably, no reference has been provided to allow further analysis of the problem for airworthiness issues.

To maintain the airworthiness of the aircraft knowledge of faults, errors and failures and, if accepting that some faults are dormant, then NFF as well must be known and monitored for trends if the risk is to remain ALARP and tolerable. Trending is a requirement of EASA and also the MAA (2015a; 2022a).

2.10 Risk-to-life events

When assessing whether an activity is safe a term used to quantify it is *risk*. The definition of the term has developed. In 1996 it was simply "uncertainty surrounding the loss from a peril", where peril was defined in terms of a hazard and an undesirable occurrence (Michael, 1996). Nowadays, the HSE define risk in terms of hazard and effect:

> "A risk is the likelihood that a hazard will actually cause its adverse effects, together with a measure of the effect. It is a two-part concept and you have to have both parts to make sense of it". (HSE, 2018a)

The MAA defines risk in terms of "possible loss", severity and likelihood: it "Is a measure of exposure to possible loss and it combines the severity of loss (how bad) and the likelihood of suffering that loss (how often)" (MAA, 2015c, p.99; 2022c, p.63). Michael's 'uncertainty' is quantified by the MAA as a 'measure' and 'peril' by 'exposure' and 'effect'. Additionally, the MAA specifically define 'risk to life' (RtL), which includes "fatality and injury, but excludes damage to assets or the environment where no harm results" (MAA, 2015c, p.100). However, it does go on to state that "People should only be exposed to risk of harm where some defined benefit is expected and where the risks are adequately controlled" (MAA, 2015c, p.100; 2022c, p.63). The Defence Standard (MOD, 2017, p.vi) only defines RtL as a 'risk of harm' but their definition of harm includes "physical or psychological injury, or short or long term damage to health", which is more precise than the MAA definition (where no definition of harm is provided); this again identifies a difference between MOD documents, which could cause confusion and ambiguity. Interestingly the HSE does not use the term RtL within their Official site (HSE, no date-b), although documents on their webpage mention "risk to members".

The first use of the term, RtL, appears to have been by Haddon-Cave (2009, p.13). It should also be understood that the HSW act does not apply to the MOD when working or operating overseas (HSE, 2018b). However, this does not absolve the MOD of Health and Safety responsibilities as the Secretary of State

for Defence's policy statement makes it clear that when operating overseas Defence is to ensure these operations are at least as good as UK law where practicable (Gov.UK, no date). Another definition of risk is more unambiguous: "A state of uncertainty where some of the possibilities involve a loss, catastrophe, or other undesirable outcome" (Hubbard and Seiersen, 2016, p.40). However, any dictionary will provide different definitions for 'uncertainty'. The risk needs to be measured and the outcome will be different but each is associated with assessable probabilities and calculated losses (Hubbard and Seiersen, 2016). Whoever is responsible or accountable for the risk needs to ensure which definition is applicable. For the MOD operating in the UK, it would be from the HSE. When operating overseas it would be the MOD. This may then determine the 'acceptable' risk and how it is managed. However, the airworthiness definition is explicit in that it is 'without specific hazard to third parties'.

The FAA points out that system safety (the aircraft) should be enhanced by recognizing "safety related risks" and eradicating them through design or procedures (FAA, 2000). This links with the need for redundancy.

So, understanding or at least recognizing the fault-error-failure chain and how this leads to risks is closely linked with the need for safety, having an aircraft with a risk that is ALARP and the airworthiness definition (Section 2.4).

Linked with this is the need to understand how hazard is connected to the risk to life. The HSE defines a hazard as "something (e.g., an object, a property of a substance, a phenomenon or an activity) that can cause adverse effects" (HSE, 2018a), with an example of an adverse effect being a loud noise causing hearing damage. An earlier MOD (2011) definition considered a situation and the *potential* of injury, to a human or damage to property, assets or environment, which is more specific than the HSE definition, which only considers the human. The MOD (2017) goes further to include the requirement for an initiating event. However, MOD (2020a) now omits property but does relate the potential to causing "an adverse impact" on people and this may be fatal, physical, psychological or other damage to health. The MOD (2011) definition is similar to that of De Florio (2011, p.305) but he includes a "reduction of ability to perform a prescribed function".

However, he is clear that a hazard is not automatically damaging and the context has to be considered, which is the interface with the system providing the function—when the hazard can become a safety concern. It is at this point that it becomes a risk-to-life event. An example of a risk to life would be when the fault leads to failure and this becomes a hazard, such as the AAIB Bulletin: 6/2012 G-JECF, which had components returned as NFF.

So, the important point in aircraft design and continuing airworthiness is to be able to identify a hazard, understand the risk, conduct a risk assessment to establish ways to mitigate the risk and then monitor to determine if the measures have been effective. Bowtie analysis is one method of depicting (recording) this analysis, and includes an initiating event, which will be incorporated into an organization's risk management plan or safety case.

The implication is that poor training, culture and communication systems are connected via "error inducing factors" to a disaster and produce a causal network (Embrey, 1992). This could also be a read-across for a NFF. Poor communication between the pilot and the engineers, an imprecise set of instructions/procedures (i.e., what to record within a post-flight engineering debrief) and distractions in the environment (i.e., where the debrief is taking place).

The complexity of industries, such as aviation, has the potential for a disastrous event (Embrey, 1992). By understanding this complexity and addressing the error-inducing factors, the level of disaster should be able to be reduced. So, for this research understanding the impact of NFF and how to manage debriefs along with training should contribute positively. In essence, by reducing the level of disaster (i.e., significant hazard) that may be caused by a NFF it will improve the airworthiness of the aircraft. Hence, improving the quality of the debriefs will aid the competence of the individuals involved. This again builds on the concept of a link between NFF and airworthiness.

Whilst Embrey (1992) questions whether qualitative modelling of the complexity is a suitable means for understanding the potential failures he does go on to state that it is achievable but will entail much work. A weakness of Embrey's paper is

that he jumps between the terms error and failure without providing clear definitions.

2.11 Risk responsibilities

With the need to maintain an airworthy aircraft, the accountability and responsibility for risk identification and management must lie with someone within the organization. What the individual requires is a way to measure the impact on airworthiness and thus safety, of a NFF event for the aircrew and or third parties.

Within the MOD the person accountable is the duty holder. Within a civilian organization, the term used is the 'accountable manager' who is envisioned to be the chief executive officer and as such is responsible for running the organization and for the maintenance activity the holder should have corporate authority for guaranteeing that all continuing airworthiness management activities are conducted (EASA, 2017).

However, the language used to establish the culpable person is complicated as the terms responsible and accountable overlap, as explained below. The reason for explaining this is that a responsible person determines the acceptable risk to fly an aircraft and the safety of those on board, including third parties. If this accountability and responsibility are unclear the need to analyse NFF and its link to airworthiness may be missed or dismissed (Italic emphasis added in this quote).

> Aviation Duty Holders "are legally *accountable* for the safe operation, continuing airworthiness and maintenance of systems in their AoR [area of responsibility] and for ensuring that RtL is reduced to at least Tolerable and ALARP" and they are "personally accountable for their *responsibilities*" and "will be *accountable* and *answerable* to the Secretary of State" (MAA, 2017, pp.1-2).

Whilst this appears clear, there is ambiguity because of the words used. A legal dictionary does not provide definitions of accountable, responsible, responsibility or answerable but in an English court of law, the definitions from a dictionary may

be used (LawTeacher, 2013). For this reason, the definitions provided by the Oxford English Dictionary (OED) are proposed, namely:

> Accountable – "Liable to be called to account, or answer for responsibilities and conduct; answerable, responsible (OED, 1989, Vol I, p 87).
>
> Responsible – "Morally accountable for one's actions; capable of rational conduct" (OED, 1989, Vol XIII, p. 742).
>
> Responsibility – "The state or fact of being responsible; …a charge, trust or duty, for which one is responsible" (OED, 1989, Vol XIII, p.742)

It is worth noting that answerable means "liable to be called to account; under legal or moral obligation; responsible, accountable" (OED, 1989, Vol XIII, p.742).

The MAA did not define 'responsible' but declared that 'accountability' meant "being liable for agreed results to be achieved: obligation to achieve in accordance with agreed standards" (MAA, 2015c, p.5). However, in the latest edition of the glossary, the term 'responsibility' has been added and refers to acting independently, taking decisions without Authorization, a legal obligation but states clearly that it excludes "the legal Accountability for Risk to Life" (MOD, 2022c, p.63). The MAA (2015c) has interestingly introduced the term liable—meaning "bound or obliged by law or equity" (OED, 1989, Vol VIII, p.878)—but as shown the OED definition for accountable includes the words responsible, responsibilities and answerable; each is intricately linked and means the same thing. This could and does confuse who ultimately is 'culpable' when things go wrong as it is accepted within the UK military environment that only responsibility, not accountability, can be delegated. Further exploration of the terms is outside the scope of this research but it is worth noting the confusion here as it may be relevant when undertaking risk analysis for the research. Personal responsibility, along with attitudes, norms, values and behaviours are integral parts of an organization's safety culture (Glendon and Stanton, 2000, p.206).

2.12 Training

The importance of NFF's impact on airworthiness may be 'challenged' by any education or training provided. EASA (2008) include NFF training within their training programme; however, the training is created to ensure the attendee can "Demonstrate the process and procedures to successfully use the troubleshooting procedures and charts of current aeroplane faults and know re-occurring problems causing No Fault Found on removed LRU" (EASA, 2008, p.16). It does not consider the information required from the aircrew when they are providing a post-sortie-engineering debrief (PSED). Some limited research has established that UK military aviation engineers have very little if any training on NFF, its causes and the implications (Hockley, Lacey and Pelham, 2016). During this research, it was evident that those in the Royal Navy had received more than their counterparts in the other two UK military services.

Flewwelling (2012) conducted usability tests on medical equipment and discovered many faults that would have been recorded as NFF (or descriptions that would have resulted in a NFF after diagnosis) were the result of incorrect use by the operators or because the operator did not understand how information was being displayed to them. In essence design flaws that could have been better understood from a maintenance task analysis before introduction to service may have resulted in the design flaws being eliminated; this links with Reason's (1991) view on dormant faults. Training and retraining were recommended and to be focused on device features where NFF incidents were occurring (Flewwelling, 2012). In essence, he was advocating that NFF should be acknowledged and that training was targeted at the key weaknesses within a system. This reinforces the view of Jones and Hayes (2001) who understood the weaknesses of staff who were only partially trained on how to use the equipment, even when the equipment had been in use for some time, and added that the operators' expectations were different from the functioning, designed equipment. However, Flewwelling's observations differ from the attitude practised within the RAF engineering community visited by Hockley, Lacey and Pelham (2016). Similarly, the EASA (2008) guidance was only for troubleshooting and not for resolution if

the NFF could not be eliminated. Yet ARINC (2008) Report 672 clearly identified the need for training for designers, operators and technicians, and went on to confirm that aircrew training limited or omitted maintenance training and impacted their ability to troubleshoot, interpret abnormal behaviour and do failure reporting. Additionally, they recommended technicians were trained in how to access, use and interpret maintenance history (ARINC, 2008).

Even though the ARINC (2008) guidelines were published in 2008, a survey conducted by Copernicus (2015) established that whilst a large number of respondents stated that training was the top mitigation for NFF only 22% of respondents actually provided any training to the technicians. The survey participants were mostly from worldwide aviation engineering professions and were not aircrew (Copernicus, 2015). Based on their industry survey from 2012 to 2015 (Copernicus, 2012; 2015) there has been little improvement noted over these three years. In 2012, 78 of 108 participants completed the survey in full compared with 65 of 88 who completed the survey in 2015. It is acknowledged that this is not an academic report; however, the key author, Huby, is an engineer, has knowledge of this topic and is a keen advocate who is trying to find a solution. One notable comment provided in the survey questioned the poor resources engineers and pilots have to use to record the debrief and their lack of time or desire to undertake a review of the aircraft history. This same respondent went on to claim that:

“Once pilots realise they can sort, filter, review defect history quickly and effectively, I truly wonder how many pilots will challenge cases where the same component is changed several times, or log entries such as ‘Ground test serviceable’, ‘System reset/box re-racked – please report further’, etc.” (Copernicus, 2015, p.32).

In an era where there is an overabundance of data recorded, the ability to review an aircraft’s fault history is a feature that many RAF engineers still lack (Hockley, Lacey and Pelham, 2016); it is still inaccessible and/or not exploited. Rolls Royce brought together different airline companies’ mechanics and maintenance engineers for an educational workshop to establish why some companies had

higher removal rates of NFF than others (Hockley, 2016, p.56). A key factor was a lack of education regarding the available supplementary data that the aircraft maintenance system could provide along with the associated troubleshooting tools. It was observed that for those airline companies that attended the Rolls Royce educational workshop, their rate of NFF removal decreased for the following two years, thus indicating that this education needs to be periodically repeated (Hockley, 2016). It could be judged that this lack of education is inadvertently, or even deliberately, putting aircrew lives at risk. The training of the engineers on the implications of NFF is necessary and similarly, the aircrew needs a solid understanding of how NFF maintenance is recorded and actioned for the aircraft they fly. The operator usually provides the first input to a NFF investigation (Figure 2-1). The focus of Khan et al. (2014: 2015) was not on the operator level but on the component level. The importance of the aircrew input is not considered and yet they are generally the first observers and repeat observers of an intermittent fault and a NFF and the first-hand recipients of an air incident.

What has not been evident when reviewing the literature is the training provided to aircrew for how to conduct the PSED. It is presumed that this is provided but clarity is required. Any training should address the explanation of the flight conditions when the fault occurred and the symptoms.

Due to financial penalties and subsequent reputational impact, there is minimal time afforded for maintenance and in-depth investigations to resolve a NFF, as fee-paying passengers, who provide an operator's income, and the availability of aircraft is more important (Khan et al., 2015), but that is until there is a major incident or accident. In a military context, this also includes aircrew who do not have the time for the debrief or who do not fully understand the importance of the PSED for the maintainers.

Therefore, as the saying goes "if you want different outcomes you need to do different things" (Copernicus, 2015, p.3) and this may start with considering the aircrew input to the whole maintenance process (Figure 2-1 and Figure 2-2). The key NFF industry themes (Figure 2-2) and the stakeholders and their interaction

at the component level (Figure 2-1) have little to no input from the aircrew. Adding sub-sub themes for engineers and aircrew to ‘communication’ (Figure 2-2) would indicate those to be communicated with. The NFF may remain on the aircraft (system level) so Figure 2-1 would benefit from being redrawn for the system level as additional data about the fault reported by the aircrew as the ‘operators’ would enable the engineers to better understand the events of when and how the fault was manifested.

Haddon-Cave (2009) endorsed the Australian definition of airworthiness and the three elements, one of which is operational airworthiness. What Haddon-Cave (2009) emphasized in his report was the need for *competent* operators. The Australian definition of competency is “The capacity of an individual to effectively and safely complete a task to a required standard of performance through the application of appropriate skills, knowledge and attitude” (Defence.gov.au, 2015, p.5). However, the Australian definition of operational airworthiness includes the requirement for competent and *authorized* individuals (Defence.gov.au, 2015). ‘Authorized’ indicates some form of assessment has been passed. DASR Mar 18 Release (DASR, 2018) indicates the qualification required by the pilot trainers and for specific instructors and assessors. In contrast, the MAA’s definition of competency is “with regard to a specific standard” (MAA, 2015c, p.30) and not “to a required standard” (Defence.gov.au, 2015, p.5) and there is no mention of attitude. The MAA definition of a competent person determines that the individual must have training and experience *or* knowledge (MAA, 2015c). This is an interesting distinction as having facts about a thing and training for it are different from having experience. Online training for how to put out a fire is completely different from the experience of actually putting out a fire. Yet according to the MAA, without experience, an individual is deemed to be a competent person or maybe it is that any experience can supplant the requisite knowledge. This distinction may become problematic when a pilot experiences a fault, and this may be an intermittent fault, for the first time. So how then does a pilot learn about what is an intermittent fault, that is assessed to be a NFF, and how this may affect the flight controls of an aircraft to prevent it from becoming a

"*significant distraction to the crew at a late stage in the approach*" (italics added) (AAIB, 2012b, p.26)?

Bowers, Jentsch and Salas (2000) examined the competencies required by aircrew and the effect on behaviour; the competencies are subdivided into two areas, namely generic teamwork skills and application skills, which had input from team-specific and task-specific knowledge. They determine that the crew were those who flew the aircraft, such as the pilot, the co-pilot and the engineer (Bowers, Jentsch and Salas, 2000) but for military aircraft, this may also include mission operators. For team competencies, whether team generic or team specific, Bowers, Jentsch and Salas (2000) recognize the importance of leadership and communication and that for all missions, knowledge of each team member's ability is important for team cohesion. For aircrew all their training will be similar and as they are working within small, non-interdisciplinary teams a common vocabulary is adopted for the confined, well-documented (manuals and guidebooks) number of tasks they perform and consequently, common communication problems are limited (Bowers, Jentsch and Salas, 2000). As a result, the aircrew does not need to possess the competencies non-interdisciplinary teams require. However, the issue is where the boundary of the team is drawn, as will be explained later. Generic competencies encompass skills, knowledge and attitude; remember that the MAA (2015c) did not include attitude in its definition of a competent person. Whilst 'skills' competency requires a level of situational awareness, communication and feedback, the 'attitude' competency acknowledges that the end goal is more important than an individual and positive behaviour is required to achieve this. The knowledge competency highlights the need for crew coordination, with a shared mental model (image) of the environment that *includes the equipment*, an ability to communicate their understanding of the equipment, and knowledge of the other team members (Bowers, Jentsch and Salas, 2000). Task-specific competencies are broken down into three elements: task-specific attitude, task-specific skills and task-specific knowledge (Bowers, Jentsch and Salas, 2000). The latter is important for this research as it includes a requirement to know "recent and anticipated equipment problems" and for task-specific skills an ability to assess the

consequences of various behaviours and select the best strategy for choosing the generic coordinating skills (Bowers, Jentsch and Salas, 2000). Any team should be able to tailor their responses to the crew composition and the situation.

However, throughout a normal day, people become members of different teams, depending upon the activity or mission. So, when flying the aircraft, the aircrew is the team. Yet, when working and communicating with the engineers, they together form a different but equally important team. At this point the definition of communication is useful to consider:

> "The process by which information is clearly and accurately exchanged between two or more team members in the prescribed manner and with proper terminology: the ability to clarify or acknowledge the receipt of knowledge." (Bowers, Jentsch and Salas, 2000, p.73)

Furthermore, a shared situational awareness of both the external and internal environment (including the equipment as covered earlier) and the ability to provide and receive feedback should not just relate to the intra-aircrew communication (Bowers, Jentsch and Salas, 2000) but also the communication with the engineers. So, whilst there is a link between attitude and behaviour this may not always be direct, (Bowers, Jentsch and Salas, 2000) and the attitude of aircrew to provide a quality PSED is just as important as the aircrew debrief on the mission success. By changing the knowledge and skills via competency assessment the behaviour of aircrew towards the technical debrief may become positive.

Training is also required for the engineers and logisticians involved with returning defective aircraft components for depth maintenance or storage. Clear labelling and tracking of NFF components are required both within an organization and with the OEM and contractors. Maintenance organizations compliant with 145.A.70 should have within their exposition a procedure for managing the line maintenance control of defects and repetitive defects and parts returned to them (EASA, 2015). This training will again aid NFF resolution and airworthiness by having a set procedure to allow an analysis of aircraft and component history but these need joined-up databases.

Training and competencies are deemed key elements of safety defences and are used as leading indicators to monitor the state between a hazard and an incident (Milburn et al., 2012, cited in Farnell, 2016), with the aim to prevent the incident from occurring. Amongst others, leading or lagging indicators relevant to NFF and airworthiness are procedures, staffing, maintenance and inspection, critical communication and the effects of fatigue and shift work (Milburn et al., 2012, cited in Farnell, 2016); all of these effects have been considered in the analysis.

2.13 Data recording

To assist with any NFF analysis relevant data should be recorded (IMRBPB, 2011; 2016). Whilst this should not be an issue for aircraft avionics, there are NFF problems associated with telephone data rates that affect the resale value of telephones and are often a result of buyers' expectations in terms of speed not being met. The "over-the-top" data downloaded for the same information from different sites make the buyer assume their device is not working as advertised in terms of speed. However, the fault is not within the telephone but the sites sending the information. So intermittent faults, which lead to NFF, could be the result of the speed of the data bus feeding information to avionic LRUs, or timing errors of information being received. When the aircraft lands, it will be very difficult to reproduce these conditions but they need to be recorded within the fault history for possible future events.

Good data is needed but this is linked to information and exploitation of that information. Khan (2015) identified that data capture needs to improve and this includes the operating environment and usage. As noted, “adequate reporting can ensure that correct and sufficient data is collected and recorded to allow maintainers at all levels … to have the complete fault history of a suspected component” (Khan, Farnsworth and Erkoyuncu, 2017, p.27). However, this should also include the primary data about the fault or the conditions leading to the fault being provided by the aircrew. This aspect should be considered for any NFF strategy or policy developed by a company. Moreover, as acknowledged earlier the exploitation of the data is not being carried out, especially within a UK military environment.

Ungar (2015, p.8) acknowledges

> "an inherent bias that technicians may have when documenting the NFFs at the depot. When a technician decides to shot gun (repair based on a guess) a UUT [unit under test] that experienced NFF in the initial depot test, he/she is more likely to record this situation as a 'repair' than a NFF. Since a correct repair and a NFF will both pass the test, the technician having expended time and parts for the repair will unlikely decide that the repair was unnecessary. Documenting this action as a correct repair will skew the NFF rate."

This is supported by similar findings by Hockley, Lacey and Pelham (2016) who established that RAF engineers wished to be seen to be doing something rather than declare a NFF and this is compounded by the terminology used by the technicians to record the fault as anything but a NFF, such as "retest OK" and "assessed serviceable" (Khan et at., 2012; Hockley, Lacey and Pelham, 2016). Doing so may been seen as a way to aid the military aircrew who need serviceable aircraft to maintain the requisite flying hours per year.

The importance of logging data so that it can be used for a search of trends and component history is known (MAA, 2015a; EASA, 2017), and this is especially important if a component is removed and refitted to a different platform. Rogue components need to be known and monitored. Khan (2015), giving an example of a turboprop de-icing system failure that was a NFF and also a flight safety system, identified the issue of needing accurate data "at the initial stages of the fault diagnosis process." Good data recording, as stipulated by a regulatory organization, would have speeded the diagnostic investigation. Within the RAF the F731 is an equipment conditioning label that is used to indicate a component's un/serviceability and it needs to include a description of the fault. However, descriptions such as "fails test" or "fails functionals" do not clearly explain what has taken place and "SST carried out satis" does not let the aircraft engineers know how the component was tested (Hockley, Lacey and Pelham, 2016). This information is not being passed from one organization to another or even from one squadron to another if the item has been for onsite bay maintenance.

Additionally, the fault description from the pilot needs to be passed to the engineers conducting bench testing. Words such as “fails in pitch and roll” would massively aid the diagnostics and reduce the testing time (Hockley, Lacey and Pelham, 2016).

2.14 The operators

2.14.1 The operator and NFF

The operator, i.e., the aircrew and not the owner, is part of the aircraft system. The manned aircraft will not fly without the aircrew. Yet, when reviewing NFF publications most either show the operators as an input at the start of the process or do not show the operator at all (Qi, Ganesan and Pecht, 2008; Khan et al., 2015, pp.29, 46, 104). The importance of the operator’s input was considered by Thomas, Ayers and Pecht (2002) when analysing the Ford Duraspark ‘trouble not identified’ experience and found that for many items the customer had to be re-contacted as the original recorders of the fault, who were not trained sufficiently in technical matters, had failed to obtain all the relevant information from the driver at the time of the fault. The full conditions at the time of the fault were unknown, especially for an intermittent fault. Qi, Ganesan and Pecht (2008, p.664) acknowledge the “Lack of skills or proper behavior of engineers, maintenance personnel and technicians can contribute to NFF” but they also consider the importance of communication and how well people communicate the relevant information and how this is comprehended and recorded by the recipient, the engineer, or in the Ford example, a non-specialist. This will become more important if the information is being relayed by a third party between the operator and the engineer undertaking the fault diagnosis as discussed by Hockley, Lacey and Pelham (2016). With the ARINC (2008) publication of guidelines for the Reduction of NFF, the role of the operators and pilot reports were identified. Key areas for consideration and improvement were communication, documentation completion, training and aircraft system behaviours that were unexpected by the aircrew. The Guidelines (ARINC, 2008) provide recommendations that include the need for consistent post-flight sortie reports, the terminology to be used, improving communication between rotating crews and also the maintainers,

training to improve observations about the flight deck, the importance of aircrew feedback being fed back to the designers, and using non-engineering language to report the faults.

Whilst this report had been published for seven years, the findings by Hockley, Lacey and Pelham (2016) indicated that the Guidelines were not being implemented successfully or at all. There is direct read-across where aircraft engineers failed to get a full debrief from the aircrew on the condition when a fault occurred and Hockley, Lacey and Pelham (2016) observed that inexperience of the technicians or the aircrew may be a cause. This problem is further compounded by the poor information being provided by the engineers to the OEM or repair depot (Section 2.13).

> "NFF is inherently a by-product of a lack of detail given by the environment in which the failure occurred, and the testing inability to replicate that environment and fault. In other words, a NFF is sentenced by the supplier, or repair station, due to a lack of incoming information about the part and/or the bench test procedures are too restrictive" (Khan et al., 2015, p.106).

From the perspective of this research, the important aspect is the environmental detail. This can be provided by HUMS and condition monitoring techniques, cockpit voice recording and aircraft on-board monitoring systems but importantly the pilot-initiated event where a button on the control stick can be pressed to mark the HUMS recording of anything notable. Unconfirmed reports of aircrew taking photographs of the console configurations to assist the engineers with the fault diagnostics cannot be verified; however, DASOR does have a field to attach files, such as photographs, but these are often "stills taken from mission system recordings (such a HUD video of an incident) or post-flight images (such as the damage caused by birdstrikes)" (Reid, 2022).

An established view is that NFF will "create customer inconvenience and dissatisfaction, damage company reputation and in some cases create potential safety hazards" (Ungar, 2015, p.9) and this supports the view that NFF will impact the aircrew and may impact the reputation of the engineers conducting the

maintenance, especially in a UK military air context where the engineers will work in much closer proximity and have a closer professional relationship with the aircrew. In their research Erkoyuncu et al. (2016) concurred with this view and stated that as well as direct engineering reasons there are other prominent influences in the cause of NFF, such as customer culture, poor training and human influences with the example given of the pilot wanting action. Again, this example links to the findings by Hockley, Lacey and Pelham (2016) who noted that components were being changed just to be seen to be doing something. However, in doing so they provided aircraft to aircrew to enable them to maintain flying currency.

> "If spares are unavailable, the aircraft is grounded and the consequences can be devastating in terms of meeting mission goals and in terms of economic impact. Clearly, an FA [false alarm] or a bad actor can lead to aircraft grounding and scrubbing the mission" (Ilarslan, Ungar and Ilarslan, 2016, p.2).

However, this considers the bigger picture of the operation and not down to the impact upon the aircrew because of either wasted time having prepped for flight, or frustration at being inconvenienced or being away from home again. For some airworthiness definitions, the aircrew falls into the "safe to operate" criteria or "by competent and authorised individuals" (Table 2-1) and competent and authorized does not consider the behaviour of the individual's frame of mind at the time. It must be emphasized that this research will not consider the psychological impact in detail but the impact of NFF on the aircrew workload is a valid consideration, especially considering the findings of AAIB Bulletin: 6/2012 G-JECF (2012b).

2.14.2 Operator workload

Research by Samel, Wegmann and Vejvoda (1997) highlighted the effect of fatigue on aircrew and this included the flight duration, direction of flight, circadian rhythms, the increase in electronic cockpit systems, and boredom because of automatic systems. These all contributed to the fatigue pilots experienced and raised concerns about reducing the number of pilots just because of the amount of automation. The analysis was based on a questionnaire looking at aircrew

stress factors. Within the analysis, the legal aspect was examined and proposed that the flight duty time, including rest and time limitations, should be examined (Samel, Wegmann and Vejvoda, 1997). The MAA (2015a) and EASA (2017) require trending analysis to be conducted for corrective maintenance. It is contended that a lack of analysis for trends will miss NFF occurrences and, thus, will have a direct link with airworthiness. This may have a greater impact on aircrew who are fatigued and be dependent on whether they conduct long- or short-haul flights, with the CAA (2015c) defining a long-haul flight as anything over 3,500km. Additionally, aircrew may be less able to correctly monitor the information presented and may miss key information that would aid fault diagnosis and specifically any contributory factors that may have helped create the conditions for a NFF. The quality of the PSED may be reduced.

Ungar states that NFF will “compromise confidence in the product, [and] create customer dissatisfaction.” Ungar (2015, p.1). Most research considers the NFF impact from a business or maintenance perspective. However, as apparent from the air accidents, e.g., Flybe aircraft DHC-8-402 Dash 8, G-JECF (AAIB, 2012b), it must also consider the operators, namely the aircrew, of aircraft and whether a NFF will consciously or subconsciously impact their actions or behaviours. It is not disputed that some NFF is a result of operator error (Ungar, 2015). Yet, according to Ungar (2015), operator error may be the prime contributor to false alarms. This is because complex systems that require monitoring and inputs inevitably result in incorrect controls being activated by the operator at the wrong time (Ungar, 2015). It is these incorrect actions that result in unexpected outcomes as the operator will, when under pressure or boredom, describe them as faults to the engineers (Ungar, 2015). As explained earlier (Section 2.5) the design of a system may include dormant faults from latent design errors but for the operator, these will manifest themselves as faults or later NFFs and affect their confidence. This is another hidden consequence of NFF. No research appears to have been conducted in this area. From the research conducted the emphasis and focus is the physical technical component or aircraft.

Research has been conducted into the handling qualities of aircraft (Cooper and Harper, 1969) and later the practical assessment of the pilot workload. Cooper and Harper (1969) defined handling qualities to achieve the operation and the overall pilot-vehicle combination that covered more than just the aircraft characteristics but also included the aircraft environment and pilot stress, with examples given of distraction and surprise from disturbances. The necessity of their research was on the grounds of advancing the understanding of pilot rating schemes and had two components. It was established that theoretical analysis in isolation could not satisfactorily provide a complete understanding of a pilot's handling of complex interactions, such as flying. Therefore, the second part of the research was to measure and analyse the pilot's performance (Cooper and Harper, 1969). The aim was to establish "what constitutes objectionable inputs". An essential aspect was to establish clear language and definitions to overcome previous analyses where inaccurate and 'loose' terminology had been used. Interestingly for them, the term 'workload' comprised both physical and mental aspects and they later use the terms effort and attention (Cooper and Harper, 1969), whereas newer research does not define workload but *mental workload* and this is then linked to situational awareness (Salas and Maurino, 2010, p.219). The performance was intended to convey the "precision of aircraft control" experienced by the pilot and 'pilot performance' being a measurement of the pilot's physical exertions (workload) to attain the performance but it was determined that these were intertwined and difficult to differentiate between. In 1969 pilot evaluation was deemed the only method to assess the pilot-vehicle interaction for performance and total workload required to complete a mission (Cooper and Harper, 1969). Whilst emergencies were handled differently, they stated that for the evaluation "the pilot must always treat a failure state as having to be coped with for the duration of the task or flight phase, depending on which is being rated" (Cooper and Harper, 1969, p.14). For a transient disturbance, e.g., a system failure, the pilot still had to make a trade-off decision between performance and workload and for what duration (Cooper and Harper, 1969). An explanation is provided as to why they opted for an ordinal scale.

Later studies such as the AGARD report (Roscoe, 1987) were the result of a literature review into the different techniques for assessing a pilot's workload and it was deemed to "provide a useful guide for the person wishing to assess pilot workload for practical reasons". However, the report does caution that using these techniques for combat aircraft pilots, combined with the reported guarded analysis of physiological responses, led to a limitation of these techniques for military pilots (Roscoe, 1987, p.2) as, additionally, the workload is subjective and 80% of pilots viewed workload as an assessment of effort (Roscoe, 1987), which differs from Cooper's and Harper's (1969) assessment. Therefore, workload assessment methods to assess how a pilot reacts to an in-flight NFF need to be considered with caution. Moreover, defined scenarios should be incorporated into the application of any technique (Roscoe, 1987, p.2).

The importance of understanding and considering workload is due to the number of activities a pilot can be expected to perform before mental resources are drained to the point where the performance diminishes (Salas and Maurino, 2010, p.229). This happens when the mental resources required surpasses the pilot's current ability (Salas and Maurino, 2010, p.229). This is linked to human error that is caused when under duress. However, caution must be recognized. It is simplistic and counterproductive to explain this merely as evidence of the operator's inadequacy but more useful as warnings of system weaknesses (Salas and Maurino, 2010, p.371) and thus why workload assessment has been conducted during the aircraft's design and development stages, so changes can be implemented. It was a system 'weakness' that resulted in the aircrew becoming distracted resulting in Flybe aircraft DHC-8-402 Dash 8, G-JECF flying below the designated altitude (AAIB, 2012b). This workload must also include the pilot's ability to monitor instruments, sounds, vibration etc. during the flight to provide a quality and useful PSED.

However, whilst workload techniques have been established and reviewed, they are also linked to situational awareness and, similar to Roscoe's analysis of workload, research indicates that what constitutes situational awareness is unknown (Salas and Maurino, 2010, p.225).

Whilst the pilot's experience should be recorded and noted, so should the pilot's style of writing. One pilot may describe three separate tasks. Another may combine all three into one, as all three need to be conducted simultaneously. No matter how the tasks have been described, the same decision needs to be made by the airworthiness assessing team (Gratton, 2018, p.238). However, linked to this must be the information imparted by the operator to the technicians, exactly the same as for the Ford car problem (Thomas, Ayers and Pecht, 2002). This will affect how the pilot records the PSED in the aircraft logbook and how the next pilot understands what the previous pilots have written. Likewise, how one engineer records work conducted to rectify a fault compared with another, may not be easily understood by different aircrew. An issue arises if the aircrew does not know how a fault has been cleared and whether this will impact the next flight. Understanding a fault declared NFF may cause the aircrew to exercise some caution, whereas a recording of 'test carried out satis', may not, but maybe should as it does not declare the fault has been resolved. This notion of understandable terminology, links with the proposal put forward by Hockley, Lacey and Pelham (2016) for a debriefing proforma for RAF aircrew debriefs to the engineers. Khan also raised the need for "a system in place to share appropriate information between all the stakeholders to enable an effective, speedy transfer of shared knowledge" (Khan, 2015, p.189) but the focus of the paper is on engineers and manuals and not operators or between operators and engineers. Khan (2015) does identify the importance of collating the correct fault symptoms and fault reporting information at the start of the fault diagnosis process. So, a common language/taxonomy between all parties is a necessity along with competent engineers and aircrew to be able to accurately use this information. This was a problem highlighted by the Ford car example (Thomas, Ayers and Pecht, 2002).

Harris et al. (2000) determined that the Cooper-Harper scale rating was concerned with whether the aircraft was not just controllable but also whether the pilot workload, for the performance required, was tolerable. This assessment provides a direct link back to the definition of ALARP and whether the risk to life is tolerable as purported by the MAA (MAA, 2015c) and includes "fatality and injury. It is important to note that

> "In this context, '**tolerable' does not mean 'acceptable'**. It refers instead to a willingness by society as a whole to live with a risk so as to secure certain benefits in the confidence that the risk is one that is worth taking and that it is being properly controlled. However, it does not imply that the risk will be acceptable to everyone, ie that everyone would agree without reservation to take the risk or have it imposed on them." (HSE, 2001, p.3). [Emphasis added by the author]

Due to time and cost it is not possible to create an experiment for aircrew that assesses their workload, frustration or complacency caused by repeated intermittent faults and NFF. However, the view of aircrew regarding the impact of intermittent failures, and an associated NFF, handling, air safety and airworthiness implications are valid aspects to investigate. As the author is not a psychologist only a general feeling or belief by the aircrew is required.

2.15 Cost to aircrew and airworthiness

The cost of NFF for businesses has not been categorically established but estimates have been made (Section 2.5.1). This has been from the view of the cost of NFF from the maintenance perspective. Some consider operational cost but this is rare. Train doors were seen as the third-highest reliability issue and a contributor to NFF (Khan, 2015) and this directly impacted customer satisfaction. Even as early as 2002 it was accepted that avionic NFFs from test and repair were an enormous cost to readiness (Steadman et al., 2002). Within the literature, the cost and impact on aircrew were not considered but it does not mean that there is no indirect or intangible cost.

If military aircrew needs serviceable aircraft to maintain their flying hours then in a period of austerity where the UK military reduced the number of personnel and equipment, including aircraft but not missions, the aircraft needed to be available. Intermittent faults and NFF impact this availability if the data in Table 2-3 is assumed to be the tip of the iceberg. Of greater consequence is the trust between the engineers and the aircrew if faults are not resolved in a manner acceptable to the aircrew. This erosion of trust can further degrade the quality of the PSED

and the willingness of both parties to check their understanding of one another. If assessing the *impact* against the airworthiness definition then the aircrew may believe the fault could pose a 'significant hazard' and may not be a 'technical attribute of the material' but an inability or unwillingness of the engineers to conduct diagnostics to the correct level, or they are using ineffective 'approved procedures and instructions'. Moreover, both parties may doubt the 'competence' of each other. The airworthiness definition, (Section 2.4), includes the requirement for competent people. Any doubt about an individual's competence to fly or maintain the aircraft may have a direct *impact* on airworthiness. Singh, Ganguly and Samad (2022) contended that NFF management included human management within the framework of NFF literature. In the explanation for human management, the word trust was included but as this was the only place that it was mentioned in the paper, it is unclear between whom trust needed to be established or if trust was an issue. The level of trust between the aircrew and engineers provides an identifiable link between NFF and airworthiness—their perceptions. This relationship between the engineers and aircrew is critical if NFF occurrences are the be minimized. NFF is a designed-in *technical attribute*, so thus a key component of the airworthiness definition.

2.16 Literature Review Summary

There are different definitions of airworthiness but in simple terms, it is being worthy of being in the air. However, for the remainder of this research, the definition used will include the requirement for competent and trained individuals using approved procedures. These aspects were missing from the MAA (2015c) definition but are viewed as essential parts of any airworthiness environment and recommended by Haddon-Cave (2009) for inclusion in the MOD definition. Likewise, there were different definitions of NFF. Some only included the diagnostics conducted off platforms, bench-testing. These revealed a weakness in understanding, as NFF can be recorded for on-platform faults as well and will have a knock-on effect on the engineers, aircrew and operators of the capability.

There is a cost due to NFF and, whilst not accurately established, it is acknowledged to be in the billions. However, the intangible costs are not defined,

specifically any impact on the aircrew and airworthiness but it was acknowledged that there was an enormous cost to readiness (Steadman et al., 2002). Safety cases are an assessment of the risk and the hazard and are a judgement call that should not be made against an individual risk but holistically. The issue with this is that some faults are dormant and require specific conditions to appear (Avižienis, Laprie and Randell, 2001). A dormant fault has been designed into the system and is, thus, categorized as a technical attribute in the airworthiness definition. This is *important* to acknowledged as it provides a noticeable *impact* on airworthiness and the link between NFF and airworthiness. Training for engineers and designers on the phenomenon of NFF is limited or non-existent and aircrew fair no better even though they have direct, and early, input into the NFF investigation. Associated with this are poor data recording and an inability to trend for repetitive faults, even though this is stipulated by regulators. Another contribution is the different terminology used by aircrew such that, between different pilots, fault symptoms will be recorded differently, and that aircrew fatigue will contribute to this difference. Importantly words such as accountable, responsible and answerable are used to determine a person's position of responsibility. Yet, aircrew are deemed 'responsible' for the aircraft even though they may not fully understand its state of serviceability and airworthiness.

The concept of a link between NFF and airworthiness has been established, namely "a connection between two …things, or ideas" (Cambridge Dictionary, 2023c). NFF is a technical attribute of the aircraft and can be unknowingly designed in. They can remain dormant until activated by specific events. From the accident investigations it has been established that NFF have contributed to or caused a significant hazard to the aircrew. Not knowing about NFFs, their causes and manifestations, indicates a lack of competence. These aspects support the conceptualization of the link between the NFF phenomena and airworthiness.

The literature review analysis has met the first two objectives, namely:

A. To explore current theories for different definitions of airworthiness and NFF and provide ones to be used as the basis for this research.

B. To establish the current understanding of NFF across different industries and the perceived impact of NFF upon operations.

From this, an area of concern for research going forward is the contribution by aircrew toward NFF and whether their experience and assessment of a NFF deemed the aircraft to be unairworthy. This can only be achieved by establishing the aircrews' understanding of NFF and airworthiness and, from this, whether they understand the engineers' terminology, because if the aircrew writes the PSED in a manner another aircrew may not understand it is a logical jump to assume they may not understand the engineers' terminology. The outcome of this information can contribute to the aim, that being to determine if there is a direct link between NFF to airworthiness as suggested during the literature review analysis.

2.17 Research aims

It is evident that NFF has a big impact across disciplines and whilst the impact of NFF on aviation is acknowledged there has been no link to the *impact* on airworthiness. From the definition of airworthiness and NFF and the air accident investigation reports a link has been established between the two terms. The definition of airworthiness requires no significant hazard to impact the aircrew, ground crew, passengers and third parties and it is a technical attribute. NFF is a technical attribute, especially if it can remain dormant or be activated under specific circumstances. Furthermore, a technical attribute, as it is designed in, should be understood and managed. NFF is not always understood and managed. From the AAIB incidents and military aviation examples, there is an impact on the aircrew and the airworthiness has been reduced. However, the literature reviewed has not explicitly exposed this aspect—the aircrew experience and perception of NFF on airworthiness. Therefore, this needs to be examined further and it will be the focus of the ongoing research.

Going forward the main aim of this research is:

> to explore the relationship between the NFF phenomena and airworthiness to establish if there is, or is not, a link between the two.

If the aim is proven then this can be used to consider the importance of fully investigating military aircraft NFFs and, furthermore, designers will have a greater responsibility to consider how to design these complex pieces of equipment to avoid the possibilities of NFF and how to improve diagnosis and test for further designs. If the aim is not established at all, or not with any certainty, it is hoped that a greater understanding of the impact of NFF on aircrew can be established.

The outcome of the research may lead to changes being implemented within military or civilian organizations on how NFF should be managed.

A general contribution to knowledge will be to provide aircrew and engineers alike with evidence to support their need for greater safety in the air environment.

2.17.1 Research questions

Research questions are questions the researcher means to answer by conducting the research into that topic (Wilson, 2014). To support the aim of this research two research questions are as follows:

1. Is there a link between the phenomena of no fault found and airworthiness?
2. Do aircrew perceive a link exists between the phenomena of no fault found and airworthiness?

The first question has been partially met as part of the literature review (Section 2.17). It may be reinforced by the aircrews' experiences and views.

2.17.2 Objectives

These were the objectives to support achieving the aim and answering the research questions:

1. To determine the views of aircrew and accident investigators on the impact of NFF and any links to airworthiness and to assess any differences from the literature view.
2. To analyse the results to establish strengths and weaknesses of current processes that surround NFF and the link airworthiness.
3. To explain the links between NFF and airworthiness.

4. To devise an approach to be used by aviation establishments to assess the level of NFF and its impact on airworthiness.
5. To make recommendations for improving the knowledge of NFF and the link to airworthiness.

The first objective is of prime importance as it establishes a direct link to Research Question 2. Moreover, the aircrew are key components of the airworthiness definition. Even so, their views on NFF and airworthiness have not been previously sought. This contributes to new research in this discipline.

3 RESEARCH METHODOLOGY

Introduction

This chapter describes the methodology and methods used that led to the results and analysis stated. It starts with the high-level design of the research, then describes how the data was collected and why, before it details how the data was analysed and presented. The methods used will be explained, with more detail provided for non-standard methods. Ethical considerations and approval will be discussed.

This chapter aims to detail the method to achieve the research aim:

> To explore the relationship between the NFF phenomena and airworthiness to establish if there is, or is not, a link between the two.

Chapter 1 introduced the NFF phenomena and demonstrated how it could impact the safety and airworthiness of the aircraft. Examples from air accident reports demonstrated the seriousness of NFF on airworthiness and human life. The UK military position was explained but no link between NFF and airworthiness was proposed. The literature review took this further with explanations and definitions of the terms NFF and airworthiness. The effect on airworthiness due to NFF in terms of cost, real and intangible, operational readiness, training, fault appearance, trending and terminology were appraised. These provided clear areas for further research to clarify the link between NFF and airworthiness.

3.1 What is a research methodology?

The research methodology is namely “the approach and strategy used to conduct research” (Wilson, 2014, p.3) but it can be a very complex undertaking. It considers the philosophy through to data collection and analysis. It can be viewed as essential but also a quagmire when establishing the route the research should undertake with many unfamiliar terms needing to be considered. Although different methodologies are proposed by authors, such as the Honeycomb of Research (Figure 3-1) (Wilson, 2014, p.8) and the Research Onion (Figure 3-2)

(Saunders, Lewis, and Thornhill, 2016, p.124), this is further muddled when these authors apply different terms for the same things, such as strategies/methodological choice and research design/strategies. However, the methodology adopted depends much upon the research question and the researcher's preferences and this is endorsed by Wilson who makes the point that the researcher should ask "which is your preferred philosophical stance, how this relates to your research approach, and the research strategy required to help you to address your initial research questions" (2014, p.20). For ease of understanding the process adopted, the following sections will examine the terms within each honeycomb (Figure 3-1) and identify the outcome selected for this research. For note, the three hexagonal sections are shaded to emphasise the main research philosophies, approaches and strategies Wilson (2014, p.7) discussed in his book.

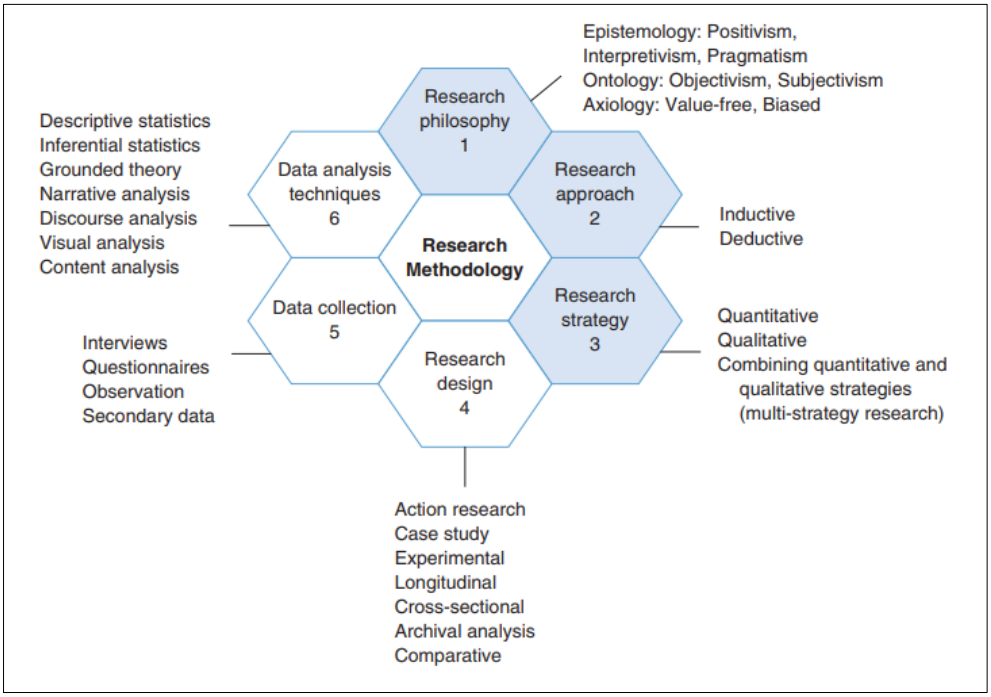


Figure 3-1: The Honeycomb of Research Methodology (Wilson, 2014, p.8)

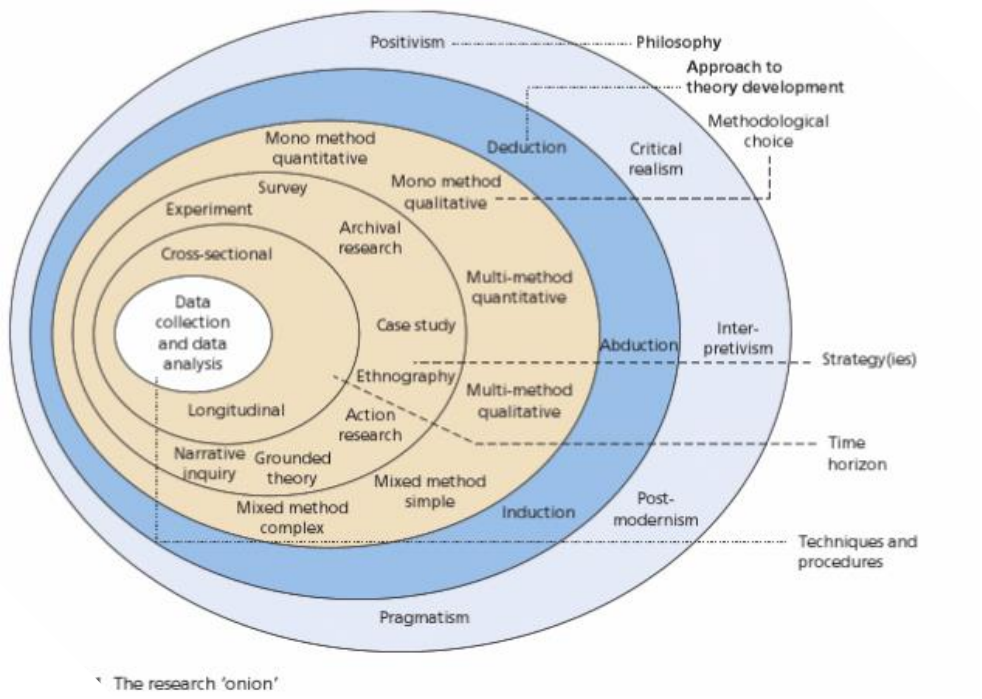


Figure 3-2: The Research Onion (Saunders, Lewis, and Thornhill, 2016, p.124)

Terms to understand are epistemology and ontology as they impact the research methodology; the former considers “What is acceptable knowledge?” (Wilson, 2014, p.9) and the latter is “concerned with the nature of reality” (Wilson, 2014, p.11). Textbooks highlight the differences between the terms but for this methodology, only the link to the philosophy was considered.

3.2 Research design

In simple terms, the researcher’s overall design is the plan demonstrating how the research will be conducted to answer the research question and it will detail the objectives, from where and how data is being sought, along with how the data is to be analysed, whilst highlighting any ethical considerations and constraints (Saunders, Lewis, and Thornhill, 2016). Succinctly, the research design is a framework that leads to the generation of evidence to answer the research question (Bryman and Bell, 2015). The belief is that the researcher should know what data is required before determining the research design type to be adopted (Saunders, Lewis, and Thornhill, 2016). However, the researcher should not be constrained by one approach (Collis and Hussey, 2013, p.8; Wilson, 2014).

3.3 Research philosophies/paradigms

Different authors present different interpretations of research philosophies and paradigms. Collis and Hussey (2013) assert that the research design will reflect an individual's beliefs. They believe that the terms paradigms and philosophies are the same as defined by Morgan (1979, cited in Collis and Hussey, 2013) but the term "refers to the scientific practice based on people's philosophies and assumptions about the world and the nature of knowledge; … [in essence] about how research should be conducted." Whereas Wilson (2014) opines that it depends upon one's assessment of how knowledge is developed and that the researcher's beliefs of what comprises knowledge will affect how the research is conducted. However, Bryman (2016) does not define philosophies, only paradigms, and again describes them in terms of "how research should be done, and how results should be interpreted". Saunders, Lewis and Thornhill (2016) document five paradigms, namely positivism, critical realism, interpretivism, post-modernism, and pragmatism. With the introduction of pragmatism, research was not bound to one philosophy but considered both positivism and interpretivism philosophies and focused "on the 'what' and the 'how' of the research problem". The research problem and question are at the hub of the research and the most suitable methods of achieving this are adopted (Wilson, 2014). So, this research considers, what is the link between airworthiness and NFF and how is this evident.

Therefore, for this research the pragmatics philosophy was adopted as whilst the researcher may wish to be detached this will not be possible as interviews, questionnaires and active tasks will be necessary to gather the relevant primary data. Additionally, as advocated by Wilson (2014, p.19) the ontological stance will be a combination of objective and subjective as the subject matter was known to the author but aspects were new and it was these new aspects where better objectivity would be evident.

3.4 Research approach

There are two main approaches to conducting research, namely inductive, and deductive but other authors also offer abductive to overcome the shortcomings of the other two approaches (Bryman and Bell, 2015). The inductive approach "will be seeking to make observations about your research, and then perhaps contribute to a new theory" (Wilson, 2014), which is in contrast with the deductive approach that applies theory or experiments etc. to test a hypothesis. What is important is that it is feasible to combine the different approaches depending on the research being conducted (Wilson, 2014). Whilst an inductive approach would be deemed to apply to a qualitative research strategy and a deductive approach to a quantitative approach both may be suitable if numerical and textual information from surveys and interviews are to be implemented to gather the necessary data to analyse the research problem. Due to the data being gathered to support a problem being researched, which is not testing a hypothesis, a combination of the inductive and the deductive approaches was considered the most appropriate.

3.5 Research strategy

In simple terms, research may be *qualitative* or *quantitative*; however, Saunders, Lewis and Thornhill (2016, p.148) state that these categories can be subdivided to consider mono-, multi-method, or mixed approaches. Wilson (2014) advocates the term multi-strategy as he believes it is a layering of both strategies and not a combination of the two together and argues that "multi-strategy can be viewed as pragmatic research" (2016, p.18) and allows the researcher to adopt the most suitable one. Due to the human element of the project, a mixed approach of qualitative and quantitative research was considered the most appropriate. The inductive approach allows observations to be made and from this, a theory is developed; however, it is not guaranteed to be true due to the limited observations. Whereas, the deductive approach starts with a theory, which is then tested, and allows a true or false outcome. A limitation of the deductive approach is that it requires a well-designed test. Adopting the mixed approach offers the benefit that, by using a range of methods, the validity and generalizability of the

results and their potential theoretical contribution will increase (Easterby-Smith, Thorpe and Jackson, 2015).

3.6 Research design types

The research design is the framework or the plan to enable data to be collected (Bryman and Bell, 2015, p.48; Wilson, 2014, p.119), namely exploratory, descriptive or causal (Wilson, 2014, pp.118-119). Whereas the research methods are the techniques used to collect the data (Bryman and Bell, 2015, p.49; Wilson, 2014, p.119). A combined research design would utilize mixed methods and whichever design is chosen the researcher needs to be cognisant that the chosen path may vary as the research progresses (Saunders, Lewis, and Thornhill, 2016, p.163 and p.176).

A descriptive research design would describe an existing or a past phenomenon and would utilize qualitative or quantitative strategies. From these strategies, the data gathered can be analysed and may lead to further research questions. It was for this reason it was assessed as the most appropriate research design. It is trying to answer the 'why' and 'how' questions of the research to provide clarity and focus on the area of research.

As evidenced by Figure 3-1 and Figure 3-2 authors again use different terms for the same things, but the main types remain consistent. Whilst caution is advised, a combination of research design types can be implemented but the key is to remain on focus to ensure the research question is being answered (Wilson, 2014, p.127).

There are numerous research design options, e.g., experimental, survey, archival etc., (Wilson, 2014, p.120). Only the survey was appropriate and whilst it is usually linked to the deductive research approach, it can also be inductive. The survey aims to answer the 'what', 'who' 'where', 'how much' and 'how many' queries (Saunders, Lewis and Thornhill, 2016, p.181). For example, what did the aircrew think, where were they, and how many NFFs did they experience? A perceived benefit of the survey strategy is that it permits the comparison of different views, and from large sizes, in a relatively easy manner using descriptive

analysis and inferential statistics, and is professed to be authoritative (Saunders, Lewis and Thornhill, 2016, pp.181-182). Importantly it can be used to propose possible reasons for the association between variables, in this case, reasons for NFF and airworthiness being associated.

3.7 Reliability, Validity and Generalizability

Any technique used to collect data, primary or secondary, needs to be approached with reliability and validity in mind to ensure the data is testing what is meant to be tested. Reliability is "concerned with the extent to which a measure provides stable results" (Wilson, 2014, p.132), i.e., how repeatable the data collection technique is to provide consistent findings. One way to improve the reliability of data is to be fully transparent "to allow others to judge for themselves and to replicate … [the] study if they wished to do so" (Saunders, Lewis, and Thornhill, 2016, p.192). Ways to achieve reliability include, maintaining a chain of evidence, creating a database of evidence (Wilson, 2014, p.130), and using alternative forms for data collections (Saunders, Lewis, and Thornhill, 2016, p.430). Wilson (2014, p.129) advocates that whilst reliability is important it is insufficient unless joined by validity. Validity is important as it is linked with the generalization of the research findings to all relevant context (Saunders, Lewis, and Thornhill, 2016, p.671). Both Wilson and Saunders, Lewis, and Thornhill agree that validity should consider internal and external validity. Internal validity considers the content, namely face and sampling validity, and construct validity, which ensures the test measures what it was intended to measure (Wilson, 2014, p.133). A way to achieve face validity is to use specialists or a research supervisor to review questions before they are used with participants (Wilson, 2014, p.133). Content validity is to ensure "the measurement covers all aspects of the concept being measured" (Scribbr, 2023a).

Within the data collection (Section 3.8), analysis technique (Sections 3.9) and the Analysis (Chapter 6) the reliability and validity and thus applicability to the general population will be discussed.

3.8 Data collection

When using the survey design (strategy), it can involve more than just questionnaires, although they are the most common (Saunders, Lewis, and Thornhill, 2016). They can also include structured interviews and observations. For this research, qualitative and quantitative data are required and so both semi-structured interviews and a questionnaire were used to collect primary data. Secondary data in the form of an aviation company's maintenance database was provided.

3.8.1 Interviews

Whilst interviews can be viewed as a series of steps with a logical process from one step to another (Creswell, 2013) an advantage advocated by Rubin and Rubin (2012, cited in Creswell, 2013, p.163) is that the questions posed can be modified, as well as changing the interview site. The semi-structured format allows information to be gathered more informally than a questionnaire and can be analysed qualitatively against themes. To answer Research Question 2 and meet Objective 1 of this research eight semi-structured interviews were conducted. All additional information and data relating to the interviews are in Appendix A.

How questions were devised – The open and closed semi-structured questions were devised from the researcher's experience, previous questions posed to engineers on NFF (Hockley, Lacey and Pelham, 2016) and the literature (Appendix A, A.1). Other questions were to gather background information on the interviewee's experience and authority to answer questions on the topic. This approach was chosen to align with the deductive and inductive approaches. Before conducting the interviews, a pilot study was conducted. A 'pilot study' is a small-scale study of the questionnaire before the main distribution. The pilot study was to assess clarity, logical order, ambiguity, interpretive differences, other possible weaknesses and to ensure there were no leading questions and is deemed necessary to increase the levels of reliability before the official distribution (Wilson, 2014, p.168). The 'pilot' study was undertaken by subject

matter experts (SME), who had military aviation and engineering experience, research supervisor, academics and information specialist to test the face validity of the semi-structured interview questions. The SME and research supervisor reviewed the questions to ensure 'sampling validity', namely to check the interviews "included all areas within the nature of …[the] study" (Wilson, 2014, p.133). Following their feedback, the questions were refined to improve clarity and remove ambiguity.

How participants were selected – Candidate interviewees were proposed by a supervisor, SMEs and via direct contact with the AAIB and Defence Accident Investigation Branch (DAIB) who provided details of those willing to be interviewed. Each interviewee was contacted before the interview to explain the purpose of the research and to give personal assurance of the ethics in place before the interviews were conducted, as advocated by Saunders, Lewis, and Thornhill (2016, p.378). To remove possible researcher bias impacting the interviews the author did not know any of the interviewees. There were eight interviewees, with aircrew (military and civilian pilots) and aircraft accident investigators, four apiece.

Where – The face-to-face interviews were conducted at a location chosen by the interviewee, so work or a neutral establishment. This has the advantage of being convenient for the interviewees, thereby making them feel at ease and more likely to respond, and reducing the possibility of being disturbed (Saunders, Lewis, and Thornhill, 2016, p.386). Additionally, it reduces the participants' bias as the location is one where they feel confident and will not be overheard (Saunders, Lewis, and Thornhill, 2016, p.192)

Whilst face-to-face interviews were chosen, the caution advised by Creswell (2013, p.164) was acknowledged, considered, and implemented, that being the interviewee was willing to speak and share thoughts and the location was conducive to enable a relaxed environment.

When – The aircrew interviews were held between November 2018 and May 2019, whilst the Air Accident Investigator (AAI) interviews were all conducted on 30th July 2019.

How conducted – To reduce any researcher bias, e.g., via tone, mannerisms, or remarks, (Saunders, Lewis, and Thornhill, 2016, p.381) each interview was conducted with a neutral observer. This lessened any interviewee doubts about the validity and reliability of the interviews. The neutral observer was to ensure a consistent, unbiased approach. The observer had copies of the interview questions.

Moreover, the measures to overcome interviewer and interviewee bias were implemented, e.g., by recording the interviews, providing transcripts and attentive listening (Saunders, Lewis, and Thornhill, 2016, p.383).

At the start of each interview, the purpose of the research and the ethics being followed were stated. To ease any possible anxiety the consent form was provided. Each interviewee signed a participation consent form (Appendix A, A.2), which assured the interviewee anonymity unless permission was granted; this was to build trust between the interviewer and the interviewees and reduce any interviewer bias (Saunders, Lewis and Thornhill, 2016). To gain credibility the researcher's background was stated, as recommended by Saunders, Lewis, and Thornhill (2016, p.389). Whilst the interviews were semi-structured (Appendix A, A.3 and A.4) in nature and, therefore, ensured repeatability and reliability, there was freedom to explore different avenues as they arose. Permission was sought and given by each interviewee to record the session and, afterwards, a transcript was given to each interviewee to further obtain consent that it was an accurate record. Only minor corrections for unclear terminology were received from Interviewee 5. These corrections were implemented. The neutral observers were provided access to the transcripts to check for accuracy if required.

Following the first interview and further literature analysis, the questions were modified as proposed by Rubin and Rubin (2012, cited in Creswell, 2013, p.163). The initial interviews were quickly analysed before conducting the remainder; this was to prevent data overload and enable suitable reflection to be conducted (Saunders, Lewis and Thornhill, 2016, p.571).

Timings – Each interview lasted for about one hour.

These interviews were the first stage of the research design survey to gain primary data on which to build the questionnaire and contribute to answering the research Aim, Question 2 and Objective 1. Following analysis, key themes were considered and taken forward to the questionnaire.

3.8.2 Self-administered questionnaire

To answer Research question 2 and meet Objective 1 of this research, a self-administered questionnaire was used to collect a wide range of primary data, both quantitative and qualitative. The advantage of a questionnaire is that it is cost-effective, reliable and enables quantitative and qualitative feedback (Wilson, 2014, p.164). However, it is impersonal, no clarification on a question's meaning can be provided and this may lead to misinterpretations, resulting in imprecise information being provided (Wilson, 2014, p.164); however, the advantages offset the disadvantages.

The primary data from the questionnaire used in this research is available at: 10.17862/cranfield.rd.21707741. This is provided to ensure reliability by maintaining a chain of evidence so that external observers can follow the derivation of any evidence (Wilson, 2014, p.132). All other additional information and data relating to the questionnaire are in Appendix B.

How were questions designed – The questions were based on the literature review findings, the key themes analysis of the interviews (primary data), and the author's knowledge and experience (Appendix B, B.2). This included alignment with questions from the *Report for Air Command on the impact of no-fault-found on a selection of RAF aircraft fleets* (Hockley, Lacey and Pelham, 2016), which was interested in the aircraft systems most prone to NFF. Adopting and adapting these questions was specifically to compare aircrew responses with those of aircraft engineers and let the reliability of the response be judged (Saunders, Lewis, and Thornhill, 2016, p.431).

The questionnaire was 'pilot' tested on current military aircrew, engineers, and academic colleagues. Whilst testing the clarity and interpretive differences of questions and the overall functionality of the questionnaire it was established that

the survey took about 12 minutes to complete. The estimated completion time was included in the Survey Instructions. Amendments to the questionnaire were made based on the 'pilot' feedback received and a second 'pilot' test was undertaken before the questionnaire was published. The 'pilot' tests were to "obtain some assessment of the questions' validity and … reliability of the data collected" (Saunders, Lewis, and Thornhill, 2016, p.451). The pilot test contributed to the internal validity of the research by using the SMEs (aircrew and engineers), academics colleagues and research supervisor to consider the face and sampling validity aspects by applying their subject matter expertise and research experience (Wilson, 2014, p.133). Moreover, the SMEs ensure the construct validity measured what was intended. Combined these reviews improved the validity of the research and linked to the interview questions and the literature review ensured there was means of triangulation by ensuring results from two or more different methods of data collection or … data sources were available for the analysis (Wilson, 2014, p.136). Reliability is also concerned with the *robustness* of the questionnaire (Saunders, Lewis and Thornhill, 2016, p.430) and analysis of the consistency of the 'pilot' feedback and answers to questions within the questionnaire contributed to the robustness.

The form of questions - The question comprised 10 sections and 52 questions (Appendix B, B.2 and 0), which were in the form of multiple-choice, matrix and free-text questions. In total, there were five interval, 11 ordinal, 19 nominal, and 15 qualitative questions (Appendix B, B.4).

Due to the function of Qualtrics, the Survey Instructions were classed as Question 1. This reduced the number of answerable questions to 51. This was acknowledged as a risk as too many questions, and the time to complete them, may diminish the goodwill of the respondent (Saunders, Lewis, and Thornhill, 2016, p.182). To minimize this a combination of multiple-choice and typed response questions was included.

Question 2 was a filtering question to exclude those who were not aircrew.

How were participants selected? The participants were selected anonymously. Emails, which included the questionnaire details (Appendix B, B.1) were

distributed by SMEs, colleagues involved with aviation, the RAF Flying Branch and NCA Trade Advisor and the Army Air Corps (Coleman, 2019; de Labillière, 2019; Lacey, 2019a and 2019b). It was posted on the RAF Aircrew bulletin board and Coleman (2019) aimed "to publish it on … [the] Defence Connect blog that is currently seen by 1,250 of our 3,000 Aircrew cadre." To widen the response rate, an attempt was made to distribute the questionnaire via PRrune; however, this proved unsuccessful.

How was the questionnaire conducted? - The questionnaire was created and conducted via the Internet using Qualtrics ® survey software.

When conducted – The questionnaire was open for six weeks, from 1st October to 15th November 2019.

How conducted – In line with University's ethics and to improve the response rate, the questionnaire was anonymous and the respondents had to provide consent before undertaking the survey. To improve the response rate, Coleman (2019) reissued the questionnaire on the RAF Aircrew bulletin board. However, after six weeks the number of views was just 81.

Sample size and response rate – The sample size was 50 but was reduced to 45 post-sanitization. Incomplete responses were removed, e.g., insufficient questions were completed.

3.8.3 Aircraft maintenance data

To support meeting Objectives 2 and 4, an aviation company's maintenance data for a small fleet of aircraft was provided. This secondary data was categorized as documentary and textual as it was from the company's database (Saunders, Lewis and Thornhill, 2016). Further, it was longitudinal as it covered a 13-year period. The disadvantages of secondary data are that it has been collected to meet the aims of the company and not research and the quality of the data may be questionable (Saunders, Lewis and Thornhill, 2016). However, to meet these objectives, how the data has been recorded will indicate the various ways of recording NFF.

The reliability of the secondary data from a company can be difficult to verify. Wilson (2014) asserts that it is mostly dependant on the credibility of the source. Saunders, Lewis, and Thornhill agree and add that data provided from “large well-known organisation … are likely to be reliable and trustworthy” (2016, p.325). However, it is incumbent on the researcher to analyse the data for “inconsistencies and inaccuracies” (Saunders, Lewis, and Thornhill, 2016, p.325). The aviation data was from a large credible company. Additionally, whilst there were some variations in how terms had been written, for example some entries used abbreviations, such as lube for lubrication, these were consistent throughout the full period of data provided. As the data was provided for the 13-year period it is assessed as having internal validity. However, it was also checked by the research supervisor to assess whether the data measured all aspects of the maintenance data required for the analysis and to meet the content validity (Scribbr, 2023a). Thus, the content validity was assured.

3.9 Data analysis techniques

To meet Objective 2 of this research, data analysis was conducted via descriptive statistics, Template Analysis and visual analysis. Some inferential statistics were made from the questionnaire quantitative data.

3.9.1 Interviews

The interviews were qualitative (Appendix A, A.5) and were analysed using descriptive analysis and Template Analysis (King and Brooks, 2017). As advocated by Creswell (2013, pp.182-184) the starting point was to read each interview transcript numerous times to get an overall feel for the content before looking for code and categories and then reducing the categories to allotted themes. The themes represented common ideas or thoughts that could be aggregated into higher-level units. Not all data were relevant to the analysis and this was discarded.

The semi-structured interviews (Appendix A, A.3 and A.4) covered five topics: classification data, knowledge of intermittent faults and NFF, training with regards to the PSED, the impact of intermittent faults, and NFF on airworthiness and air

safety and categorization of an intermittent fault. From these themes emerged. These were areas that the literature review indicated were contributors to NFF rates and the system's ALARP and tolerable levels but within the literature review, no aircrew's view was evident or considered. This was a gap in the research that the interviews were aimed at addressing.

To improve a chain of reliability, it is recommended a chain of evidence is maintained to allow "external observers to follow the derivation of any evidence from the initial research questions to ultimate … conclusion" (Wilson, 2014, p.132). To achieve this the interview questions and full transcripts are contained in Appendix A.

3.9.2 Template analysis

Template analysis is a form of descriptive analysis that can be used to analyse nearly all forms of text from most methodological and epistemology positions (King, 2014). Its advantage is its flexibility, which has few specified procedures to be followed and, thus, allows a researcher to tailor it to match the requirements of the research (King, 2014).

A coding template is developed that summarizes themes identified as important, which can be ordered into a hierarchy. "A code is namely a label attached to a piece of text to index it as relating it to a theme or issue in the data which the researcher has identified as important to ... her interpretation" (King, 2014). *A priori* codes are stated for themes firmly assumed to be relevant to the analysis and these can originate from the literature review, informal evidence, anecdotes or the researcher's experience (King, 2014). Frequently these are formed from the interview questions. These *a priori* codes are not fixed and can be modified if deemed not relevant following the analysis.

Like Creswell (2013), King (2014) advocates reading the transcripts before establishing the themes. Relevant sections should be highlighted where they align with *a priori* codes. New themes should be identified and added to the template. King (2014) is firm that the frequency of a code does not correspond to its importance; a theme mentioned once may have equal importance. Counting

codes denote quantitative assessment but may not be suitable for Template Analysis. The aim was to “look for code segments that can be used to describe information and develop themes” (Creswell, 2013, p.186)

A full description of how to apply the technique can be found on the University of Huddersfield web pages (University of Huddersfield, 2022). The basic technique applied was as follows:

1. Define *a priori* themes.
2. Transcribe the interviews.
3. Read them thoroughly to become familiar with the content.
4. Conduct initial coding of the data. Identify the transcript parts that are pertinent to the research question(s). If these align with an *a priori* theme, ‘attach’ the code to the identified section. Where no relevant theme is evident, change an existing theme or create a new one.
5. Create the initial template. Generally, the initial template is created post the coding of a sub-set of transcripts. Group the identified themes from the transcripts into a reduced number of higher-level codes that describe broader themes in the data.
6. Develop the template by applying it to the full set of transcripts.
7. Apply the ‘final’ template to aid the interpretation and write up the findings.
8. Apply some form of quality and reflexivity check to reduce any inadvertent bias in the analysis.

(University of Huddersfield, 2022).

3.9.3 Self-administered questionnaire

The Questionnaire data was processed in Qualtrics before being imported to Microsoft Excel and IBM SPSS statistics™. The data was sanitized by excluding question (Q) 1 (survey introduction), Q2 (non-aircrew responses) and Q3 (consent). Data entries were deleted for the start and end times, status, progress, duration, finished state, recorded date, response ID, distribution channel, and user language. From the responses of 50 participants, five were deleted as insufficient questions were completed. Three did not progress beyond Q8, one did not proceed beyond Q11 and one did not proceed beyond Q14. In total there

were 45 usable responses. The full results can be seen by question order in Appendix B (B.4).

To make an inference about the whole population, Wilson (2014) advocates the sample size must comprise 30 or more but rather than dictate appropriate sample sizes for varying population sizes he promotes using a sample that is representative of the population. The sample size was greater than 30 so inference was acceptable. The trained pilot population was assumed to be approximately 1800 for the RAF, 550 for the Army and for the Royal Navy/Royal marines 540 (Defence Statistics (Tri-service), 2015), as anecdotal evidence stated the numbers had not increased or decreased by the time the questionnaire was distributed.

3.9.4 Task 1 – Analysis of functional resonance analysis method conducted

Task 1 was established to review the NFF/Airworthiness Functional Resonance Analysis Method (FRAM) diagram and analysis. The FRAM NFF/Airworthiness model was created using the analysis from the rich picture, influence diagram and Bowtie and the preliminary flow charts.

Purposive sampling (Wilson, 2014, p.219) was applied as credible critiquing based on experience was necessary to validate the FRAM analysis. To improve the reliability of the analysis and alleviate the researcher's bias the FRAM model and analysis (Appendix D, D.1 and D.2) were reviewed by four SME volunteers with knowledge of current aviation systems, varied military aviation experience and who could withdraw their consent for inclusion in the analysis. Two SMEs were retired RAF engineering officers and two were currently serving, who had attained the ranks of Squadron Leader and Group Captain. Between them, their aviation experience ranged from 411 to 606 months, with an average of 40.5 years. Each SME was provided an electronic copy of the FRAM model and Excel Spreadsheet, weblinks to the FRAM website (FRAM, 2016), a verbal explanation of the task and a consent form (Task 1 - Appendix D, D.3). Affirmation was received from each SME that they fully understood the Task 1.

Using SMEs to review the analysis addressed the reliability, i.e., “the extent to which a measure provides stable results” (Wilson, 2014, p.132). The SMEs’ combined feedback contributed to the credibility of the analysis. Few changes were required and overall, the FRAM model and analysis of the FRAM Excel spreadsheet was complete. The SMEs’ review also address the validity, i.e., how repeatable the data collection technique is to provide consistent finding. One way to improve the reliability of data is to be fully transparent “to allow others to judge for themselves and to replicate … [the] study if they wished to do so” (Saunders, Lewis, and Thornhill, 2016, p.192). To support this reliability, the instructions for the review are presented and the final FRAM model and analysis (Excel Spreadsheet) are available at (10.17862/cranfield.rd.24106071). This creates a chain of evidence recommended by Saunders, Lewis and Thornhill (2016).

Task 1 comprised three parts. It entailed a detailed review of the FRAM model against the detailed FRAM analysis presented in an Excel spreadsheet. Each FRAM Function and Aspects (Control, Output, Input, Time, Resource, Pre-condition) (Hollnagel, 2012) were checked to confirm that no Function was omitted, all Aspects were complete and accurate and each link from one Function Aspect to another was accurate. Secondly, a review of the Internal/External Variability was conducted to consider the following questions:

- For each function how can its variability be affected by the change to each Aspect (Input, Output, Pre-condition, Control, Resource and Time)?
- Do you agree the Most Likely Dimension of Variability is as stated?
- Do you agree with the Most Likely Description of the Variability?
- Do you agree with the frequency of output performance variability stated?
- Do you agree with the amplitude of output performance variability stated?
- Do you agree with the stated Potential Performance Indicator?

Thirdly, a review of the Upstream/Downstream Coupling was conducted to consider the following question:

- Do you agree with the stated ‘Most Likely Form of Upstream Variability for the Aspect’ being considered? I.e., what could cause the change.

- Do you agree with the stated Frequency of Upstream Performance variability?
- Do you agree with the Amplitude of Performance variability stated?
- Do you agree with the description of the effect the upstream variability will have on the function?
- Do you agree with the stated 'Possible effect on this (downstream) Function Output Variability [increase, decrease, remain unchanged]'?
- Do you agree with the stated 'What Potential Damping Factors could be put in place to counter upstream-downstream coupling'?

If the SMEs disagreed with any aspect of the FRAM model or Excel Spreadsheet analysis, they provided written feedback on the FRAM model or Excel Spreadsheet. Each feedback comment was carefully reviewed and either implemented or a discussion was held with the SME to explain why the comment was not applicable. By following the approach detailed above, reliability can be assured.

No reward was provided for completing the task. Ethics approval was applied to ensure anonymity unless permission was granted (Section 3.11).

3.9.5 Task 2 – Post-sortie engineering debrief (PSED) airworthiness levels

Task 2 was aimed at military aviation engineering SMEs. It was to determine the number and level of the aircrew PSED airworthiness selections, due to a NFF, that needed to be recorded, within a stated period, before an engineer would assess a change in the aircraft's overall airworthiness level and move it from one level to another. The aim was to evidence the vagueness between an airworthy and an unairworthy aircraft. Purposive sampling (Wilson, 2014, p.219) was adopted as specific military aviation experience in a role (Junior or Senior Engineering Officer) was required to complete the task but any bias would be minimized by anonymity. The Task was reviewed to ensure the correct measure was being requested and it was aimed at the correct participants who had been provided with consistent descriptions of the task and the definitions. The Task 2 reviewers were one SME and the research supervisor, who had research

experience. They confirmed the correct measures were being recorded. This provided internal validity, namely face, sampling and construct validity (Wilson, 2014, p.133-134).

Therefore, Task 2 (Appendix E, E.1) was distributed to 11 SMEs within the UK RAF (serving and retired). Their military ranks ranged from flight lieutenant (n=1) to group captain (n=2) with their aviation experience ranging from 87 to 606 months, with an average of 31.5 years. Furthermore, no reward was provided for completing the task, as this could introduce participant bias.

This PSED assessment was based on the airworthiness level recorded by the aircrew following a sortie—key definitions and descriptions used by the aircrew to make the assessment were provided. After the sortie, the aircrew would assess the aircraft's airworthiness level from 'negligible to severe' impact based on the description provided (Appendix E, E.1, Table 1). This was for the same fault recurring after being assessed by the maintainers as a NFF or intermittent fault over one, three, six and 12-month periods. A recording of 'tested satis' would be categorized as a NFF (see Section 2.3 and 2.14.2).

This data was provided to the SMEs who were to assess from an engineering perspective whether there was a change in the aircraft's airworthiness levels over periods of one, three, six and 12 months. In effect, they were to determine how many aircrews reported PSED airworthiness levels for the initial fault and repeated NFF or intermittent faults recorded over a stated period were required before they assessed that the overall airworthiness level of the aircraft moved from one level to another—from Negligible through to Severe. This was achieved by completing a table for each period and then justifying the assessment made.

Then if the **same** (or very similar) fault was reported on the PSED for the **same** aircraft again, they were to indicate how they would assess these subsequent events impact the overall aircraft's level of airworthiness. These may or may not be recorded as NFF or intermittent. The fault has not been found. In effect, they were assessing how many occurrences at one PSED level would be required before the aircraft should be categorized at a higher, more critical airworthiness level. So, four tables in total with justification for the decision were to be provided.

For example, the SMEs were to assess how many Aircrew PSED level 2 recordings for a fault related to a NFF or intermittent fault would be required within a set period before the combined number moved the overall aircraft airworthiness up to level 3.

As there was no access to the aircrew, a normal Gaussian distribution was used. There are limitations with this approach in that it is not precise and does not consider cognitive thinking, experience-based knowledge, skill level or emotion. It affects the membership function curve, i.e., how each input is mapped to the membership function.

Ethics approval was requested and provided (CURES Team, 2017). Each SME was a volunteer, no rewards were provided and each SME could withdraw their consent for the response to be used.

To increase the reliability of the data and analysis a chain of evidence is provided (Wilson, 2014, p.132) with the results from Task 2 available in Appendix E, E.2 (Engineers SME results), E.3 (Example best-fit lines) and E.4 (Sugeno Fuzzy Logic rules and surface plots for months one, 3, 6 and 12).

As this task was undertaken by only RAF engineering officers, it may impact the external validity of whether the results can be generalizable to other relevant groups (Wilson, 2014), such as the British Army, Royal Navy or civil aviation.

3.10 Data analysis presentation

The following methods were used to present the analysis: rich picture, influence diagram, Bowtie diagram, flow charts, FRAM (Hollnagel, 2012) and MATLAB® Fuzzy logic inference. In essence visual analysis.

3.10.1 Rich picture

The rich picture is a systems engineering tool and describes the '*As is'* problem situation for human activity, i.e., the NFF/airworthiness situation and before any improvements or recommendations have been implemented. The rich picture includes the main factor affecting the situation, and can include processes and structures, concerns and issues, and is aimed at providing the overall

relationship, climate, between the different people, parts, and aspects, (Patching, 1990) such as aircrew, engineers and regulations. The rich picture was developed from the literature review, interviews and questionnaire analysis and Template Analysis. The latter two enabled the incorporation of aircrew viewpoints on NFF and airworthiness an aspect not previously given attention in the literature. The aircrew worldview (Waring, 1996) was incorporated.

3.10.2 The influence diagram

The influence diagram depicts how two factors influence each other, with all other aspects remaining constant. They are used to explicitly show a person's perception of the causes of change in a system (Sage and Armstrong, 2000). The influence diagram omits words such as good, bad, poor, low etc., as these bias the outcome and without them, positive or negative outcomes can be established, such that an assessment can be made as to whether there are negative—balancing—feedback loops, which provide regulation towards some norm, or positive—reinforcing—feedback loops, which can lead to extremes, exponential growth, that requires controls to be established (Hitchins, 1992). Identifying whether there are positive—reinforcing—feedback loops and what contributes to the loops allows the user to consider how to turn the loops into negative—balancing—feedback loops by adding controls and thus stability to the system. Nouns or noun phrases are used to describe the factors (Hitchins, 1992). The influence diagram was developed from the rich picture to capture any influences that would contribute to an airworthiness and NFF link.

3.10.3 Bowtie

The Bowtie is a barrier risk model; other models are available. The CAA view the diagram as a means to aid the identification and management of risk (CAA, 2015d). For others, they are a means to describe and analyse the route of risk from the causes of the event to the consequences (BSI, 2019). It was used to represent the risks and the means to mitigate the effect that could cause the hazard. It was developed from the rich picture, influence diagrams and preliminary flow charts; it was an iterative process. Post the FRAM creation, a review was conducted for completeness and to highlight those risks (threats) and

controls deemed most significant and which required focused attention. The source material that contributed to the Bowtie is detailed in Appendix C.

The following explains the changes with version of Bowtie analysis and key terms used within the model and analysis. Between the BSI 2010 and 2019 versions, there was a slight change of emphasis, with more inclusion of 'likelihood' and modification of the event or the consequence, undesirable as well as desirable, and from brainstorming to teamwork building the scenario (BSI, 2010; 2019). This change of emphasis may have been in line with research or known usage and implementation of the techniques between 2010 and 2019. The 2019 version states that it provides more detail on "the process of planning, implementing, verifying and validating the use of the techniques" (BSI, 2019). The benefit of the Bowtie is that instead of producing full fault and event trees the many scenarios are reduced to one cause-and-effect relationship, with the aim being to communicate risk to the audience, such as managers, engineers and aircrew (De Ruijter and Guldenmund, 2016). Additional benefits of Bowties and Bowtie analysis are that they can be updated as new information becomes available, are simple to understand—so long as the reader understands the terms—like a rich picture, provide an illustrative depiction of the situation (problem), draw attention to the controls placed to prevent or mitigate the event, their effectiveness can highlight desirable and undesirable consequences, and do not require expertise to use (BSI, 2019). The ability to update the Bowtie with new information will be necessary once the FRAM has been conducted. However, Bowties come with disadvantages, namely the Bowtie cannot represent situations where numerous 'causes' occur concurrently to contribute to, or result in, the 'consequence' and, also, they may greatly simplify complex situations (BSI, 2010; BSI, 2019). So, whilst barriers are drawn sequentially, they do not act sequentially but may act in parallel. Additionally, the purpose of determining the effectiveness of a Barrier (control) is to highlight the strength or weakness of the overall Bowtie (CAA, 2015d); however, the scale needs to be useful and measured. The creator of the Bowtie needs to know the adequacy of the control for the scenario and how well it works when required (CAA, 2015d). To do this effectively the creator would need to know the organization and scenarios exceptionally well, otherwise, best

estimates based on the evidence available will be used. Thus, the Bowtie will need a review, be iterative following usage, and be updated as necessary. It is for this reason the Bowtie was reviewed following the FRAM model and analysis.

An additional problem for the creator and users is that there is no universally agreed definition of safety barriers, nor are the types, categories and classification (e.g., technical, operational, human, software etc.) of barriers (Sklet, 2006; Sobral and Guedes Soares, 2019), so caution needs to be taken when comparing between different organizations and diagrams. This is evidenced in Figure 3-3 which does not show the Hazard, Top Event, or Threat, but it does include the Escalation Factor Control advocated by the CAA (2015d). Table 3-1: Bowtie terminology and meaning Adapted from: CAA (2015d); Wolters Kluwer (2022); Sobral and Guedes Soares (2019)Table 3-1 provides an explanation of the terms used within the Bowtie diagram and analysis.

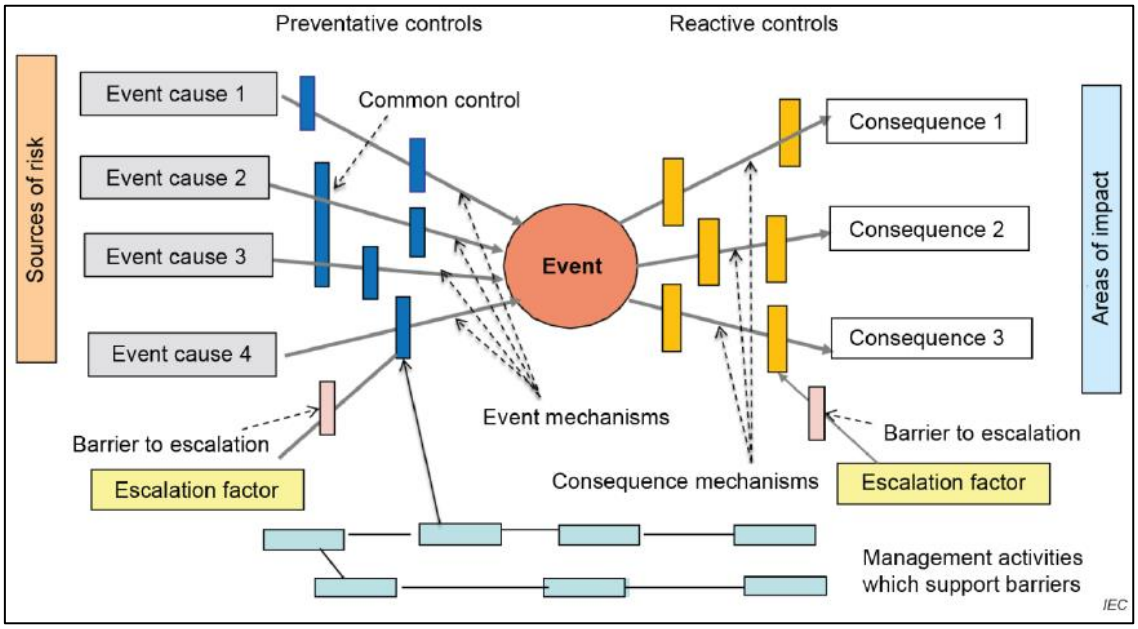


Figure 3-3: Bowtie example (BSI, 2019, p.81)

Table 3-1: Bowtie terminology and meaning Adapted from: CAA (2015d); Wolters Kluwer (2022); Sobral and Guedes Soares (2019)

Term	Description
Hazard	The hazard is the thing required for business success and instigates the context and scope of the Bowtie. An activity, condition object, or state of the thing with the potential to cause harm to people, equipment, structures, loss of material, or reduction of a function's ability but without it there is no business. It needs to be managed to keep it under control. It is not unwanted.
Top Event	The event that causes a deviation, release, or loss of control over the hazard. Not catastrophic but evident. It is the undesired system state. Has possible multiple likely causes and outcomes.
Threats	The factors that can cause the top event and an unsafe state, possibly release of the hazard, if no preventative controls are in place to manage the state. All threats should have the ability to cause the top event, with a logical cause-and-effect relationship between the two. They are not listed in any order of importance but the convention is to place the most significant threat at the top (CAA, 2022). (This will be undertaken following the FRAM model and analysis).
Consequences	The possible, undesirable, outcome of the top event if not managed, results in the release of the Hazard and, thus, loss or damage. Unwanted events that the business wants to avoid by all possible means. Should be stated in operational terms so the depicted scenario is evident. Any consequence should result if a Top Event is not controlled.
Barrier (Prevention control)	Their purpose is to provide a means of protection for people, the system, and the environment from the event by removing the threat completely or by preventing the threat from evolving into the Top Event. The Barrier should be written with a verb and a noun. The preventive (proactive) barriers, which are on the left side of the Top Event, prevent the top event from happening.
(Recovery control)	A measure that is put in place to protect (reduce the severity), manage the consequence from happening and maintain the desired state. As the focus was on preventing the Top Event this was not used within the analysis
Escalation factor	Conditions that can cause the barrier to fail. It leads to increased risk by overcoming or diminishing the

	effectiveness of a barrier (recovery or preventive). Whilst unable to directly cause the Top event or Consequence, they increase the likelihood that the outcome/scenario will develop due to the failure or degradation of the related control. When developed they should incorporate historical lessons learned.
Escalation factor control	This was not available in the BowTie XP Software ©

3.10.4 FRAM

FRAM was developed to focus on everyday activities, rather than failures as per many safety tools, without specifying an obvious cause and with the view that outcomes are not always caused by linear events (Hollnagel, 2012). Whilst the method promotes a description of *work-as-done* instead of *work-as-imagined*, it can be used to analyse past events as well as possible future events, but without a focus on negative outcomes (Hollnagel, 2012). The FRAM NFF/Airworthiness model was created using the analysis from the rich picture, influence diagram and Bowtie and the preliminary flow charts. The outcome of the internal/external function variability and upstream/downstream functions coupling was used to highlight the areas of the Bowtie diagram requiring greater consideration, as these are where the greater variability within the system will be felt.

3.10.5 Fuzzy logic inference

MATLAB Fuzzy Logic Toolbox™ was used to demonstrate the fuzzy inference between the aircrews' and engineers' viewpoint of an aircraft's airworthiness based upon the PSED and the number of NFF recorded. According to Kosko (1994, pp.18-19), the "fuzzy principle states that everything is a matter of degree" and the solution will not have just one of two outcomes. The human introduces vagaries that need to be considered for the analysis of the effect NFF has on airworthiness. Humans use imprecise words such as tall, small etc. It is asserted that the terms and boundaries between the terms airworthy and unairworthy are also vague as they depend on the individuals making the distinction. That will be impacted by the individual's experience and education etc.

There are two main ways to analyse fuzzy inference, either Mamdani or Sugeno fuzzy inference systems. Both systems apply fuzzification to the inputs and then apply a fuzzy operator but where the Mamdani method demands fuzzy sets for the output membership functions that require defuzzification, the Sugeno system does not (Kalogirou, 2014). The advantage of Sugeno is that the output membership functions are linear or constant (Kalogirou, 2014); it applies the fuzzy rule: *IF x is A and y is B THEN Z = f(x,y).*

With two inputs (x and y), the Sugeno system operates as shown in Figure 3-4 and Figure 3-5 by applying and Equation (3-1). The output is the minimum value. If there is more than one rule applicable at the same time, then the output is the sum of these by applying Equations (3-3) and (3-3) (Topperly, 2021).

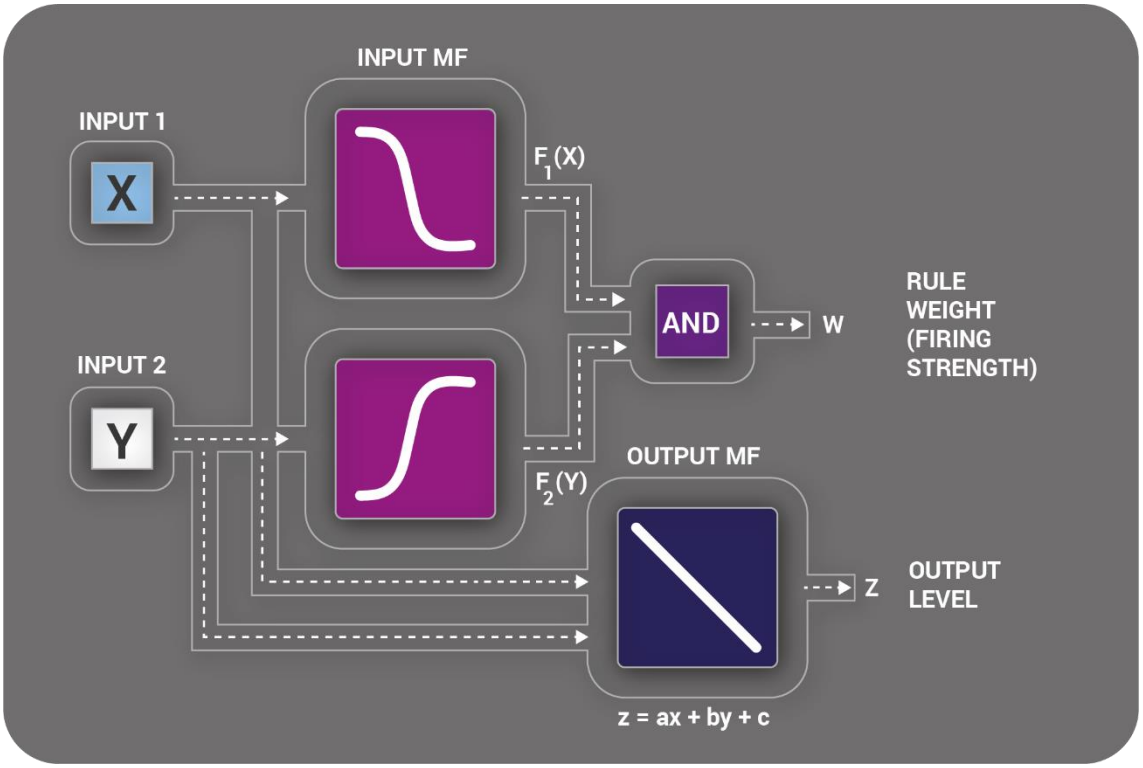


Figure 3-4: Diagram of Sugeno fuzzy inference system (Mathworks, 2022)

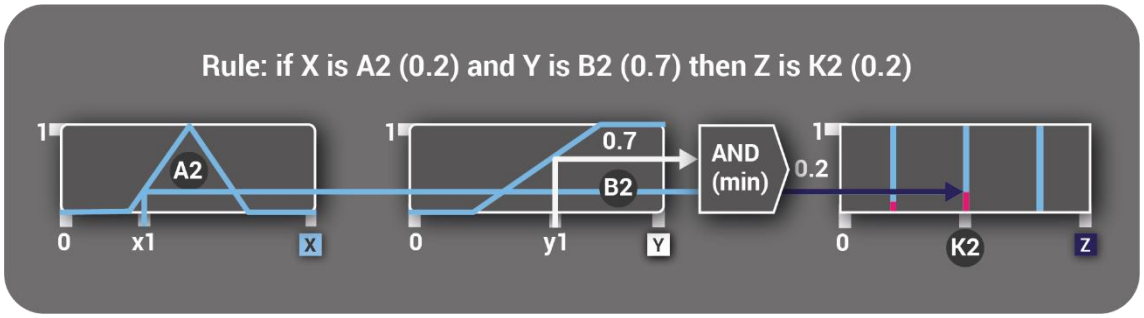


Figure 3-5: Depiction of Sugeno system AND rule (MathWorks, 2022)

$$z_i = a_i x + b_i y + c_i \quad \textbf{(3-1)}$$

$$w_i = And\ Method\left(F_{1(x)}, F_{2(y)}\right) \quad \textbf{(3-2)}$$

$$Final\ Output = \frac{\sum_{i=1}^{N} w_i z_i}{\sum_{i=1}^{N} w_i} \quad \textbf{(3-3)}$$

Where *x* and *y* are fuzzy sets input values 1 and 2, a_i, b_i, and c_i are constant coefficients of the members of the fuzzy set, z_i is the output and its value depends on the strength of each rule, namely w_i, which is the rule firing strength and *N* is the number of rules being applied (Mathworks, 2022).

Thus, the Sugeno method is applied to nonlinear systems by interpolating multiple linear models and it assures continuity of the output, namely a surface plot (Mathworks, 2022). Moreover, the Sugeno system's "defuzzification process is more computationally efficient compared with that of a Mamdani system, since it uses a weighted average or weighted sum of a few data points rather than compute a centroid of a two-dimensional area" (Kalogirou, 2014) as shown in Equation (3-3). By applying the parallel rules, the resultant surface plot flows smoothly from the inference rule applicable to one membership function to the next depending on which is dominant, and this prevents crisp breaks or delineation in the plot (MathWorks, 2022).

It is for this reason the Sugeno fuzzy inference system was chosen for the fuzzy logic analysis.

3.10.6 Aviation company maintenance data analysis for NFF

Maintenance data for a small aircraft fleet was provided for analysis. This data covered the period from 2009 to 2022. This was analysed to determine the number of NFFs over that period, and the average number of NFF per key system per year, as identified from the interviews and survey. The effect of the average number of NFF recorded for 12 months being condensed into 6, 3 and 1-month periods were analysed using the reported maintenance data. This was to indicate the number of NFFs that would be an abnormal event and require additional investigation. These periods were chosen to align with the Task 2 analysis so comparable data were assessed together.

Additionally, the OEM maintenance data for the period 2018 to 2022, 75 months in total, was provided and analysed. This data identified those work cards that had correctly and incorrectly been recorded as NFF. No specific alignment with the company data was possible due to different coding and recording mechanisms. However, this data provided an assessment of the accuracy of the company's NFF recording.

The company maintenance data has been withheld for commercial reasons (Cranfield University, 2022). Therefore, these data are not available via Cranfield Research Online Data (CORD).

3.10.7 Flow charts

Flow charts provide a visual representation of a process and can include dependencies, so thereby permitting a clear understanding of the workings and interactions of a system (Microsoft, 2021). The preliminary flow charts were constructed using the information from the rich picture, influence diagram and interview and questionnaire analysis. They were created to capture the '*As is*' situation and then developed to incorporate changes to support the system and processes required to reduce the impact of NFF on the aircraft's airworthiness level.

The flow chart analysis is a model identifying the risk areas where additional attention is required to minimize the impact of NFF on airworthiness.

3.11 Research ethics considerations

Ethics is not just a social responsibility but a moral obligation and it is important to acknowledge an individual's viewpoint may differ in what is acceptable and what is unacceptable (Wilson, 2014, p.91). Before commencing this research, ethical approval for the research was given by Cranfield University Research Ethics Committee (Reference: CURES/2419/2017) (CURES Team, 2017). This was completed to establish the ethics in place for the interviews, questionnaires, Task 1 and Task 2 and to ensure an individual's anonymity was protected unless prior approval was granted.

Additional CURES approval was granted for the analysis of secondary data provided by the third-party aviation company (Reference: CURES/16287/2022) (CURES Team, 2022). Due to the nature of this research, no approval was provided by the third-party company for the aviation data to be shared publicly due to commercial sensitivity, so supporting data is not available.

3.12 Limitations

This research was conducted during the COVID-19 pandemic. Consequently, access to SMEs and aviation companies was very limited. A high response rate to surveys is always preferable but in reality, this is very rare. The analysis was based on the responses received and this may inadvertently skew the analysis. Every effort was made to reduce this effect and negate any possible limitations. The use of SMEs was to counter any unintentional bias the researcher may have demonstrated.

3.13 Summary

The research methodology was a key step in establishing the overall outcome of the research. Nevertheless, depending upon which source was read there are different explanations of the research methodology and the route to collecting data and the technique applied to analyse them. This was highlighted by the differences between Figure 3-1 and Figure 3-2. Whilst there are differences in

terminology expressing the research approach, it was for the researcher to feel comfortable with the research methodology being adopted.

To summarize, the research was conducted as follows: Pragmatist philosophy, with an ontological stance, including objectivity and subjectivity, with inductive (via the questionnaires and secondary data) and deductive (via the interviews), research approaches, incorporating a multi-strategy approach, and surveys (Figure 3-6).

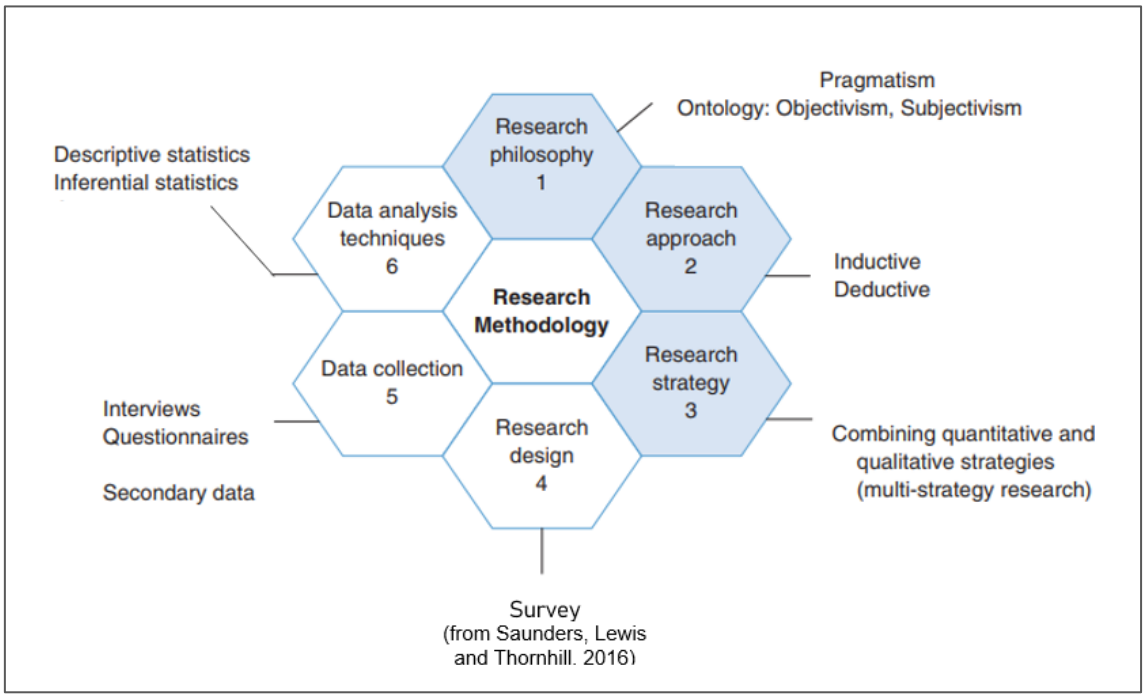


Figure 3-6: Implemented Honeycomb of Research Methodology Adapted from: Wilson (2014)

The surveys were semi-structured interviews and a questionnaire for the primary data collection. Additional primary data was collected from the SMEs' responses to Tasks 1 and 2. The data analysis was via descriptive statistics, Template Analysis (King and Brooks, 2017), with some inferential statistics. It commenced with a literature review to understand the current situation regarding airworthiness and NFF. The aim was to acknowledge whether there was a consensus on whether NFF affects airworthiness. The literature review was also to assess what factors needed to be considered when developing the sources of primary data collection, the interviews and surveys. Following the survey analysis, a rich

picture, influence diagram, flow charts, Bowtie, FRAM analysis and fuzzy logic inference were created to analyse the link existing between NFF and airworthiness and the key factors contributing to one. Feedback from the FRAM model and analysis to the Bowtie was conducted to highlight significant contributors to the NFF and airworthiness link. The fuzzy logic inference analysis was developed to indicate the fuzzy boundary between an airworthy and an unairworthy aircraft from the aircrews' and the engineers' perspective - *Weltanschauung* (Waring, 1996. p.7). This was to contribute to the investigation required and actions to be taken by stakeholders to mitigate the impact on the airworthiness because of the NFF.

Now the research methodology was established the collecting of primary data could commence to find out if the objectives and aims of the research (Section 2.17) could be met.

4 INTERVIEWS ANALYSIS

4.1 Introduction

The purpose of the pilot and AAI interviews was to establish a foundation of knowledge, experience, and perspectives to support the survey, which otherwise would be based on the literature review and the author's engineering and operational knowledge. The outcome of all the interviews was checked for similarities or differences and these contributed to the questionnaire. This was to reduce any author bias that could ensue if the survey was devised only on the literature review and the author's experience.

The semi-structured interviews (Appendix A, A.5) covered five topics: classification data, knowledge of intermittent faults and NFF, training with regards to the PSED, the impact of intermittent faults, and NFF on airworthiness and air safety and categorization of intermittent faults. These were areas that the literature review indicated were contributors to NFF rates and the system's ALARP and tolerable level but within the literature review, no aircrew's view was evident or considered. This was a gap in the research that the interviews were aimed at covering.

The interview data collection method and analysis technique, including how reliability and validity were addressed, are explained in Chapter 3. The interviews were analysed using descriptive, qualitative data analysis by following the Template Analysis approach (King and Brooks, 2017). Template Analysis enables a researcher to comprehend the experience or *Weltanschauung* (Waring, 1996. p.7) of the sample population as a whole instead of just an individual holistic view while still appreciating the phenomenon (NFF) being examined (King and Brooks, 2017, p.31). Whilst the interviews were conducted with aircrew and AAI the analysis will be combined as there are similarities in the discussions and viewpoints. This section details the key findings from the eight interviews against themes, how the analysis supports the assertion that there is a link between NFF and airworthiness, and how these findings contribute to the development of the questionnaire questions and future analysis. As only eight

interviews were conducted, no generalizations about the population can be made.

4.2 Template analysis themes

Template analysis can be used to analyse most textual data. It has minimal rules to follow and thus allows flexibility for the researcher in how to apply the outcomes (King and Brooks, 2017). For the template analysis, *a priori* themes were identified for the development of the aircrew interviews and whilst not essential, they provided some links between the two sets of interviews—aircrew and AAI—and some focus for the preliminary coding and clustering process (Table 4-1). As emphasized, *a priori* themes may prove inappropriate or not useful as the analysis progresses and, in such cases, they can be rejected (King and Brooks, 2017, p.30).

Table 4-1: 'A priori' themes for aircrew interview template analysis

'*A Priori*' Theme	Description and sub theme
Categorization	Considers the experience and authority of the interviewee to comment on NFF and airworthiness.
Fault Understanding	Considers whether intermittent faults are understood and experienced
	Considers whether the phenomenon of NFF is known and experienced.
	Use of documentation to record the faults
Training	Trained to conduct a PSED
	Understand the engineers' terminology
	Considers to time available for training
	Regulations in place
Airworthiness and Air Safety	Impact on airworthiness
	Intermittent fault impact on air safety
	Intermittent fault severity
	Intermittent fault consequence
PSED	Format taken
	Key information to impart
	Time available to conduct
	Effect of day or night

Similarly, an original list of '*a priori'* themes was created for the development of the accident investigators' interview questions and template analysis (Table 4-2).

Table 4-2: 'A priori' themes for accident investigators' interview template analysis

'*A Priori'* Theme	Sub Theme
Categorization	Considers the experience and authority of the interviewee to comment on NFF and airworthiness.
Fault Understanding	Considers whether intermittent faults are understood and experienced
	Considers whether the phenomenon of NFF is known and experienced.
	Use of documentation to record the faults
Training	To establish if intermittent or NFF training has been provided.
	To establish if there is a disjoint between the engineers' understanding
	Considers to time available for training
	Regulations in place
Airworthiness and Air Safety	To establish the systems most prone to an NFF or intermittent fault. systems
	Impact on airworthiness
	Intermittent fault impact on air safety

After reading the aircrew interview transcripts, the first aircrew interview was further analysed to identify preliminary coding and clustering (Table 4-3). AP denotes '*a priori'* themes and sub-themes originally identified in Table 4-1. PC denotes preliminary clustering.

The coding and clustering following analysis of all the interviews was created (Table 4-4).

Table 4-3: Initial template identifying preliminary codes and clustering following analysis of Interview 1

Classification	Theme
AP	1. Categorization
AP	1.1 Experience
PC	1.1.1 Flight Experience
PC	1.2 Years of flying experience
AP	2. Fault Understanding
AP	1.1 Intermittent faults
AP	1.2 No Fault Found
AP	1.3 Documentation
AP	3. Training
AP	1.1 Post-sortie engineering debrief
AP	1.2 Engineers' understanding
AP	1.3 Time available
AP	1.4 Regulations
AP	4. Airworthiness and Air Safety
AP	4.1 Intermittent fault impact on airworthiness
AP	4.2 Intermittent fault impact on air safety
AP	4.3 Intermittent fault severity
AP	4.4 Intermittent fault consequence
AP	5. PSED
AP	5.1 Format
AP	5.2 Key points
AP	5.3 Time available
AP	5.4 Time of day
PC	5.5 Solutioneering
PC	6. Continuity and management
PC	6.1 Junior/senior engineering management
PC	6.2 Strategic management of fault investigation
PC	7. Trust reduced
PC	7.1 Causes
PC	7.2 Reluctance to challenge engineering judgement
PC	7.3 Tension between aircrew and engineering
PC	8. Communication of faults (NFF)
PC	8.1 Forced rank structure
PC	8.2 Check understanding
PC	9. Time available
PC	9.1 Cabin crew composition
PC	9.2 Time of day

Table 4-4: Final Template identifying preliminary codes and clustering following analysis of all the interviews

Theme	
1.	**Categorization of interviewees**
	1.1. Experience
	1.1.1. Ground school
	1.1.2. Technical manuals
	1.1.3. Flight experience
	1.2. Years of flying experience
2.	**Definition of NFF**
	2.1. Definition/description
	2.2. Effect of ambient conditions
3.	**Fault understanding**
	3.1. Intermittent faults
	3.2. No fault found
	3.3. Documentation
4.	**Airworthiness and air safety**
	4.1. Intermittent fault impact on airworthiness
	4.2. Intermittent fault impact on air safety
	4.3. Intermittent fault severity
	4.4. Intermittent fault consequence
	4.5. Prominent aircraft systems
5.	**Training**
	5.1. Post-sortie engineering debrief
	5.2. Engineers' understanding
	5.3. Time available
	5.4. Regulations
	5.5. On-the-job training
	5.6. Responsibilities of a captain
6.	**PSED**
	6.1. Format
	6.2. Key points to provide
	6.3. Time available
	6.4. Time of day
	6.5. Solutioneering
	6.6. Regulations/procedures/processes
	6.7. In-flight diagnostics
	6.8. Hypothesis
	6.9. Engineering clarification

7.	**Time available**
	7.1. Cabin crew composition
	7.2. Time of day
	7.3. Crew duty time
	7.4. Work/social commitment
	7.5. Complexity of fault
8.	**Documentation**
	8.1. Engineering terminology
	8.2. Insufficient detail
	8.3. Unofficial engineering records of NFF
9.	**Continuity and management**
	9.1. Junior/senior engineering management
	9.2. Strategic management of fault investigation
	9.3. Synchronization of aircrew and engineers shifts
	9.4. Limitation of engineers' shift pattern
	9.5. Flying programme
	9.6. Inexperienced engineers and aircrew
10.	**Trust awareness**
	10.1. Causes
	10.2. Reluctance to challenge engineering judgement
	10.3. Tension between aircrew and engineering
11.	**Communication of faults (NFF)**
	11.1. Verbally between aircrew
	11.2. Social media
	11.3. Experience of engineers
	11.4. Aircraft technology
	11.5. Forced rank structure
	11.6. Check understanding
	11.6.1. HUMS/Event markers
12.	**Impact on flight programme**
	12.1. Risk versus reward
	12.2. Repair time
	12.3. Cancelled/curtailed/amended profile flight
	12.4. Refusal to fly aircraft
	12.5. Disinclination to report ongoing historical flight

The top-level themes identified (Table 4-5) are the basis for the analysis. Where a theme emerges throughout the interviews as an underlying theme, this will be

identified as an *integrative* theme (King and Brooks, 2014, p.35). Similarly, if a point overlaps with more than one theme or sub-theme, this will be identified by stating the relevant theme number indicated in Table 4-4, e.g., (3.1).

Table 4-5: Top-level themes from template analysis of interviews

Theme No.	Top-level theme
1	Categorization of interviewees
2	Definition of NFF
3	Fault understanding
4	Airworthiness and air safety
5	Training
6	PSED
7	Time available
8	Documentation
9	Continuity and management
10	Trust awareness
11	Communication of faults (NFF)
12	Impact on flight programme

4.2.1 Categorization of interviewees

The questions on experience and background were to establish the interviewees' authority to give opinions on airworthiness and NFF.

For the pilots, the average flying experience was 24 years, with experience covering helicopters, training, transport (both military and civilian), and fast jet aircraft. Their experience of flying their current or latest aircraft ranged between seven to 20 years, with an average of 10.5 years. Positions held were squadron pilot, flight commander, test pilot, duty executive, and duty authorizer. Two were current military pilots, one was a reserve RAF pilot, who also flew civilian aircraft, and the fourth had retired after serving in the RAF and flying with more than one civilian company. Knowledge of NFF and airworthiness was gained via ground school and flying and technical manuals. Additionally, an awareness of NFF became apparent from the experience of reporting a fault that the engineers could not replicate. (2).

For the AAI, the average years of involvement with and interest in aviation were 34, with one holding a Private Pilot's Licence. The average period as a formal AAI was 8.5 years but the DAIB investigators are posted every three years, so the average is not a true reflection. The range was 19 years, between two and 22 years. The DAIB interviewees classed themselves as AeroSystems engineers, whilst the AAIB interviewees were engineering inspectors. This partially highlights the difference between the two organizations. Between them, they investigate accidents across the military register, general and commercial transport, including; unmanned air systems, such as the Zephyr; microlights; helicopters; fighter aircraft, such as the Hawk; and large transporter aircraft, such as the Airbus 380 or Boeing 777.

From this, it was assessed that their combined experience demonstrated authority to talk on the subject of NFF and airworthiness.

4.2.2 Definition of NFF

The interviewees correctly described a NFF and intermittent fault, describing the former as an engineering decision output, based upon some diagnostics prescribed within the aircraft technical maintenance manual and the latter as a technical event that was substantial enough to be noticed but not constantly present during a single flight. It was further acknowledged that it could be recorded as a NFF and recur during subsequent flights. However, for aircrew, the awareness of NFF within and across a fleet of aircraft would diminish as the fleet size increased. This factor should be considered when analysing the answers from a larger sample of the population.

The effect of ambient conditions on the appearance and maintenance of an intermittent fault and a NFF were acknowledged and would contribute to the number of NFFs recorded. Bench testing of components did not reflect the environment in which the fault manifested.

An issue stressed was that a NFF often disguised latent issues. This could impact airworthiness and trust.

4.2.3 Fault understanding

All interviewees explained what is an intermittent fault, namely a fault that could not be replicated on the ground or where the reported fault was not considered to deem an aircraft unserviceable. The latter explanation is not strictly correct as this may only be established after an engineering investigation. Accurate explanations were provided for a NFF and the type of maintenance conducted to determine that the fault was a NFF. Understanding these terms was important as it created a link between an intermittent fault and a NFF as advocated in the literature (Steadman et al., 2005; Guanqian et al., 2014).

The pilots reviewed the aircraft logbook including the engineering documentation available but this was more difficult with an electronic system. As the previous engineering conducted was no longer available to them, they were unable to understand how a fault was resolved (8.2).

The AAI accepted they were not specialists in all areas and requested support from specialists if required. Whilst not actively looking for a NFF or intermittent fault, they would review the aircraft documentation (paper or electronic) for trends of abnormality as part of the investigation and advice if there was an urgent safety issue. This was evident in the G-SPAO investigation (AAIB, 2015) that had a long-standing NFF issue, with the operator's chief engineer advising the AAI to "be aware that we have now been wrestling with a really odd issue for years on this aircraft type". This NFF issue was sporadic and had been ongoing for 10 years.

4.2.4 Airworthiness and air safety

Except for the now-retired civilian pilot, it was asserted that an intermittent fault did impact airworthiness. Whilst no formal definition was provided during the interviews, the interviewees' descriptions of a fault, the severity of the fault, and the explanation of how it impacted airworthiness demonstrated alignment with the MAA airworthiness definition (MAA, 2015c). However, among the pilots, there were differing views as to whether it impacted air or flight safety and this was due to the understanding of those terms and the redundancy available within the system. An AAI stated, "It's more about the continuing airworthiness …, to the

people who are not understanding the failure modes effectively and how they may present" (9.6) but with the repeated view expressed ably by an interviewee:

> "… an intermittent fault … has the ability to severely divert the attention of the crew and actually takes them away from that general aviate, navigate, communicate, but saps their SA [situational awareness] and can lead to pretty poor occurrences." (Interview 7)

This needed to be balanced against the "fit-to-fight, fit-to-fly" dimension that was absent from civilian aviation.

Examples of prominent systems for intermittent faults or NFF that could severely impact the flight were provided, such as the captain's display disappearing during flight, which was assessed as "a serious erosion of safety" and upon investigation, all the components were returned as NFF. Any intermittent fault involving the autoflight system or the transponder would be categorized as important due to the increase in pilot workload (12.3); the aircraft could not be flown in reduced vertical separation minima (RVSM) areas and, consequently, the pilot would have to change the flight path down to a lower flight level. This increases the fuel consumption and again increases the workload. This was reinforced by another interviewee who also confirmed that with the advent of computerized systems these cause faults/problems, noticeably with avionics equipment and transponders. However, many were software dependent and once a system was shut down the software would reset. So it was asserted that electronic components have become more reliable but were also less so as there was an inability "to mechanically diagnose electronic components so much" (Interview 5).

Systems such as radios, gearboxes and engine bleed-off valves, in the main, would be classified as not important but much depended on the specific fault and flight. For example, radios were an issue in terms of clearances, phased response clearances, air situational awareness etc. However, this could be mission and location-dependent. For example, if operating over London it was an issue but if operating in Afghanistan a different radio could be used.

Although not obvious, hydraulics on helicopters was an issue because if they fail or there is a fault there is nothing the pilot can do. Engines are a problem but that again is dependent on the flight profile, attitude, and country.

On commercial aircraft, intermittent faults with radios and communication systems did not appear to be an issue. In fact, Interviewee 4, with commercial flying experience, had never had a radio, engine, or fuel system failure. These systems were all reliable. Thus, the categorization of systems prone to intermittent faults and NFF may differ between military and civilian aircraft operating profiles and locations.

For investigations, the frequency of a NFF would not be actively looked for unless some part of the investigation indicated it was a cause or contributory factor. Mainly the investigation would look at “what did happen, what normally happens and what should happen”. Like aircrew, the AAI conceived that a NFF could impact the airworthiness of the aircraft.

One important factor, that could impact the maintenance, investigation and airworthiness specified was the security of data, especially for joint project aircraft, for instance, F-35B, Lightning II. Whilst technology can aid the maintenance and investigations, the security shrouding access to the data can prevent exploitation of said data. The impact of this is unknown and is a cause of concern for the DAIB.

4.2.5 Training

This section considers the training available to aircrew and AAI, indicates any deficiencies and states if the interviewees felt that specific training would be beneficial.

Whilst pilots are trained how to fly an aircraft there appeared to be differing views on the training for completing a PSED, the fault record in the aircraft logbook or similar documentation. The question was specifically regarding the wording to describe the fault. Some stated no formal training was provided; on-the-job training appeared to be the norm. This entailed shadowing the instructor whilst undertaking basic flying training and when on a squadron consulting with the duty

authorizer. Interviewee 2 viewed knowing how to give this information and conduct the PSED were part of the “Responsibilities of an aircraft captain”, and he *thought* it was briefed in basic ground school. However, when pushed to state a document that detailed the training to be provided none was provided but the belief was it was the responsibility of the relevant training establishment.

A view opined by the aircrew and AAI was that the engineers’ training was insufficient in-depth, so confident discussion about aircraft wiring diagrams or system integration was minimal. Those engineers with this knowledge were trusted more (10)

While new AAIB investigators had a wealth of knowledge and experience for specific aircraft types they were inexperienced in the art of accident investigations and, therefore, all AAIB investigators were appointed an experienced mentor. Like the aircrew, knowledge and experience were gained initially through on-the-job training. Within accident investigation courses, there was no specific mention of how to investigate an intermittent fault, a NFF or how to spot trends within the documentation. There were no specific regulations or processes to follow but relied very much on the experience of the AAI. So while it was acknowledged that NFF was a minor part of an accident investigation, it was identified as an area where the AAI training could be improved, with the following expressed:

> “So there probably is a need for training for investigators for how to best approach no fault found investigations because it is probably is a little bit hit and miss… So I think, yeah, more training would be good and perhaps in that training, you could have people from military backgrounds, civil backgrounds and the design, production and maintenance organizations to actually have an input so you are not just getting one flavour of no fault found.” (Interview 6)

So, regulations or definitions for NFF or intermittent fault were non-existent and relied on on-the-job training or experience to identify an occurrence.

4.2.6 PSED

Whilst no specific training was provided for the format of a PSED it was agreed that the key points to provide had to be factual, in chronological order and included the following: observed symptoms, cockpit indications, flying control feel, within the bounds of the flight reference cards what diagnostics was taken to remedy the situation, the outcome, if the fault recurred did it manifest in the same way, the number of occurrences, other indications, and impact on the flight (12.3). If the fault occurred on a previous flight, an observation on whether the symptoms were the same. However, on modern aircraft, such as the Airbus 320 series, the flight data information is such that minimal information is required to describe the technical fault. Aspects such as banging noises and the smell of smoke would be reported. No regulation could be stated that detailed how to conduct the PSED or its format and content. This lack of formal guidance and direction contributes to poor PSEDs and increased tension between the aircrew and engineers (10.3).

When checking the engineers' understanding of the fault (5.2) this depended on the perceived experience of the engineers, the questions they posed, and their ability to fault diagnose lasting only a short while. For civilian operations, the need to check the engineers' experience was not required as it was evident. For modern commercial aircraft, the pilots did not try to provide solutions to the faults but for military aircraft, this was not the case, especially where the engineers' logic appeared flawed or perverse (10.3). In these cases, the debrief would be structured to guide the engineers to the relevant system. The engineers' personalities and experience levels were contributory factors (11). Whilst a pilot may view this guidance (solutioneering) as helpful for some engineers it was the opposite (10.3); it gave misdirection and impacted the diagnostics conducted and was observed that pilots provided "pre-conceived ideas and opinions of what the fault is rather than providing [an] accurate description of symptoms" (Hockley, Lacey and Pelham, 2016, p.47). This view was supported by the AAI, who viewed misinformed 'corporate' opinions as "muddying the waters".

No interviewee could state a regulation, procedure or process regarding the technical debrief (the PSED), or how it should be conducted. Some interviewees thought there was one, but were unable to state it. Nor could they confirm categorically whom to contact to obtain a copy of the regulation. This implies it may not exist and is, as per their descriptions, based upon on-the-job training from fellow aircrew, experienced or otherwise. The latter could lead to poor practices being accepted as the norm.

4.2.7 Time available

From research conducted by Hockley, Lacey and Pelham (2016), the time available to conduct the PSED or the aircrew availability for further discussions following the initial diagnosis was an area that contributed to a NFF being recorded.

The interviewees stated that the time available for the technical debrief depended upon several factors: the number of debriefs they provided within one day (if for example a test pilot), the time of day or night, the duration of the flight, the time zones, the closeness to an engineering shift handover (9.4), the preparation time required for another flight, the requirement to conduct a mission debrief with the duty authorizer and the cabin crew awaiting the pilot before they can finish for the day or depart for accommodation. Fatigue and mental effort were cited as a reason to conduct the technical debrief as quickly as possible. Crew duty was also a major consideration, with the military aircrew stating a requirement for eight hours of uninterrupted rest, which meant eight hours of sleep and the civilian stating 10 hours available for rest in accommodation. However, if the fault was complex and warranted a longer explanation, this was provided. These factors impact the quality of the PSED and the technical information imparted. Wider sample input was required to support these notions and to understand the impact on subsequent NFF and airworthiness.

However, the time available to conduct the maintenance was another concern raised. For electronic components, e.g. a LRU, re-racking the component could be the quickest way to clear a fault. As acknowledged though, the fault may still

be present just dormant (9.6). This was linked to the engineers' lack of in-depth knowledge of the aircraft systems.

While the pilots would review the available content of the aircraft logbook it was noted by all interviewees that the engineering terminology to describe the maintenance work carried out was coded (8.1), extremely short of detail and it was difficult to determine what had been done. It was viewed as good practice and good airmanship for aircrew instructors' to be responsible for instilling in students how to read and engage with the technical log properly, including with previous faults. Training to understand this coding would be beneficial. Unless flying a small pool of aircraft, it was difficult to follow faults by aircraft tail number but it was acknowledged that certain aircraft always had a specific fault or a long-running intermittent fault. With the rise in social media (e.g., WhatsApp™) pilot groups are better at communicating aircraft faults to a wider group across the globe.

4.2.8 Documentations

The completion of the PSED proforma and the understanding of the engineering documentation should be a straightforward process. However, no specific PSED proforma was used for the format and content of the PSED the outcome was dependent on the engineers and aircrew involved; their skill and experience levels. The engineering work conducted was frequently recorded in a code unfamiliar to the aircrew and with insufficient detail to enable the aircrew to understand what had been done to remedy the fault. This was at times frustrating, especially if the fault was recorded as a NFF. This contributed to some trust issues as there was a belief the aircrew were not believed (10.3). Additionally, the lack of a formal proforma inhibited the ability to spot trends.

An investigation identified that a "shadow tech log" was used by civilian aircrew to record the real faults as opposed to the limited faults recorded in the official documentation. This unscrupulous recording of faults not only masks the true state of the aircraft but hides any intermittent faults, which may impact airworthiness (4.1 and 4.4) and the flying programme (12.1). It should be stated that this was not a practice found in large commercial aviation organizations. For

military operations, there was the belief that unofficial records previously existed to record NFF but their use appears to have been eliminated. This problem with an unofficial engineer or aircrew recording of faults is that it masks the true extent of a fault, frequency and history and may have serious consequences on airworthiness.

4.2.9 Continuity and management

Whilst awareness of NFF became apparent from experience of reporting a fault that the engineers could not replicate, it was more evident when in key positions such as a Duty Executive or Duty Authorizer[2] as oversight of a week's flying with recurring aircraft faults and engineering diagnostics and maintenance enabled a pattern to be observed. These roles provided continuity that was not always evident from the engineers due to their shift patterns. Firstly, the aircrew and engineering shift patterns were not synchronized so no continuity between the shifts was established, as summed up by Interview 1 stating "14 handovers between four different teams." Secondly, the engineering shift patterns introduced limitations caused by, for example, the timings of the handover from one shift to another, the depth of maintenance conducted towards the end of a shift and the time available for the PSED and this consequently has an impact on the overall communication (10). A shared view was that the engineering work conducted was dependent on the amount of time remaining for a shift, i.e. close to handover a simpler maintenance process would be done even if that meant repeating an engineering process that had already been done by another shift in the off chance 'it just might work'. This was explained by Interviewee 1 (12.1) as "the risk versus reward balance as perceived by the engineering shift frequently worked against in-depth fault diagnosis or major component change." If the fault occurred during pre-flight checks the advice appeared to be to power down and

[2] The Duty Authorizer runs the flying programme, supervises the operations staff, and conducts in-briefs and out-briefs for all flights. The Duty Authorizer provides an independent overview of all flights undertaken by the squadron and may also sign to authorize some flights.

then power up the system. If this worked the flying programme could be maintained.

For an intermittent fault, the usual action taken was to follow the flight reference cards where appropriate, report the fault and discuss it with the Duty Authorizer. This was because those who held the Duty Executive/Authorizer positions adopted the approach of strategically managing the fault from the junior engineering level to senior engineering management; this prevented a situation where a captain could be deemed to be directly challenging the engineering judgement of the maintenance organization (10.3). A view expressed was that “culturally the profile of experience and authority of the RAF engineering organization is part of the problem” (Interview 1), with experienced senior non-commissioned officers “feeling duty bound to protect … the team and shift” (Interview 1) and this was at the cost of airworthiness (4.1).

4.2.10 Trust

The aircrew's frustration with recording the fault as a NFF lies with the inference that the pilot had incorrectly recorded or observed the fault or it was not important; it did not happen. Another specific example provided again highlights the issue of trust and how it is manifested. There was a hydraulic fault but the aircrew concerned believed that it was not an intermittent fault or a NFF but just bad engineering. This is a good example of why and when the Duty Executive can intervene and raise an engineering issue via the engineering chain (9.3). This erosion of trust between the parties leads the pilots to believe that there is no point in recording the fault as nothing happens with it especially if it has been recorded three or four times previously. However, it was noted that a culture existed to get the aircraft flying again as soon as possible and a NFF was a way to achieve this (12.1). Yet, with a small fleet of aircraft, the aircrew will get to know the aircraft’s foibles, and notice recurring faults; this is when the nuisance factor arises and impacts the trust.

Additionally, reading the engineering log and observing a remark, such as ‘tested satis’ did not engender good trust between the parties. This insufficient detail did not allow the pilots to understand how the fault had been resolved. They wanted

confidence that the fault would not reappear, so when it did this impacted negatively the trust. This should be countered by the engineers' frustration with the aircrew solutioneering (Hockley, Lacey and Pelham, 2016).

Trust is closely linked to faith and the aircrews wanted faith that the Defence Air Safety Occurrence Report (DASOR) for an ongoing NFF or intermittent faults was being investigated. This was endorsed by the military AAI.

4.2.11 Communication of faults (NFF)

There were numerous ways of communicating the faults between the aircrew and then the engineers. Verbally if meeting the aircrew. Via social media sites, such as WhatsApp™. This approach allows a concern regarding a fault to spread much quicker and further, with aircrew being much better informed in disparate locations. The communication of faults between aircrew would happen for curtailed flights as it would pique their interest.

Communication with experienced and skilled engineers was appreciated by the aircrew as it instilled confidence that the engineers understood the fault and an approach to rectify it. However, a military problem was the continued adoption of a forced rank structure rather than utilizing the appropriate skill level. This was observed between commissioned and non-commissioned levels and between the non-commissioned levels. The skill and experience levels were not always used effectively if a higher-ranked person felt the need to be involved. This resulted in secondhand information being passed on. Equally, the overconfidence of junior aircrew had to be managed by senior aircrew to prevent "trivia" being reported due to the junior aircrew not "knowing what … [he] was talking about. You've only been flying for 10 minutes." (Interview 5)

Aircraft technology has improved so 'indirect' communication can be via HUMS and a pilot-initiated-event marker. This provides the engineers with a wider data set to review but with the advantage that it lets the engineers link the reported time of the occurrence with the time on the event marker or HUMS and facilitates the aircraft parameter at the time to be analyzed. Additionally, the aircrew can report the fault before landing, e.g. via the Duty Pilot or the Contact Maintenance

Centre, and this enables engineers to be positioned to liaise with the aircrew on landing if required. For military operations, this may entail the engineers meeting the aircraft and observing the fault firsthand before the system is shut down. This technology can aid the fault diagnostic process. Furthermore, this technology assists the AAI with accident investigations as they can analyse the data from the cockpit voice recorder and the flight data recorders etc. but there are gigabytes of data to be analysed and the OEM or a specialist third party may have to interrogate the data. This can also be an issue for the engineers when they are unable to fully analyze the aircraft data, due to skill, experience or time.

For recurring intermittent faults and NFF, pilots would raise them with the Duty Executive. As an example, a repeated reason for going to the Duty Executive was because “it could frequently become difficult if a captain was seen to be directly challenging the engineering judgement of the maintenance organization” (9.2 and 10.2). There was an unwillingness to upset the engineers. There was a cultural aspect to consider and maintain.

For the AAI, communication was with a much wider group of stakeholders as evidenced by the G-SPAO accident (AAIB, 2015). The NFF was not the cause of the accident but had to be investigated fully to be excluded as the cause. So the AAI will communicate with the aircrew, engineers, contractors, sub-contractors, designers, OEM and specialist third parties. They believe that access to information is greater for them than for engineers, especially for the AAIB which has legal powers and obligations to investigate the accident. The difference between the AAIB and the DAIB authority impacts the ability to enforce a change. The AAIB have this authority; the DAIB contribute to the report but the decision is with the Director General Defence Safety Authority. As such the AAIB can instigate aircraft modifications, as proven in the G-SPAO accident investigation (AAIB, 2015).

4.2.12 Impact on flight programme

For commercial flights, an intermittent fault or NFF is felt in terms of additional maintenance times and the impact on financial revenue. This could lead to delayed flights, frustrated passengers and recompense. For the military, the

impact is not financial but in terms of cancelled or curtailed flights/missions or a revised flight profile. At the extreme, the aircrew could refuse to take the aircraft.

> "It's the only time I have refused to take an aircraft, because I'd put it the time before and I'd put it back in because it was the hydraulics level low, and the engineers assured me that they had checked it … they then told me there were no faults. So, I said you're wrong so either they were lying about a) stage 1 or there is a fault and then I got very strange series of odd descriptions of where this oil could have gone which were fundamentally untrue." (Interview 3)

Due to the oversight by the aircrew executive, repeated faults were readily apparent as was the impact on the flight programme. Intermittent faults and NFF could impact training programmes or military operations to a deadly effect. The maintenance time would increase and this could lead to the 'risk versus reward' balance being adopted by the engineering shift. In essence, this was a decision not to commence in-depth fault diagnostics, major component change or maintenance that would impact the engineers' time on duty. Alternatively, the opposite could occur, with aircrew disinclined to report faults as they thought nothing would change.

4.3 Overall analysis of the interviews

The following brings together the main findings from the Template Analysis of the interviews in terms of the research questions (Section 2.17.1) and considers the impact on the link between NFF and airworthiness, and the perceived link between NFF and airworthiness.

4.3.1 Training

There is no discernible training in many areas, including the PSED, the terms NFF and intermittent faults. Looking for trends within maintenance documentation is missing from current training programmes and their inclusion would be beneficial. Therefore, it is asserted that if it was in place, it could reduce the number of NFFs recorded. NFF and intermittent faults were not defined but

effectively learnt via osmosis. No formal training was provided, although it may have been covered in an engineering degree course. There was the assumption that engineers would always find the fault so there was no requirement to train for what to do if a fault could not be found. This is a naive approach, especially with the number of electronics and software within modern aircraft. This aligns with the findings from Hockley, Lacey and Pelham (2016) but is a cause for concern and impacts operational achievement and flight safety (Pickthall, 2014).

Understanding the definitions of intermittent faults and NFF and then their causes for them will aid the diagnostic process. There was no formal training on how to conduct the PSED or the format to be adopted. Associated with this, there was no proforma to use to provide some consistency from one engineering shift to the next and to consider other factors that may have caused the fault, such as air pressure, flight orientation etc. A dedicated PSED proforma could act as an aide memoir for the less experienced aircrew and engineers. The fact that there was no PSED proforma was raised as an area for review by the engineers (Hockley, Lacey and Pelham, 2016) as this could improve the quality of the engineering diagnostics and possibly reduce the number of NFF recorded.

4.3.2 Documentation

With the introduction of electronic aircraft logbooks (such as the MOD Form 700) the ability of aircrew to review the aircraft fault history diminished, especially if wanting to know how a fault was rectified or cleared. This is a current problem in that the pilots do not always understand the engineers' terminology. So, if ignorant or partially ignorant then according to Kritzinger (2006, pp.17-18) the pilots' perception of being safe is affected negatively. However, electronic records may aid the search and analysis of how NFF are recorded under different terminology (Thomas, Ayers and Pecht, 2002), so can prove beneficial if adequate training is provided on how to fully use this resource.

The regulations should be reviewed to ensure they provide guidance on how to manage a NFF or recurring NFF. Continually following the same maintenance process jeopardizes the trust between the two parties and causes frustration for both parties.

4.3.3 Time factor

Time impacts the aviation system in many ways but some are outside the control of the aircrew, for instance, crew duty time or time of flight. The engineers' shift pattern affects the PSED time and the apparent willingness to start in-depth maintenance. However, good time management will improve productivity and efficiency (Pettit, 2010) and, consequently, will prevent delays in engineering availability occurring and ensure the correct engineers were available for the crew-in and the PSED. So, whilst the aircrew may be frustrated by a fault recurring, this could be ameliorated by better time management so ensuring the best crew was available for the PSED by informing the engineers of the fault before the aircraft lands.

4.3.4 Impact on the flight programme

There is evidence that flights/missions are curtailed, cancelled or have the flight profile changed during the flight due to recurring faults. In the extreme, aircrew are refusing to fly the aircraft. This appeared as a rarity for commercial aviation but a more common occurrence for military flights. It should be noted that the relationship between the aircrew and engineers is different between commercial and military operations. The closer relationship within the military is not something that can be ignored when considering airworthiness and the risk to life. Intermittent faults and NFF were more prone to occur on electrical and modern electronic equipment, especially where software was involved and this impacted the flight programme. This aligns with Pickthall's (2014) and Jones and Hayes' (2001) views.

4.3.5 Trust between aircrew and engineers

Trust was found to be an *integrative* theme that permeated the interviews and impacted for instance the PSED, maintenance, management and continuity of the flying programme. This aspect is addressed to consider the relationship between the aircrew and the engineers but it is acknowledged that it is an area for focused research by psychologists.

Trust is defined as follows:

> Trust – “Confidence in or reliance on some quality or attribute of a person or thing, or the truth of a statement” (OED, 1989, Vol XVIII, p 638).

Similarly, trust is defined as “The sense that one can depend on another person [and it] lays the groundwork for social exchanges yielding benefits like … a sense of security” (Psychology Today, 2023).

So, for this analysis, the aircrew need to trust (depend on, rely on, have confidence in) the engineers to undertake the maintenance as per the AMM but also diligently and with integrity. Likewise, the engineers need to trust that the aircrew will give as full and accurate a post-sortie debrief as possible. Since “when trust is absent—or someone betrays the trust that has been invested in them—the possibility of a successful future relationship diminishes” (Psychology Today, 2023). In simple terms, “People who trust each other can work together more effectively at home, at work” (Psychology Today, 2023). So, for this research, the impact on the PSED, maintenance, communication and continuity are all affected by the trust between the aircrew and engineers. When this trust is eroded the impact will be negative. What this research can do is confirm whether trust exists or not within a wider sample of the aircrew population and provide an approach to improve the trust so that the impact on NFF and airworthiness is minimized. It requires a way to improve the PSED, crew-in process and communication between the parties and includes a better understanding of the engineering terminology used to record how a fault has been investigated.

It was acknowledged in the literature review that trust between the aircrew and engineers was a concern (Hockley, Lacey and Pelham, 2016; Khan et al, 2015). This was reaffirmed by the interviews. For NFF and airworthiness, this can be actioned in different ways. Firstly, the aircrew tries to solutionize or steer the engineers to what they think is the cause of the problem. The issue with this approach is that the engineers can be 'sent down timewasting-rabbit holes' and this is compounded when the aircrew is inexperienced. Aircrew is not immune to incorrectly believing how a system works. The second approach is to elevate the problem to higher management via the engineering or aircrew route. This has the

advantage of reducing any possible tension. The third approach is for aircrew to choose to not report ongoing faults as the belief is that either they will not be believed or nothing will be done to rectify the problem.

Also, current communication methods help and hinder the PSED, the maintenance and trust. These need to be levered to aid trust and improve the PSED process.

4.3.6 Airworthiness

Without being critical about anyone interviewed or aircrew, engineers etc, if applying the airworthiness definition proposed (Section 2.4, repeated below) there seems to be a breakdown in airworthiness being assured. If the requirements for how to record NFF and conduct the PSED are not detailed in approved procedures, then people may not be suitably qualified, experienced and competent. If they are not trained, they will rely on experience for what is NFF or how to complete a PSED or trending analysis. Furthermore, electronic faults cannot be fully investigated if manuals are incomplete. The examples provided show that there was a hazard to aircrew and third parties. These support the aircrew perception of a link existing between NFF and airworthiness. These *are* issues with the technical attribute of the aircraft, where the definition of an attribute was “A quality or feature regarded as a characteristic or inherent part of someone or something” (Oxford Dictionary, 2017). A NFF or an intermittent fault is an inherent part of the design. Thus, this should imply that the design has been tested for and assessed as safe, as airworthiness:

> “Is the ability of an aircraft or other airborne equipment or system to be operated *in flight and on the ground* without significant hazard to aircrew, ground crew, passengers or to third parties*; it is a technical attribute of materiel throughout its lifecycle;” it is to be undertaken* by competent and authorized individuals, according to approved procedures and instructions. Adapted from: MAA (2015c; 2022)

4.4 Summary

This chapter has sought the views of pilots and AAI to ascertain their view of NFF and if there is an *impact* on airworthiness and air safety. The interviews provided a source of primary data that aligned with the literature review and supported the notion that there is a link between NFF and airworthiness or *un-airworthiness,* not worthy, according to the definition, of being in the air. The key findings are presented in Table 4-6.

Table 4-6: Key findings from the Interviews

Theme	Key findings
NFF definition	• NFF correctly described. • Awareness of NFF within and across an aircraft fleet diminished as the fleet size increased. • The effect of ambient conditions on the appearance and maintenance of an intermittent fault and a NFF were recognized.
Fault understanding	• Intermittent fault correctly explained. • The aircraft logbook was reviewed. This was more difficult with an electronic system. • Pilots could not understand how a fault was resolved.
Airworthiness and air safety	• An intermittent fault did impact airworthiness. • Inconclusive whether an intermittent fault and NFF impacted air or flight safety. • Prominent systems for intermittent faults or NFF that could severely impact the flight were stated. • Computerized systems resulted in more faults/problems.
Training	• Inconclusive view of the training provided for completing a PSED or the fault record in the aircraft logbook. • Engineers' training was insufficient in-depth to fault diagnose. • Confident discussion by engineers about aircraft wiring diagrams or system integration was minimal.
PSED	• No specific training was provided for the format of a PSED. • No regulation could be stated that detailed how to conduct the PSED or its format and content. • The engineers' personalities and experience levels were contributory factors to the structure of the PSED.

Time available	• The time available for the technical debrief depended upon numerous factors, such as the time of day or night, the duration of the flight, time zones. • Fatigue and mental effort were cited as a reason to conduct a quick technical debrief. • The time available to conduct the maintenance was a concern.
Documentation	• The understanding of the engineering documentation should be a straightforward process but was not. • The quality of the PSED documentation was dependent on the engineers and aircrew involved. • Faults were recorded in a code unfamiliar to the aircrew and with insufficient detail to enable them to understand the work conducted.
Continuity and management	• Management roles provided continuity that was not evident from the engineers due to their shift patterns. • Aircrew and engineering shift patterns were not synchronized. • The engineering work conducted was dependent on the amount of time remaining for a shift.
Trust	• There was an erosion of trust between the parties. • An engineering culture existed to get the aircraft flying again as soon as possible and a NFF was a way to achieve this.
Communication of faults (NFF)	• Communication with experienced and skilled engineers was appreciated by the aircrew as it instilled confidence that the engineers understood the fault and an approach to rectify it. • A forced rank structure was in place rather than utilizing the appropriate skill level. • Aircraft technology can aid the fault diagnostic process.
Impact on the flight programme	• For the military, the impact is not financial but in terms of cancelled or curtailed flights/missions or a revised flight profile.

Overall, the interviews are weighted towards NFF and intermittent faults impacting the airworthiness or air safety of the aircraft. The system at fault and the location of the fault's appearance, contribute to the link. Training for the PSED, the terms NFF and intermittent faults and looking for trends within maintenance documentation are missing from current training programmes and

their inclusion would be beneficial. Current communication methods help and hinder the PSED, maintenance and trust. In establishing a link between NFF and Airworthiness, these points should be categorized as *important*, with *impact* and *criticality* (Section 1.3) and are important to acknowledge. These aircrew perceived a link between NFF that *impacted* the airworthiness. Evidence from the interviews stressed the *criticality* of the NFF on airworthiness and them being perceived as significant hazards. The safety of the aircrew could have been at risk. The *importance* of these findings supports the link between NFF and airworthiness. Moreover, they contribute to answering Research Question 2 (Section 2.17.1).

From eight interviews a generalized view cannot be made. Areas to focus on are the training provided, documents and regulations provided to both parties, whether the trust is fragile at times or how this trust is being maintained even by the inclusion of higher management, the effect of time and the perceived breadth of knowledge of aircrew and engineers.

Therefore, the next stage of the methodology is to gather additional primary data via the survey questionnaire to garner views on NFF, intermittent faults, and any impact on airworthiness from a wider sample of aircrew, as proposed in Chapter 3. The questionnaire aims to establish if the interviews represent a valid worldview of the aircrew population. From this, an approach can be proposed for how to alleviate some of the causes of NFF impacting airworthiness. The findings from the interviews will contribute to the creation of the questionnaire. Additionally, the views will be used to develop the rich picture, influence diagram and the FRAM approach (See Chapter 6).

As propounded by Masefield (Tye, 1952) no one wanted the aircraft to be “worthy of a crash”, similarly no one wants to operate, or be a passenger on, an unairworthy aircraft.

5 QUESTIONNAIRE ANALYSIS

5.1 Introduction

This research aims to *establish if there is a link between NFF and airworthiness* and Objective 1 was established to support the aim. Objective 1 is:

> To determine the views of aircrew and accident investigators on the impact of NFF and any links to airworthiness and to assess any differences from the literature view.

The main aim of the questionnaire was to obtain a wider range of primary data, both quantitative and qualitative from aircrew. The interviews (Chapter 4) went part way to achieving this activity and Objective 3. Chapter 3 addresses the reliability and validity of the questionnaire (Section 3.8.2) and details the process for the creation and distribution of the questionnaire(Section 3.9.3).

The results obtained from the questionnaire are shown and discussed in this Chapter. The key results will be presented first and then analysed in context with the research aim, objectives and literature (Section 5.5). The key results are presented in the Results section of this chapter; the full results including pivot-table cross-section results are in Appendix B (B.4). Quotes from the questionnaire responses are used to support any analysis.

The results and analysis for quantitative questions relating to responses to aircraft systems or faults were reviewed by a military aircraft SME with over 30 years' experience across aircraft types (Q18 and 19). This is a form of inter-judgemental reliability that is used "to determine the extent to which individuals with the required skills and/or authority agree in their assessment decisions" (Wilson, 2014, p.130) and thereby assure the reliability of the assessment made. Similarly, the results and analysis for quantitative questions relating to meanings (Q15), thoughts (Q21) and reasons (Q47 and Q50) were reviewed for a second opinion, by an ex-RAF engineering officer with 37 years' experience and 20 years specialising in Reliability and Maintainability, and then 6 years with Cranfield University focused particularly on NFF. Using this form of reflection with another

person to test and discuss ideas and finding is a means to aid the credibility of the research (Saunders, Lewis and Thornhill, 2016, p.206) and contributes to the reliability of the assessment by using inter-judgemental reliability.

The main findings are as follows:

- There is no training for NFF, airworthiness and for how to conduct the PSED.
- Aircrew has a poor understanding of engineers' terminology.
- The aircrew experience and qualifications impact the quality of the PSED.
- A hierarchical management structure exists to enable the escalation of ongoing NFF occurrences.

An explanation for how these findings link to the techniques applied in Chapter 6 will be indicated.

5.2 Questionnaire creation and distribution

Chapter 3 (Section 3.9.3) detailed the process for the creation and distribution of the questionnaire. To recap, the questionnaire comprised 10 sections and 52 questions (0 and Appendix B, B.2), which were in the form of multiple-choice, matrix and free-text questions. In total, there were five interval, 11 ordinal, 19 nominal, and 15 qualitative questions (Appendix B, B.4). The questionnaire (0) was split into 10 sections with 52 questions, the instructions (Q1 – Q2), the informed consent (Q3), the respondents' background information (Q4 - Q12), airworthiness (Q13), NFF (Q14 – Q30), post-flight and maintenance (Q31 – Q35), training (Q36 - Q41), aircraft logbooks (Q42 – Q50), trust (Q51) and then final thoughts (Q52). Although there appeared to be only one airworthiness question this topic was also included in Q26.

A 'pilot' study of the questionnaire was conducted before full distribution and it was established the questionnaire should take about 12 minutes to complete. Once distributed via email to anonymous participants, the questionnaire was open for six weeks, from 1st October to 15th November 2019.

5.3 Data sanitizing

An explanation of how the raw questionnaire data was sanitized was given in Section 3.9.3. There were 50 responses. These were downloaded from Qualtrics ® to Microsoft Excel to remove incomplete responses and technical data. The following criteria were applied to remove data from the questionnaire before analysis:

Setting information — Q1 (survey introduction), Q2 (on-aircrew responses) and Q3 (consent).

- Technical data entries — start and end times, status, progress, duration, finished state, recorded date, response ID, distribution channel, and user language.
- Questionnaire not completed 10% (number (n) = 5),
    - Three did not progress beyond Q8,
    - One did not proceed beyond Q11 and
    - One did not proceed beyond Q14.

After sanitizing the questionnaire data, there were 45 usable responses. The full results can be seen in B.4, by question order.

5.4 Questionnaire results

5.4.1 Categorization

The majority of the respondents were serving military (93%) male (96%) RAF (88%) officers (Figure 5-1). The majority of the military officers were at the OF 2 (31%), 3 (28%) and 4 (25%) levels (Figure 5-2), where OF 2 equates to a RAF flight lieutenant, OF 3 a squadron leader and OF 4 a wing commander (Gov.UK, 2020). The civilians were mainly captains (38%) (

Figure 5-3). For Q9, when establishing the current or previous military rank, there were 32 useful responses. If respondents had made double or triple entries (which was a fault in the design of the questionnaire), these responses were deleted as the specific service could not be established (n=7). If a respondent

had stated ‘Prefer not to say' and also provided a rank, the rank was saved (n=3). The remaining 1 of 45 was left blank (n=1)

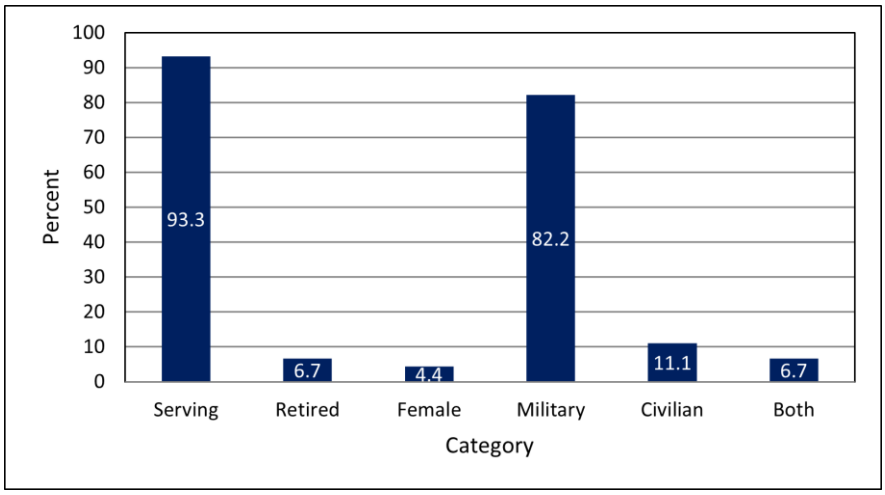


Figure 5-1: Categorization of questionnaire respondents

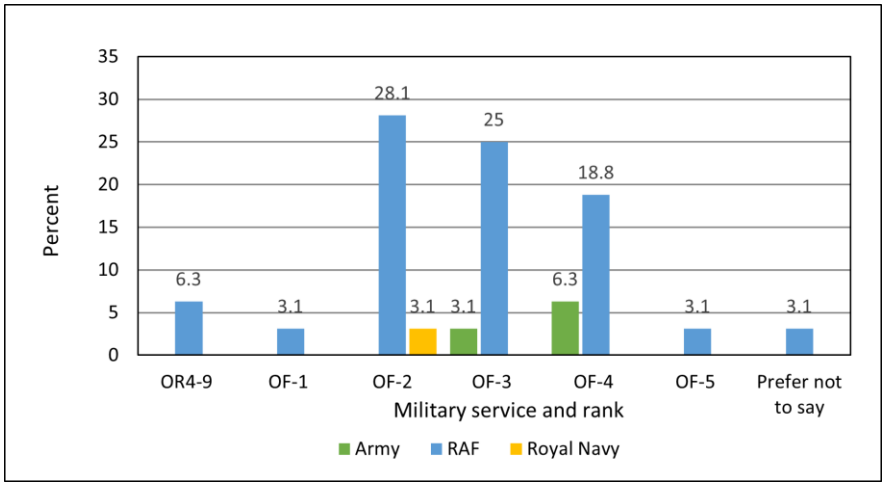


Figure 5-2: Military respondents’ service and rank

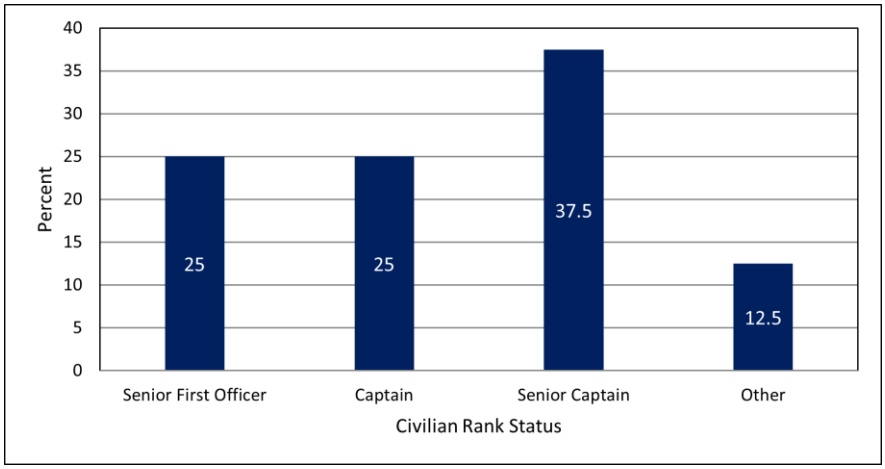


Figure 5-3: Civilian respondents’ rank or status

Figure 5-4 and Figure 5-5 show the histogram of the respondents' ages and the associated boxplot. The age was calculated by combining Q6 and Q7. The range was 565 months (47 years and 1 month), the interquartile range was at 161 months (13 years 5 months), with the minimum at 248 months (20 years) and the maximum at 813 months (67 years 11 months). The mean was 505.8 months (42 years and 2 months). The standard deviation was 118.5. So, there was widespread experience completing the questionnaire, which meant that it was not skewed to a particular age range, such as less than 30 years.

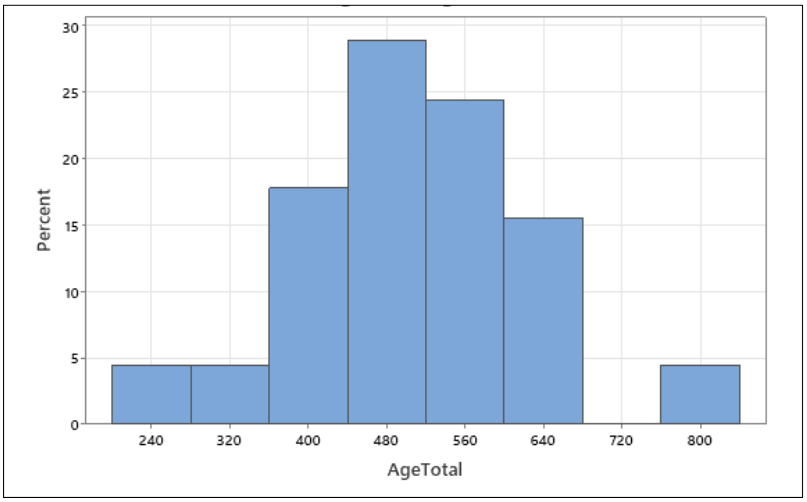


Figure 5-4: Histogram of respondents' age

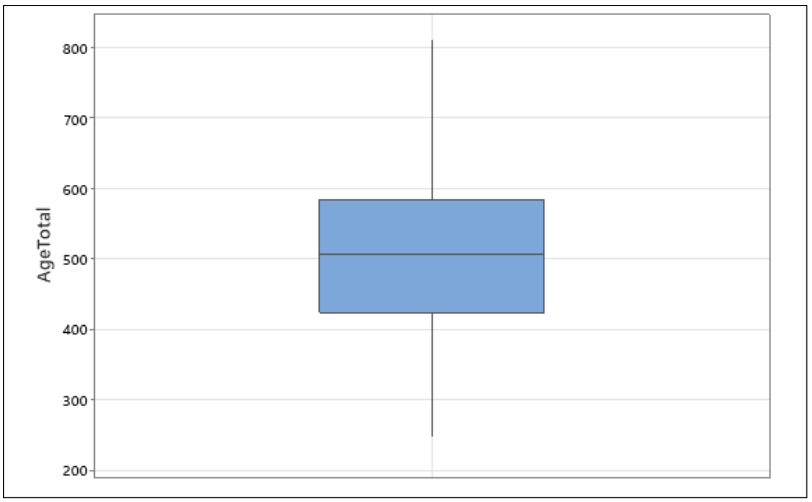


Figure 5-5: Box plot of respondents' age

The time as a member of aircrew was calculated by combining Q11 (years) and Q12 (months) as months (Table 5-1). The mode and mean indicate that the

aircrew who completed the survey had extensive experience and this should prevent the skewing of data to a group with more or less experience.

Table 5-1: Time as a member of aircrew

	Months	Years	Years and months
Minimum	11	0.9	11 months
Maximum	493	41.1	41 years 1 month
Range	482	40.2	40 years 2 months
1st Interquartile range	228.3	19	10 years
3rd Interquartile range	357	29	9
Mode	216	18	18
Median	252.5	21.0	21 years 1/2 month
Mean	286.2	23.8	23 years 10.15 months
Standard deviation	88.6		

To summarize, analysis of the respondents has confirmed a balanced spread of age and aircrew experience. The spread of military to civilian is almost non-existent and the majority are military with the RAF. This is not as balanced a spread but it reflects the allocation of aircrew within the three services. This may skew the analysis towards the RAF viewpoint (Section 3.9.3). Ranks were used for cross-tabulation analysis to ascertain if rank influenced the answer provided.

5.4.2 Airworthiness and NFF questions

Q13, 14 and 16 results are shown in Figure 5-6 and it is evident that whilst the aircrew understood the term NFF they had received no training on the phenomenon. Most (46%) thought their training included a definition of airworthiness but almost as many (39%) had a doubt. So, the result is inconclusive. The top explanation for NFF was ‘unable to replicate the fault’ (Figure 5-7) but all explanations provided demonstrated the aircrew who stated yes to Q 14 understood the term NFF.

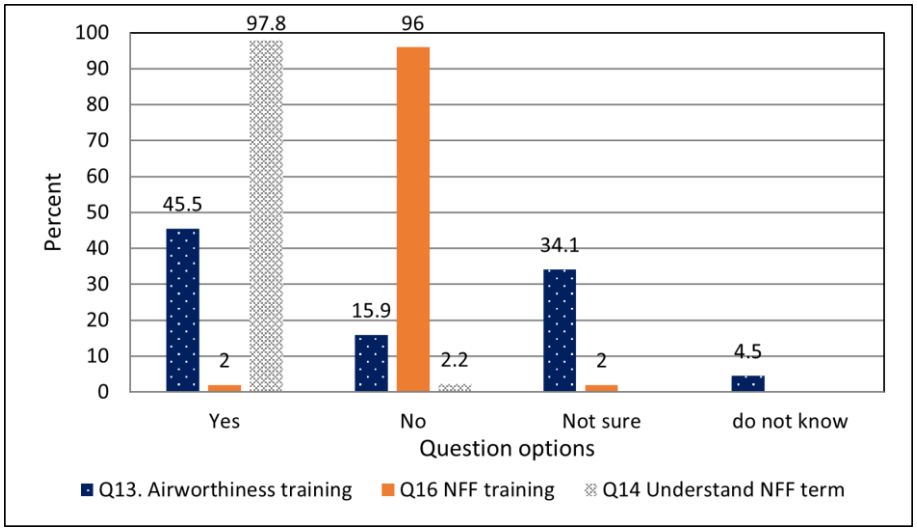


Figure 5-6: Q13, 14 and 16 results

Most aircrew (96%) had experienced a fault the engineers had fixed but which had reappeared (Q17). To provide some reliability for the answer, a definition of NFF was provided. Associated with this, the top system for a fault reappearing after being fixed (Q18) was avionics (Figure 5-8). The aircrew could select more

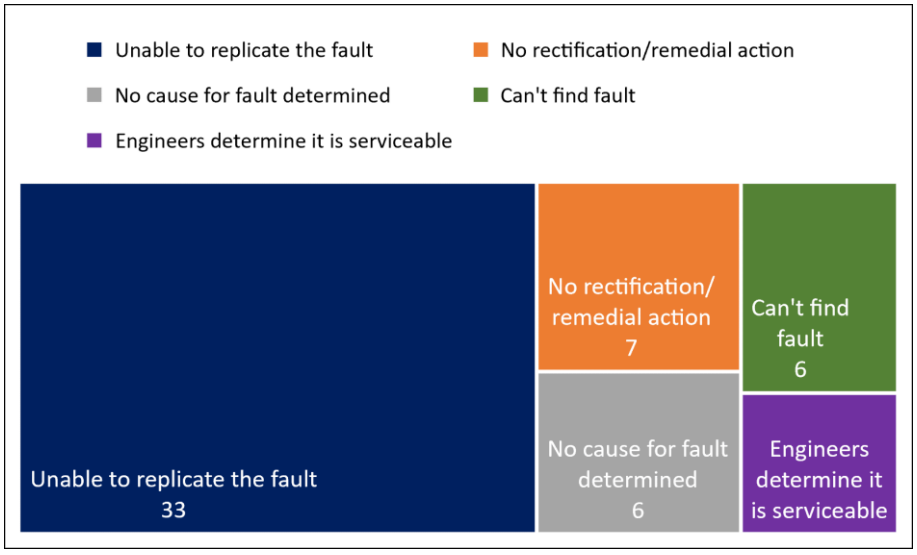


Figure 5-7: What the term NFF means to aircrew

than one system; avionics was selected 33/138. For the description of the fault that reappeared, the top response was avionics followed by communication (Figure 5-9). The most likely fault described by the aircrew as reappearing was also an avionics fault, followed by communication (Figure 5-9). The descriptions now included instruments (n=10), which may have been categorized as avionics

when referring to the system. To ensure an accurate assessment was made of the fault description the analysis was reviewed by a qualified aircraft engineer. Amendments to the fault type were made following this review.

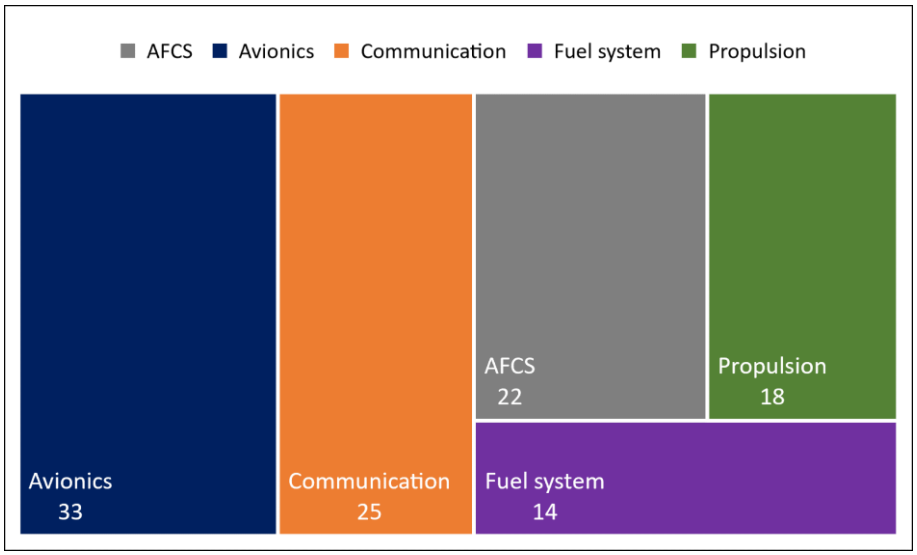


Figure 5-8: Top six systems experience a fault recurring after being fixed by the engineers

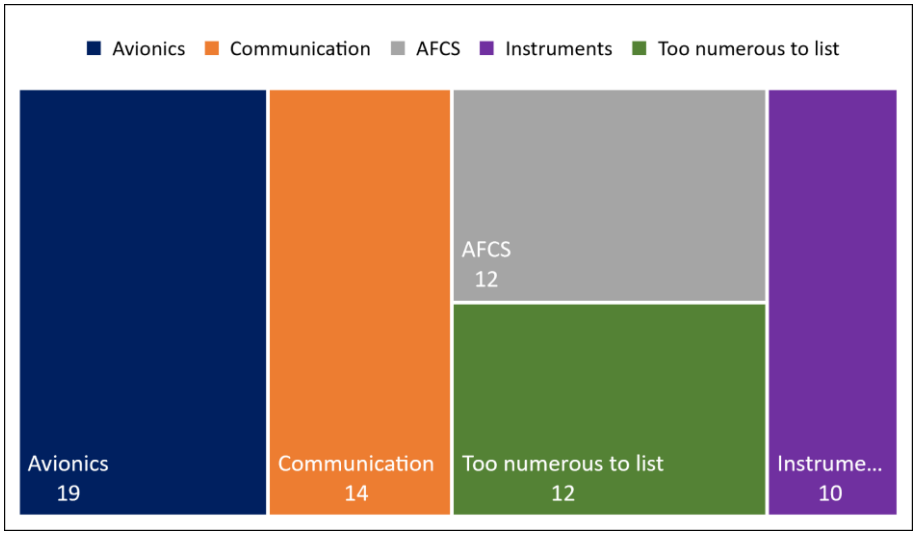


Figure 5-9: Q19 - Aircrew description of the fault that reappeared

The majority (72%) of aircrew believed the original fault was recorded as NFF but the result for the subsequent fault was inconclusive as almost as many opted for Yes (45%) and Not Sure (43%) (Figure 5-10). However, the majority (69%) of the aircrew were concerned about the fault recurring after it had been fixed. The top three words to describe the fault being recorded as a NFF were all negative, with

it being an expected outcome (n=15) as the top word/phrase. Trust was described in two ways, not trusting the engineers (n=14) and aircrew not being trusted by the engineers (n=5) (Figure 5-11).

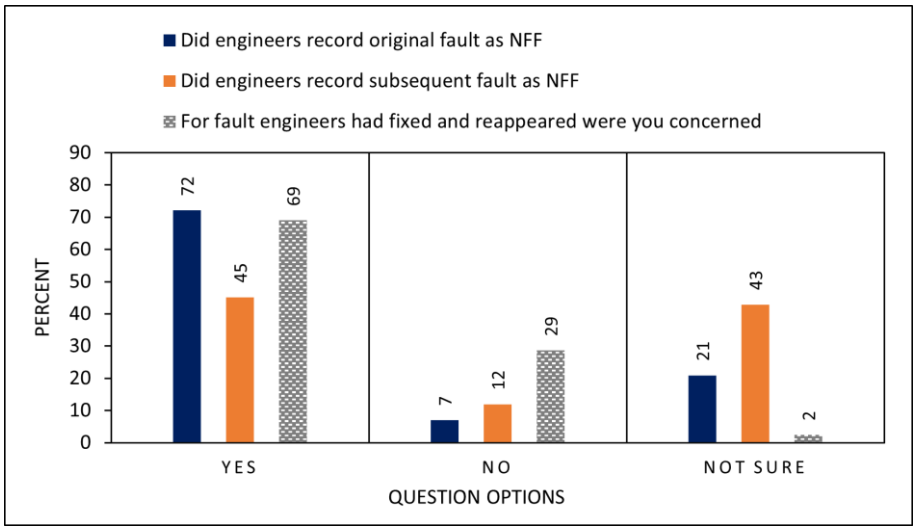


Figure 5-10: Q20 and Q22 results

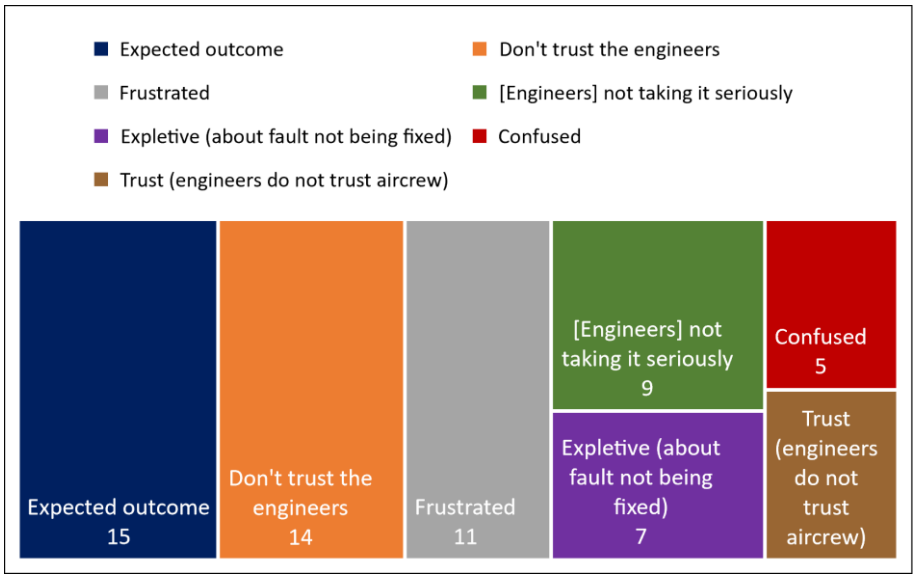


Figure 5-11: Q21 - Top three words expressing aircrew's thoughts for fault recorded as NFF

Of the aircrew who were concerned about the recurrence of the fault, the top reason was insufficient engineering diagnostics. In contrast, the top reason for *not* being concerned was because of 'an engineering decision' (Q23) (Figure 5-12).

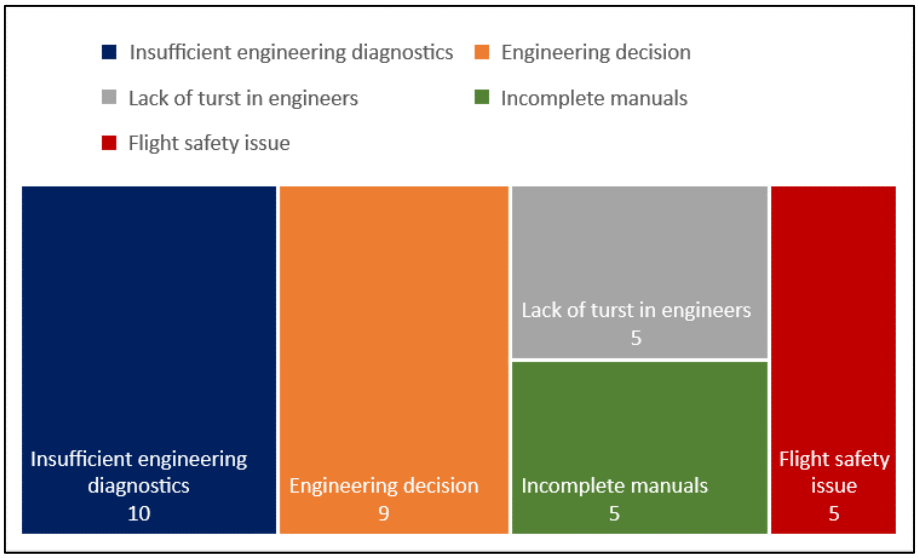


Figure 5-12: Q23 - The reason why aircrew was or was not concerned by the reappearance of the fault

The majority (68%) of aircrew believed the reappearance and subsequent reappearance of the fault (intermittent or otherwise) on the same aircraft did curtail the flight (Q24) (Figure 5-13).

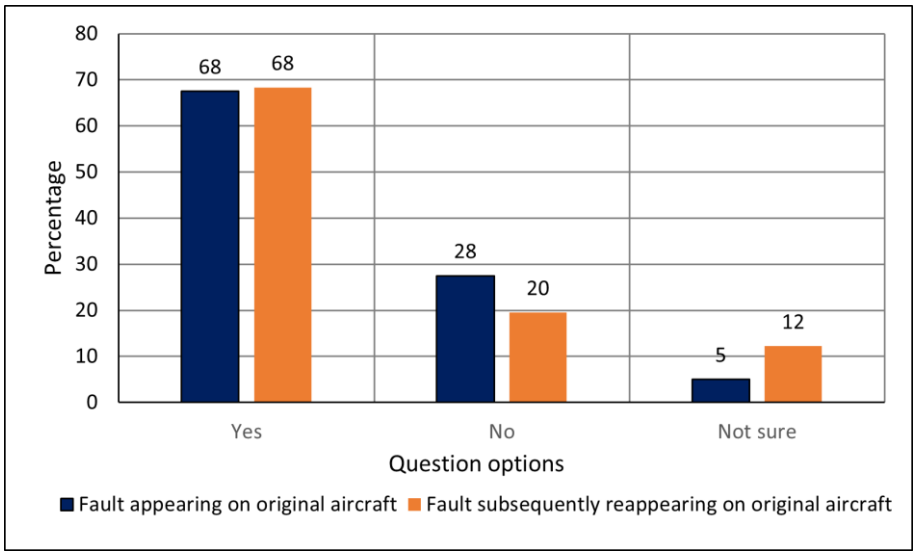


Figure 5-13: Q24 - Did fault reappearance on the same aircraft curtail the flight?

Almost a third opined that the reappearance of the fault affected aircraft handling, airworthiness and air safety (Q25-Q27) (Figure 5-14). Combining the Definitely yes and Probably yes options positively indicated that the three outcomes had been affected (44%, 56% and 54% respectively). For a 95% confidence interval the proportion answering 'probably or definitely not' was 0.17 ±0.12, so a fairly

small proportion of respondents thought that airworthiness was not affected by the reappearance of the fault. This support the perception that aircrew believe there is a link between NFF and airworthiness. Similarly, for Q27, for a 95% confidence interval the proportion answering 'probably or definitely not' was 0.24 ±0.13, so a fairly small proportion of respondents thought that air safety was not affected by the reappearance of the fault.

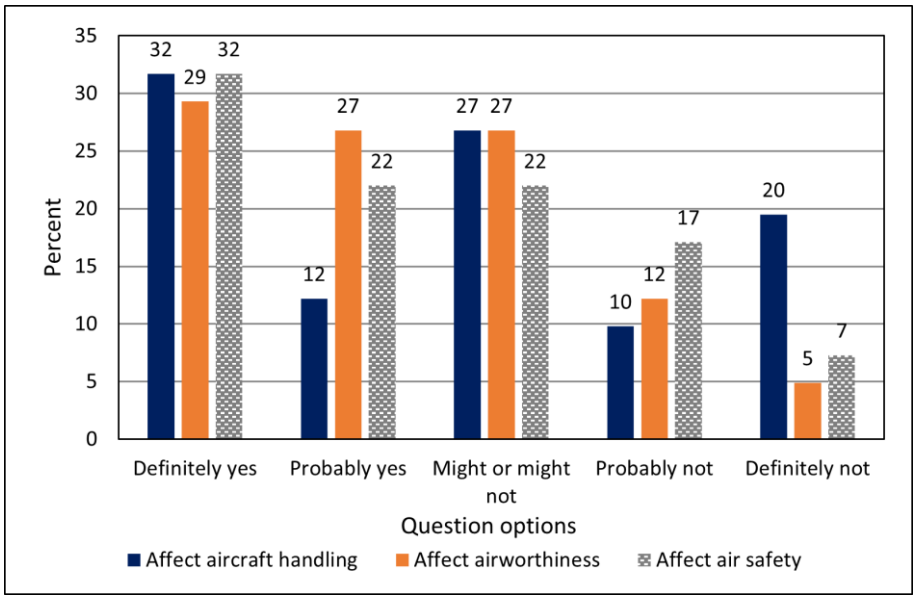


Figure 5-14: Q 25 to Q27 - Impact of the reappearance of the fault

The role most likely to have an ongoing recurring fault reported was split between Engineering Management (25%) and the Duty Executive (23%); of note, 17% chose not to report the recurrence (Q28) (Figure 5-15). The main reason for reporting the ongoing recurring fault was to raise awareness (escalation) (n=18) and for flight safety (n=9) (Q29) with the main outcome being further engineering investigation (n=11) or with no outcome (n=7) (Q30).

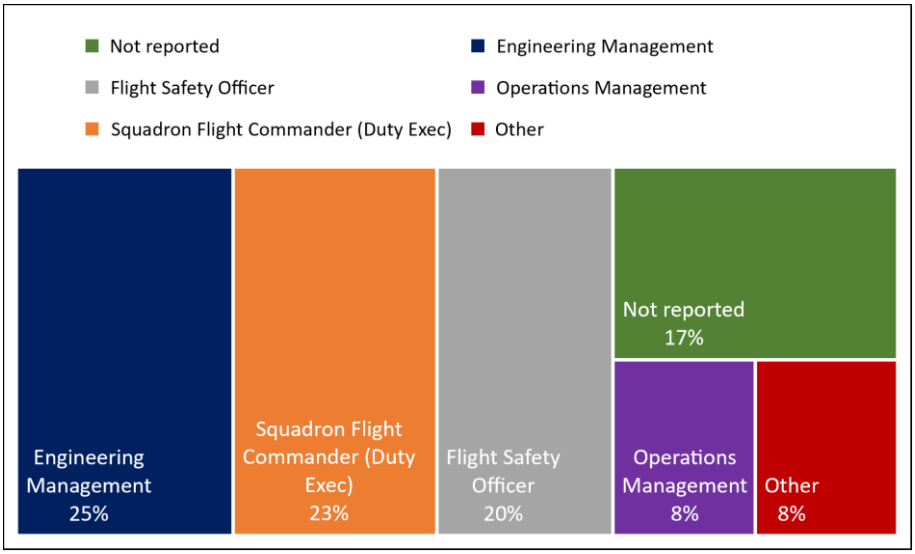


Figure 5-15: Q28 - Person to whom ongoing recurring fault was reported

5.4.3 Afterflight and maintenance

The majority (40%) of aircrew do not believe they pressurize the engineers to complete the maintenance to enable them to fly (Figure 5-16). The majority (86%) of aircrew believe they allocate sufficient time to conduct the PSED (Figure 5-17).

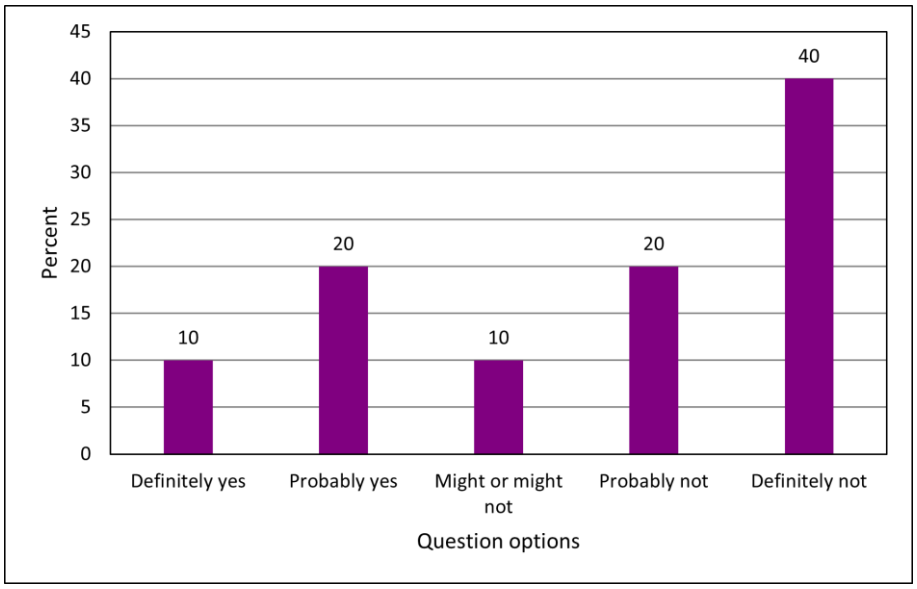


Figure 5-16: Q31 - Do aircrew pressurize engineers to complete the maintenance?

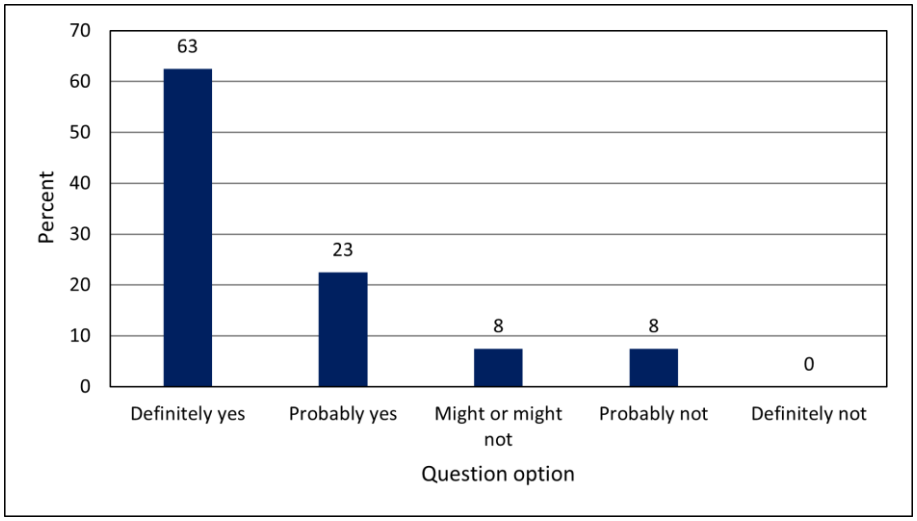


Figure 5-17: Q32 - Do aircrew allocate sufficient time for the PSED?

However, when ask to state the time allocated for the PSED (Q34), the mode was 5 minutes (300 seconds) (n=14), the median was 5.75 minutes (375 seconds) and the mean was 10.9 minutes (654 seconds). Figure 5-18 and Figure 5-19 demonstrate the spread of times provided. Where the respondent provided a range, (e.g., 10 to 20 minutes) the average of these was used to calculate the average values. The maximum value of the range provided was used to calculate the maximum time. This increased the mean PSED to 13 minutes (780 seconds). Figure 5-18 does not follow a normal distribution and this is principally due to the large stacks of identical values and also the value of zero being provided as a minimum time allocated for the PSED. To overcome this anomaly, a time-and-motion study would have to be conducted to accurately record the time taken for the PSED rather than rely on estimated values provided by the aircrew. On examination, it was evident that no standard distribution fitted the maximum times reported for the PSED. This is as expected and it would be usual to follow an extreme-value distribution, e.g., a Weibull distribution, as evident in Figure 5-19. The Weibull distribution is able to model skewed data, unlike a normal distribution.

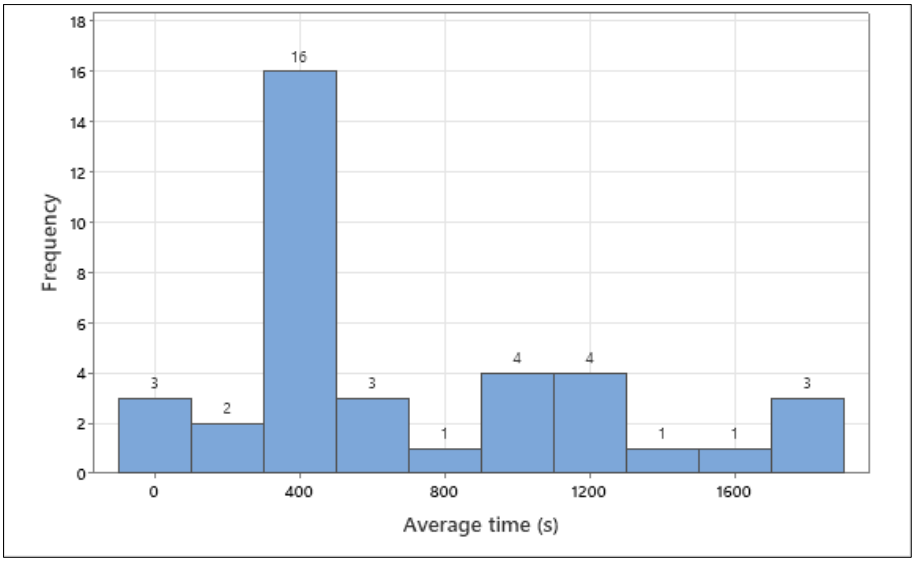


Figure 5-18: Q34 - Histogram of the average time allocated to PSED

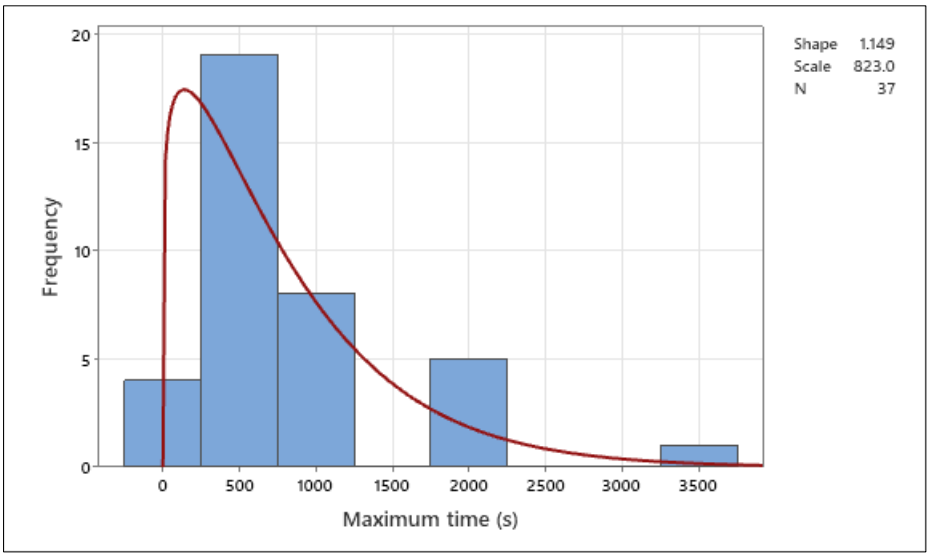


Figure 5-19: Q34 - Histogram of the maximum time allocated to PSED with a Weibull distribution

Q35, regarding whether the aircraft had an electronic logbook, was posed as a strong positive response might have impacted the average time for the PSED. The majority responded negatively (76%).

5.4.4 Training

The majority (60%) of aircrew had not received any training on how to conduct the PSED (Q36). Of those who had, the majority (62%) assessed the training as

useful (Q40) (Figure 5-20). Aligned with this, most (58%) would benefit from PSED training or further training (Figure 5-21).

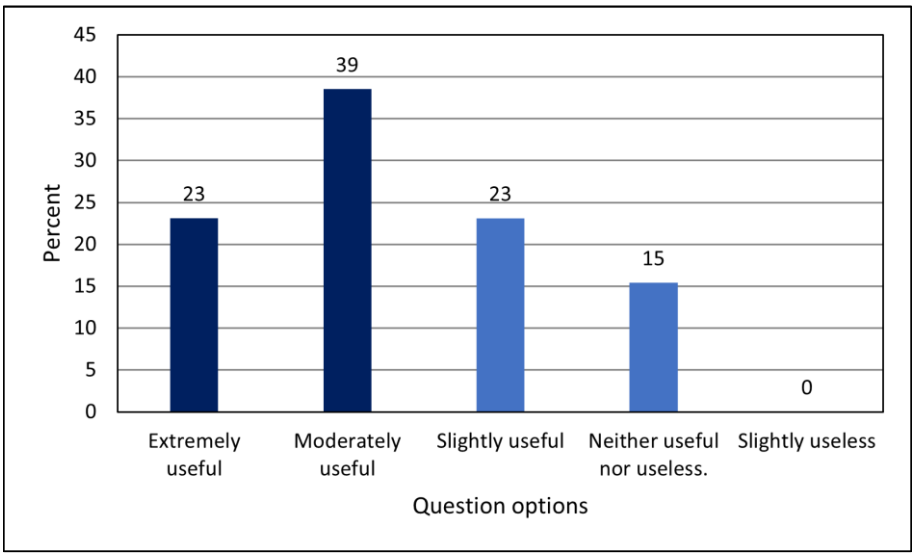


Figure 5-20: Q40 - Usefulness of PSED training

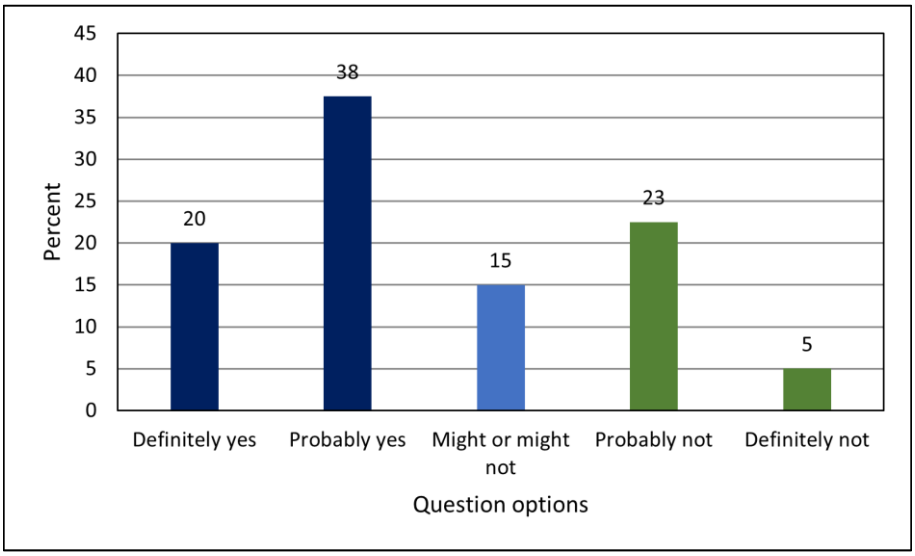


Figure 5-21: Aircrew who would benefit from PSED training

Q37, 38 and 39 were not answered. This is discussed in the limitations (Section 5.6.1).

5.4.5 Aircrew logbook

The vast majority (90%) of aircrew do read/review the aircraft technical logbook to understand how the engineers have cleared the fault (Q42) (Figure 5-22). Due to four occurrences of rounding up 0.5, the graph indicates a total of 102%. To

confirm the total was 100%. Similarly, most aircrew indicated they understood the engineer's terminology most of the time or greater (80%) (Figure 5-23). A fifth indicated they read it half the time or less, which is very surprising after the aircrew interviewee's comments regarding the responsibility of the aircraft captain. Similarly, most (85%) aircrew agreed that it matters if they do not understand the engineers' terminology (Q46). The main reasons for this positive response were due to the 'assessment of the engineering undertaken' closely followed by 'aid communication' (Figure 5-24). Linked to this, most (72%) of the time, the aircrew will seek clarification from the engineers but a quarter of the time no clarification is sought (Q48) (Figure 5-25).

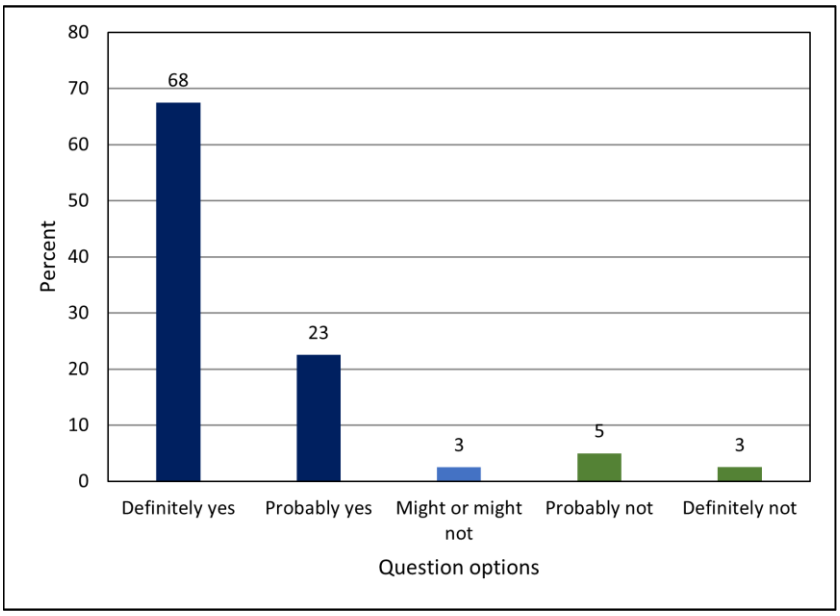


Figure 5-22: Q42 - Do aircrew read / review the aircraft technical logbook?

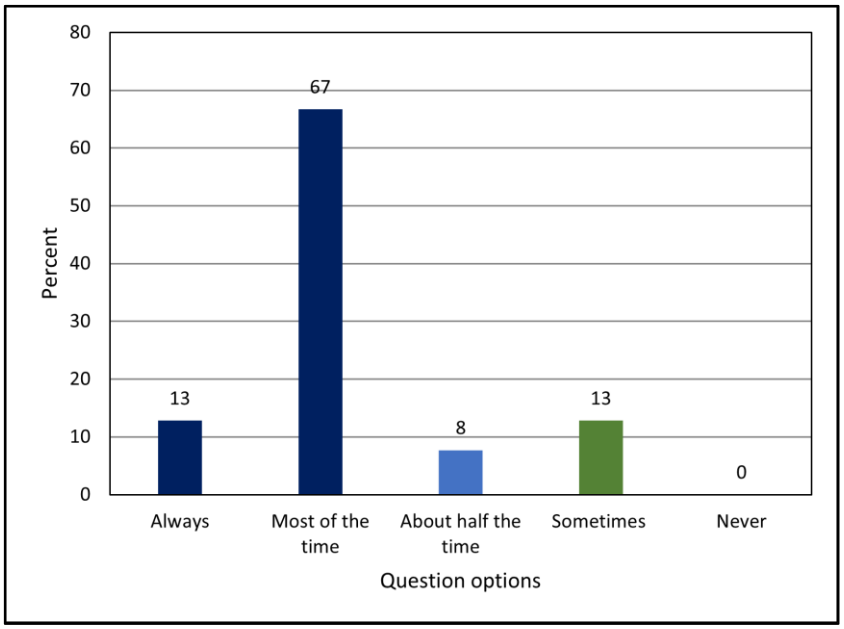


Figure 5-23: Q 45 - Is the engineering terminology understood by aircrew?

Only one person answered Q43, explaining why the aircraft logbook was not read'. The answer was discounted as it did not make sense with the question posed. Q44 was not answered and this is discussed under the limitations (Section 5.6.1).

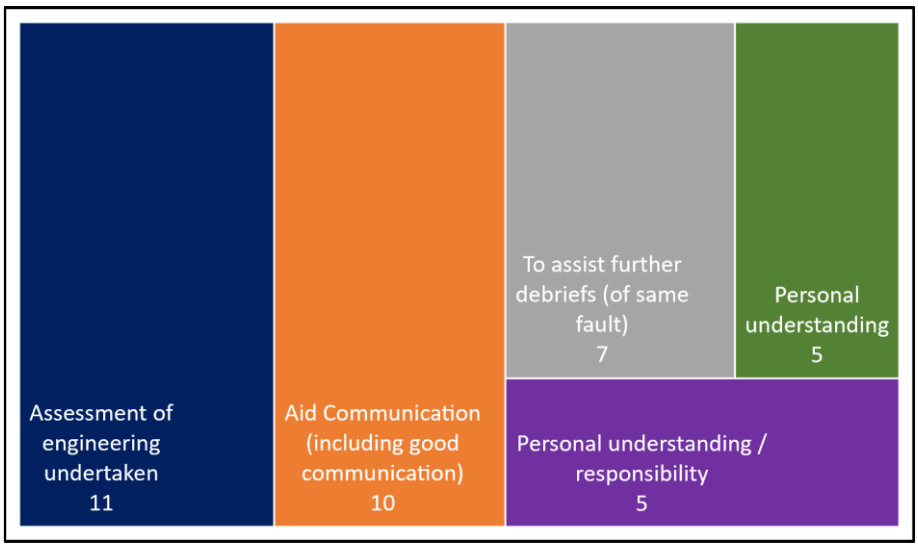


Figure 5-24: Q 47 - Top five reasons it matters that aircrew understand the engineer's terminology

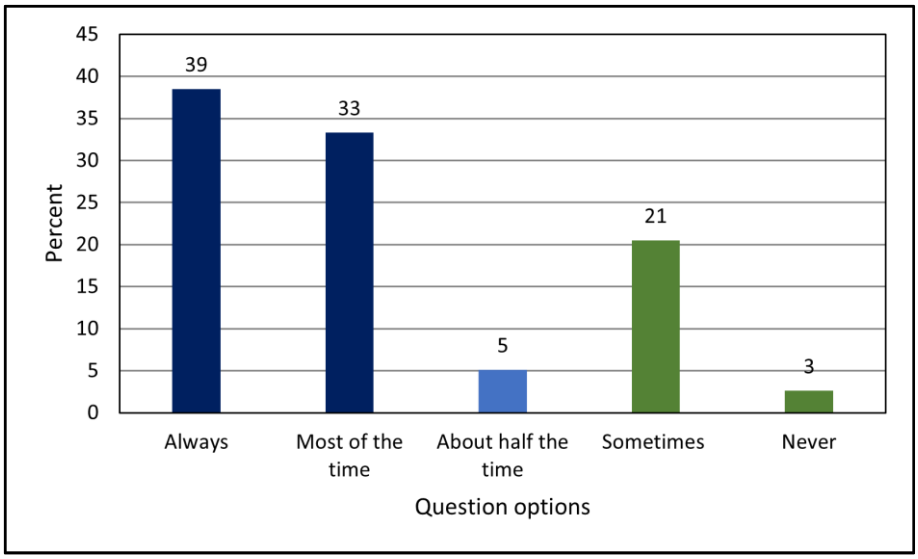


Figure 5-25: Q 48 - The times clarification is sought from engineers

Most (95%) aircrew think it is necessary to know if the aircraft has or has had a NFF recorded (Q49). The top reason for wanting to know is 'for further occurrences' (Q50) (Figure 5-26).

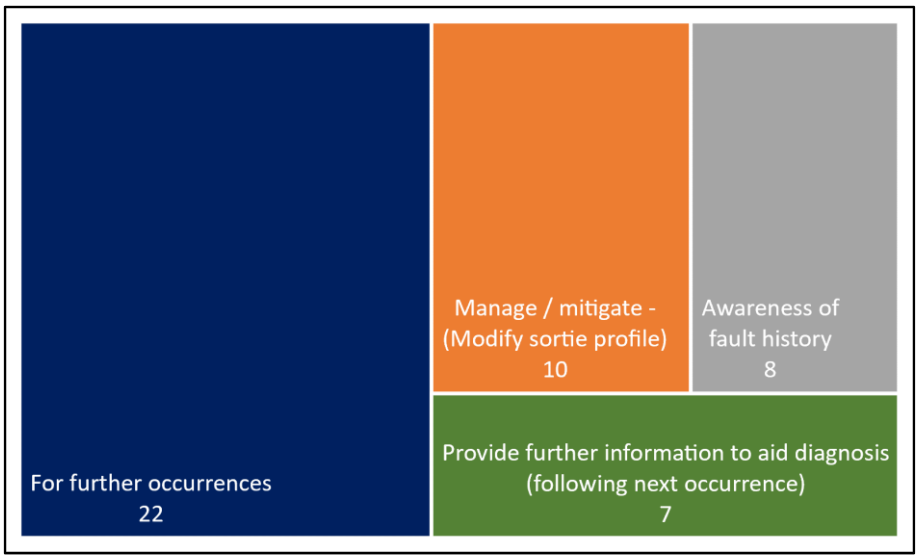


Figure 5-26: Q50 - Top four reasons for why it is necessary to know if the aircraft has had a NFF

5.4.6 Trust

The majority (86%) of aircrew do trust the engineers to investigate the fault (Q51) (Figure 5-27).

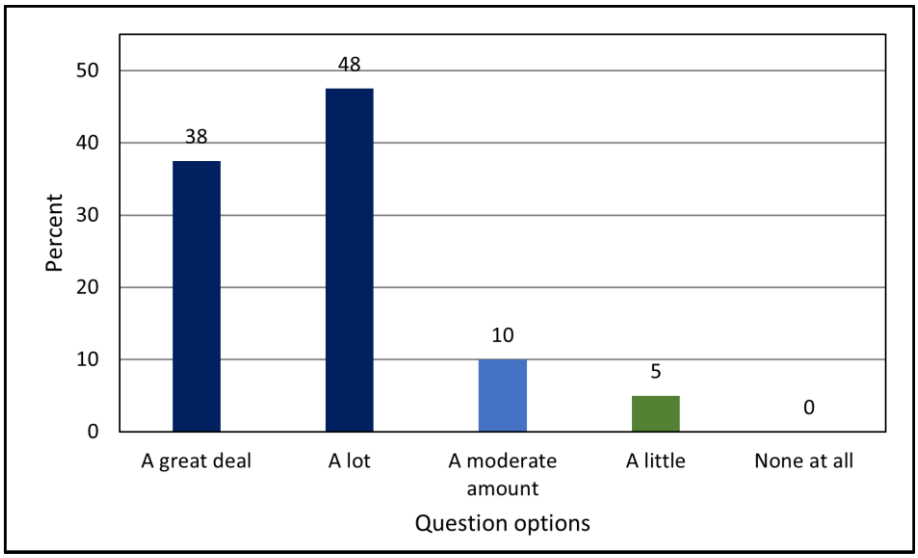


Figure 5-27: Q50 - Level of trust aircrew have in engineers to investigate the reported fault

The main experience or thought regarding NFF and airworthiness (Q52) were related to engineering issues (n=14), followed by aircrew issues (n=4) and more fault history required if NFF recorded (n=4). The stated engineering issues were varied but included the engineers' lack of knowledge, their level and depth of diagnostic skills, insufficient time or resources to complete the diagnostics, low morale and poor shift handovers.

5.5 Analysis of the questionnaire

To provide some continuity, the questionnaire responses were analysed against the Interview Template analysis themes (Table 4-4 and Table 4-5). It will be stated when a subtheme is not covered in the questionnaire analysis. 'Pressurized engineers' is added as a new theme. This was an explicit question within the questionnaire. Alignment or contrast with the literature and interviews will be highlighted.

5.5.1 Categorization of aircrew respondents

The mode and mean of the range of aircrew age and period as a member of aircrew was widespread so, therefore, this indicates they are not skewed to a particular age range, such as less than 30 years. The predominant military

service was the RAF, so any findings will be more representative of the male, RAF aircrew population, of the OF-2, OF-3 and OF-4 ranks. This needs to be considered when proposing trends and making statements about the generalizability and external validity of the research findings but it reflects the allocation of aircrew within the three UK military services so representative of the population (Defence Statistics (Tri-service), 2015).

5.5.2 Definition of NFF

The explanations tend to show that the aircrew understood the NFF phenomenon and this corresponds with the interview conducted. Whilst the majority of NFF explanations were correct, one explanation was observed to be only partially correct as it stated that the engineers have “not found anything significant”. This implies that there was a fault of some description and whatever was found was not of importance, which is in contrast with the definition of a NFF (Section 2.5).

This gives confidence that when assessing the impact of NFF on the aircraft’s handling, airworthiness, and air safety, in later questions, the aircrew responses were provided from a position of knowledge and understanding. However, it cannot be inferred that in understanding what NFF is, aircrew can correctly diagnose the cause of a NFF.

5.5.3 Fault understanding

This section will record the findings relating to intermittent faults, NFF and documentation.

Q17 explained an intermittent fault to ensure all aircrew understood the terminology being used. This established a common ground and assured reliability in the responses. The vast majority had experienced intermittent faults and the systems provided for the most prevalent intermittent faults agreed with those from an engineering stance (Hockley, Lacey and Pelham, 2016). An example is “sensors misbehaving intermittently.” It was noted that intermittent faults were hard to diagnose, with examples such as electrical or avionics systems being named, and were recorded as NFF after diagnostics were conducted. The seriousness of intermittent faults should not be underestimated

as they contributed to the Flybe DHC-8-402 Dash 8 incident when the aircraft flew below the selected altitude on approach to an airport (AAIB, 2012b). So, it is a positive finding that aircrew recognizes intermittent faults but from the narrative, more concern may be necessary. This is categorized (Section 1.3) as an *important* finding with regards to establishing a link between NFF and airworthiness. The examples stated within the data confirmed NFF existed, its impact and its effect on airworthiness. This is in agreement with the interviews (Chapter 4). Likewise, the systems stated as being most prone to NFF were the same. The aircrew confirmed they read the aircraft logbook and understood how faults were cleared. Evidence was given that the aircrew occasionally provided a poor account of the faults or they were not expressed well. This supports the necessity of a good PSED and a common but detailed proforma to be used for the PSED. This is in agreement with Hockley, Lacey and Pelham (2016) and also ARINC (2008). It should be noted that ARINC were not specific about a PSED proforma but just recommended improving the documentation (ARINC, 2008, p.7) and whilst acknowledging possible misinterpretation of non-standardized or free text (ARINC, 2008, p.16) they recommended standardization of fault reporting (ARINC, 2008, p.23) but using "improved documentation" to record and share with aircrew malfunctioning cases.

Airworthiness and air safety

Airworthiness was a concern for aircrew, especially when the flights were long.

> "I am concerned (nearly lost friends to a frozen rad alt – we ought to spot it but 10-12hrs in a cab, reduced illume over desert, fatigued)."

This quote clearly aligns directly with research that raised concerns regarding long-haul flights, duration of flights and the aircrew's mental capacity (Samel, Wegmann and Vejvoda, 1997; Salas and Maurino, 2010, p.229) and indicates that maybe NFF and airworthiness have a greater impact or possible severity the longer the duration or complexity of the flight or maybe the boredom levels. As found by Guanqian et al., (2014) intermittent faults that cannot be detected are linked to NFF events. Thus, this now indicates that the aircrew believes there is a link between NFF and airworthiness, and there was a 'significant hazard to aircrew, groundcrew' etc. This links with Research Question 2 and a positive

aircrew perception that there is a link between NFF and airworthiness. The data have established that the aircrew understood the NFF phenomenon and most had experienced a fault that had reappeared. Further, the majority believed the original fault was recorded as NFF but the results were inconclusive for the subsequent recurrence as it was split mainly between Yes and Not sure. In some agreement with the military interviewees, just over half the aircrew confirmed that airworthiness, air safety and the aircraft had been affected. From the quantitative responses, the impact of the fault severity was ably explained as follows: “some incidents have had minimal impact on airworthiness or safety whilst others have had a major impact.” The consequence of an intermittent fault or NFF is frustrating the aircrew and for some a belief, that the engineers are not doing their job correctly. This was evident by examining the three words or phrases used to describe the feeling when NFF was recorded, such as the following: “the ground crew don't believe me; they didn't take this seriously; and the system isn't reliable.” This section will consider the prominent aircraft systems that result in a high number of NFF occurrences and probably impact airworthiness the most. The majority of aircrew had first-hand experience of a NFF and the subsequent engineering outcome. The top systems that accounted for the intermittent fault of NFF were avionics, communication and automatic flight control system (AFCS). This accords with the engineers’ top systems for NFF reporting (Hockley, Lacey and Pelham, 2016). However, scrutiny of the faults (Q19) described established that avionics include instruments and would be classified as such by engineers. This is an important distinction, especially when confirming the system that caused the NFF. It may also drive the PSED in the wrong direction, toward the wrong system. What may be described as a gauge fault by aircrew, could be diagnosed as the fault of a different system, as described in the AAIB (2015) report. Engineers have more classifications for describing the system causing the fault. It is likely the faults described were the latest occurrence the aircrew experienced and, therefore, memorable or a fault that had caused more problems for the aircrew. As expected and confirmed by the interviews, the mechanical systems had fewer selections than the electronic systems. This is in agreement with research by Jones and Hayes (2001) and the systems reported by the

military engineers (Hockley, Lacey and Pelham, 2016. p.63), namely communications, navigation, AFCS and then fuel systems. However, it should be noted that avionics was not an option listed for the military engineers' survey and this can probably account for why there was not a correspondingly high number across both questionnaires. Nonetheless, strong similarities between the aircrews' and engineers' responses were observed. Those categorized as civilian aircrew listed armament, AFCS, propulsion, avionics, hydraulics, and braking systems for the systems where a fault that had been fixed reappeared. The armament response is confusing, as it was unclear what civilian aircraft would have armaments fitted. In discussions with military and civilian aircraft engineers, no explanation could be provided for how a civilian pilot could have gained flying experience with an armed aircraft unless the pilot had previously been in the military. This discrepancy could be attributed to incorrectly selecting civilian and not both for 'were you military or civilian aircrew' (Q8).

These findings are key when categorizing the links between NFF and airworthiness (Section 1.3). The NFF was seen to contribute a significant hazard to the aircrew. This is categorized as *critical* as there was a risk to life. The aircrews' perception of a link between NFF and airworthiness is *important* to acknowledge as it supports the premise for this research. The systems that were most prone to having a NFF recorded are *important* to recognize. It is these systems where during the design and testing stages, more effort should be afforded to look for the causes for NFF and the conditions under which they occur. These *impact* the airworthiness of the aircraft and may cause additional workload or distraction for the aircrew. These systems appear to have a greater *impact* on airworthiness.

5.5.5 Training

This section will cover the airworthiness, NFF and PSED training provided, the need for training in these areas and the likely consequence of the lack of training.

It was presumed that the aircrew had received training on airworthiness but this was incorrect. This presumption unchecked would make it difficult to assess if a consistent view of airworthiness was applied when assessing if the aircraft's

airworthiness had been affected. To overcome this problem with the later aspects of the questionnaire a definition was provided. However, for future analysis, a definition of airworthiness needs to be given. This trend was strongly established by Haddon-Cave (2009, p.473) who was emphatic when he stated the MOD had: “a fundamental lack of ‘ownership’ of Airworthiness” and that: “Airworthiness, therefore, expressly covers equipment and its operation. This does not seem to be widely appreciated or understood by all concerned.”

The overwhelming majority of aircrew had received no training on the NFF phenomenon, although most provided a sound explanation. Age and rank have not affected the outcome of whether NFF training was provided. This accords with the interviews. Likewise, the military engineers (89%) had received no training on NFF but declared they (73%) would benefit from such training (Hockley, Lacey and Pelham, 2016). So, whilst the question regarding benefitting from NFF training was not posed, it may be deduced that if PSED training was provided the information imparted to the engineers regarding all faults, including those assessed by the aircrew as inconsequential or intermittent faults, would improve and, hence, this may reduce the outcome of a NFF and the negative feedback for the engineers (Q23).

The information imparted during the PSED will certainly influence the diagnostics conducted. Yet the majority (60%) of aircrew received no formal training on how to conduct the PSED, yet those who had received the training confirmed it was beneficial. No link appeared between whether training for the PSED had been received and the time to give the debrief, as the average PSED time for those who responded ‘Yes’ ranged between zero and 30 minutes and the maximum time ranged between five minutes and one hour. No explanation was provided for the type of training provided (an error with Qualtrics®) but it is probable that the training provided was on-the-job training. This would be in agreement with the interviews.

ARINC (2008) and Haddon-Cave (2009) have both highlighted the effect of not understanding key definitions. Aircrew training is expensive and the focus is correctly on safety (ARINC, 2008, p.19) but a standardized PSED or fault

reporting (ARINC, 2008, p.23) has been advocated for over 14 years as a way to reduce NFF occurrences. This is linked very closely with the format of the PSED and effective communication.

It should be noted that the engineer findings were regarding the effectiveness of the engineers and aircrew to solve NFF issues when neither fully understands the NFF phenomena and its impact upon the aircraft, aircrew and engineers. The risk may not be fully appreciated. So, whilst ARINC (2008, p.10) related the need for training for designers to operators across the air transport environment it is just as applicable across the defence aviation environment.

The lack of formal training in airworthiness, NFF and the PSED may affect what aircrew deem important to report and what they expect to see after engineering diagnostics and rectification. It probably leads to misconceptions and certainly no real consideration of the true impact of NFF further down the logistics chain.

5.5.6 Time available

The 'time available' theme was not expressly asked within the questionnaire and no responses aligned with the elements of this theme, for example, crew composition or social commitments (Table 4-4), except for the *Complexity of fault aspect* of this theme. Three responses provided some clarification for their time available:

- "For complicated faults up to an hour."
- "I need to be sure they've understood - inc [including] volunteering ground run to demo [demonstrate] if req [required]."
- "Depending on number of engineering issues."

So, when deemed necessary, some aircrew will conduct a longer PSED to ensure the specific faults are adequately explained.

Whilst ARINC (2008, p.23) recommended improving the communication *channels between aircrew and engineers,* they did not give sufficient consideration to how this was to be achieved, they merely recommended using existing channels. They further advocated providing training to improve fault

reporting with a focus on the further processing of the fault data provided, i.e., to the engineers conducting the diagnostics. The time available to conduct the PSED may be a key issue to overcome this.

5.5.7 PSED

No specific question addressed the format of the PSED, the key point to impart or the time of day. So, the focus will be on the time for the PSED, solutioneering, regulations/procedure/processes, in-flight diagnostics, engineering clarification and hypotheses.

An issue raised by the engineers was that the aircrew gave insufficient time to conduct the PSED and this was a cause of higher NFF occurrences. From the analysis of the interviews and the literature (Hockley, Lacey and Pelham, 2016) the time to conduct the debrief, experience or inexperience, personality and rushing to get away after a long flight impacted the debrief, with some engineers wishing the aircrew would just admit when they had made an error. These along with providing pre-conceived ideas and opinions of what the fault was, rather than providing an accurate description of symptoms, negatively impacted the PSED and resulted in more NFF cases being recorded (Hockley, Lacey and Pelham, 2016, pp.46-49). From this study, the time available for the PSED varied considerably but the mode was five minutes. It is questionable how much information can be imparted in five minutes and in what detail. The respondent who stated 0-? had just over 37 years' experience, so his value of zero is surprising. He was a senior captain so it may be likely he was not doing the debrief; the co-pilot was. Whilst the military engineers were not asked how long an average PSED took with the aircrew there was the view that they were "not necessarily satisfactory" but did cite "aircrew experience and personality" as an impact, both positively and negatively. This contention may probably be due to the limited time some aircrew allotted for the PSED, as evidenced by the mode. ARINC (2008, p.5) determined that poor communication between the aircrew and engineers was a contributory factor to a NFF being recorded. There was consensus that proformas, such as the Aircrew Symptom Capture Tool, would

improve the quality of the debrief but the aircrew needed to allocate time to complete it (Hockley, Lacey and Pelham, 2016, p.45).

So, time did appear to impact the diagnostics that were conducted. Insufficient or incomplete information provided by the aircrew during the debrief can directly impact the diagnostics.

Aircrew did not explicitly point out that they conducted solutioneering or hypothesizing but knowing the engineering conducted enabled them to monitor for specific flight conditions and to be precise when explaining them during the PSED. By monitoring the flight instruments, it was hoped it would “aid in further diagnosis [diagnosing] any re-occurrence.” One alluded to solutioneering by offering “some info as to where the fault may lie” if it recurred. However, another cautioned that knowing a previous fault could “pre-condition … [aircrew] you to a particular diagnosis (potentially hazardous).” This differs from the view provided in the interviews. As to why they needed to know if a NFF had been recorded it was noted that knowing it had happened determined “how much troubleshooting” was conducted, so how much in-flight diagnostics was conducted. However, this was not confirmed by the majority of the aircrew. A specific question about in-flight diagnostics may establish a clearer result one way or the other. Another acknowledged that it “allows deeper thoughtful to be given to how an issue will be handled if it reoccurs rather than in-flight under pressure and enhances flight safety”. So, for this individual, it confirmed a clear contribution to flight safety.

No regulations were provided for how to conduct the PSED and an indication of who provided the training and when it was conducted, as Q37 to Q39 were not presented to the respondents. However, expanding the regulations wider to engineering regulations, it was alluded to that the AMM was inadequate and lacked sufficient depth to allow the engineers to conduct the required diagnostics and rectification work.

Whilst most aircrew sought clarification if they did not understand the engineers' terminology, only one respondent categorically stated this when explaining why he sought clarification. For most, it was Yes. It was clear from the data that the responsibility of the captain included understanding the rectification taken to

make the aircraft serviceable, even if seeking clarification caused a delay to the departure time.

5.5.8 Documentations

This theme will consider three subthemes: engineering terminology; insufficient detail and unofficial engineering records of NFF.

From the data, the majority of aircrew read the aircraft logbook, they mostly understood the engineers' terminology and thought it mattered that they understood the terminology used. This common understanding of the terminology is important as it contributes to the professional relationship between the aircrew and the engineers. Moreover, it can enhance the aircrews' ability to ask informed questions regarding how a fault, intermittent, was resolved or to ascertain why it may not have been confirmed as a fault. Reasons for wanting to understand the engineers' terminology are as follows:

> "To feel assured it has been fixed and also to debrief them again if the fault comes back."

> "Aircrew & Engineers may understand something differently - neither wrong."

> "Aircrew/Engineer cooperation is key to safe operation and it is, in my opinion, basic professionalism to understand what they have done to ensure you have confidence in their work and as important, that they have confidence in your reporting of faults."

In contrast, a No was explained as follows: I'm not an engineer, it either works or it doesn't.

While aircrew thought it mattered if they understood the engineers' terminology about a third failed to actively seek clarification. Possible reasons for this could be the time available and/or the availability of technicians. One respondent indicated part of the problem:

> "engineering were alaways [sic] under pressure to get a/c away on time."

Nevertheless, as the aircrew is *responsible* for the aircraft, as stated in the interviews and some questionnaire responses, then both thinking it matters and seeking clarification questions should have had similar results.

Further, whilst aircrew thinks it matters if they understand the terminology a greater proportion believe they should know if the aircraft has had a NFF. Yet, not all sought clarification as to how the fault was cleared. This is a mismatch.

When aircrew understood the terminology half the time or less, this can lead to misinterpretation, confusion, and a weaker professional relationship that may impact the rectification conducted and, thus, airworthiness. This is not good communication—a "process by which information is clearly and accurately exchanged between two or more team members" (Bowers, Jentsch and Salas, 2000, p.73)—and will lead to a breakdown in the relationship, accepted ignorance and any consequences.

In 2008 ARINC recommended clear terminology be used as a means to reduce NFF occurrences. Yet, over seven years later, Khan et al. (2015) established that numerous terminology was still used to describe a NFF. So the importance of a common terminology has been established to reduce the NFF occurrence and to improve relationships between all stakeholders but is not being applied.

Questions relating to 'insufficient detail' were not explicitly posed but data indicated it was a concern. One respondent had "Frustration that our diagnostics are not good enough to isolate the fault". This overlapped with another who opined "Because it was recurring and I was not convinced it was being investigated thoroughly enough." So for them, it could be argued that insufficient detail was provided for how a fault had been rectified and within the technical manuals available. Likewise, the engineers may argue that insufficient information had been provided by the aircrew during the PSED.

The questionnaire did not add to any claims that the engineers kept unofficial engineering records of NFF. A search of data for the term unofficial, or similar was conducted. The word was not found. It was during the AAI interviews that this claim was made. However, the data confirmed that aircrew did not report all

faults “by agreement” as it was highly likely they would be recorded as NFF and become “imperative for engineers to investigate - for minor snags this effort and loss of a/c from flypro not warranted [sic], but presently this denies a true fault history.” No indication was provided as to whom “the agreement” was between. However, this practice skews the true extent of NFF and any impact on airworthiness.

5.5.9 Continuity and management

The data confirms that aircrew report recurring faults and NFF to the hierarchy (engineering and aircrew management) and this is done to reduce any friction between engineers and aircrew. Escalating the fault to drive in-depth maintenance was the top reason cited as this appeared to be the only way for a full investigation to be undertaken and the risk to the aircrew recognized. This risk was perceived to be daily. However, flight safety was also important, along with concern for themselves and their colleagues. The risk the aircrew were accepting and the impact on the flight or mission needed to be realized and investigated.

The impact of NFF on the flight programme was acknowledged with resources (spares and engineers) being cited as reasons. The impact of spares on NFF being recorded has been identified as a reason for mission aborts (Ilarslan, Ungar and Ilarslan, 2016). So this acknowledgement by the aircrew is supported by the literature.

Similarly, the engineers’ shift pattern was also cited as a cause for losing a flight, especially if a fault had been recorded as a NFF. It was illustrated that a complex fault was frequently recorded as NFF if the diagnosis was conducted near to shift changeover. This aspect impacts the trust again. Moreover, the examples highlight the cost, not in financial terms, but in training and operation time, which for military operations are the crux.

The data confirmed the views of the interviewees that the recurrence of faults and NFF recordings were escalated to a higher authority. In agreement with the interviews, the aim of not causing friction or an imbalance between the engineers and aircrew was cited as a cause. Thus, it establishes that some aircrew were

not content with the fault diagnostics completed and the fault was deemed serious enough to warrant an intervention. However, flight safety was a reason, along with safety for themselves and colleagues and because they did not perceive they were being believed. This is a trust issue that will be considered later (Section 5.5.10).

For some, inexperienced engineers were more common and were unable to conduct the in-depth diagnostics and maintenance required as evidenced by this statement:

> “I have seen a gradual decline in the level of system knowledge and understanding of platforms over my career. … [and] I believe that NFF can be symptomatic of an inexperienced engineering organisation or indeed an under resourced one,”

This is supported by a survey that specifically examined if technology impacted the required skill level of RAF aircraft engineers and confirmed the dilution of engineering knowledge was a concern but conversely engineers did not believe they required in-depth knowledge of the aircraft systems (Waghorn, 2018). Her results established that the analysis skills were unchanged but the equipment and information for diagnostics were (Waghorn, 2018).

5.5.10 Trust

Overall, the aircrew did have high levels of trust in the engineers to investigate faults they had reported (Q51). So, for all the negative reasons provided for Q21 and Q23 the respondents do believe they have trust in the engineers. This is necessary if a professional relationship is to be maintained as espoused by Psychology Today (2023) who advocate that a lack of trust can lead to possible unsuccessful relationships and is necessary if quality PSEDs are to be established or continued. However, the qualitative narrative provided a contrasting viewpoint. Phrases such as “Engineers' best” were assessed as positive but “expected outcome”, “don't trust engineers”, “engineers do not trust aircrew”, “engineers' arrogance” indicate trust is an issue. The sense of security is missing and this is important as “Trust is key for collaboration, the open

exchange of ideas, and a strong workplace culture" (Psychology Today, 2023), which are key qualities between the aircrew and engineers.

Furthermore, the mode for Q23, why were they concerned the fault had reappeared was 'Insufficient Engineering Diagnostics', so thereby showing doubt in the quality and depth of engineering diagnostics done. For 10 of the 11 aircrew, whose description indicated that they did not trust the engineers, there was some misalignment with the response to Q51, the level of trust they place in the engineers; or it could be that the allotting of the phrase to the theme was incorrect. It was for this reason a second opinion was sought—to confirm the assessment made. Cross-checks against rank and age were conducted but these did not appear to influence the response.

A lack of trust or diminishing levels of trust can lead to an uneasy relationship between the aircrew and engineers and was highlighted in the interviews and the literature (Hockley, Lacey and Pelham, 2016; Psychology Today, 2023). Interviewee 1 ably summed it up well when he stated: "it could frequently become difficult if a captain was seen to be directly challenging the engineering judgement of the maintenance organization." Trust is included in the definition of 'Responsible' (OED, 1989, Vol XIII, p.742). The engineers are responsible for the diagnostics and the rectification. It would be fair to assume that the hierarchy, in the relevant management position, is responsible for listening to the aircrew. The duty holder is responsible for the airworthiness of the aircraft and the risk the aircrew has to accept. So, trust between these closely linked groups is essential. Trust engenders a willingness to cooperate, closer working relationships and promotes a greater sense of safety (Psychology Today, 2023) required if as per the airworthiness definition the air system is to be operated without significant hazard to aircrew (MAA, 2015c; 2022c).

Trust is a psychological aspect that is outside the scope of this research but would benefit from being researched as this trust may be a key contributor to NFF and airworthiness.

5.5.11 Communication of faults (NFF)

The theme Communication of faults covered the following subthemes: verbally between aircrew; social media; experience of engineers; aircraft technology; forced rank structure; and check understanding.

The communication between aircrew was not a noticeable aspect within the narrative nor was social media. So, the following will cover the remaining subthemes.

The lack of engineers' knowledge was acknowledged as a cause for NFF recordings. Black-box engineering, i.e., just replacing a LRU, was cited as poor engineering but conducted as the engineers did not fully understand the aircraft systems. Moreover, engineers failed to appreciate any second or third-order effects, i.e., increased aircrew workload, and just looked for faults in isolation. However, a view espoused was that the AMM test schedule was insufficient if the fault could not be tested or reproduced on the ground. So, a different but important aspect of communication may reflect upon the technical skill level of the engineers. For this reason, it was noted that the engineers should be trained by the OEM, which supports the view of the interviewees. The engineers' lack of knowledge of how the systems interact and that a failure in an unrelated system may affect the system was viewed by one aircrew as the most common reason for a NFF being recorded. Further, it was for this reason that the engineers should be trained by the OEM, to understand all the systems and not just adhere to the procedures. Importantly, the engineers have to sign for the rectification completed per the AMM. So, the view also indicates the belief that the AMM is inadequate for the diagnostics required.

One aircrew did not exclude aircrew from poor communication and accepted that faults recorded in the aircraft logbook were poorly stated.

A view opined was that NFF was reduced due to the built-in-test equipment and built-in test being able to provide the system status and pinpoint where the fault lay. However, this is incorrect. The more technical and complex the systems the more specific the test needs to be. For engineers, the test sets frequently did not

test to the depth required. Research has shown that built-in test equipment frequently lacked sufficient fault coverage, falsely identified faults and was insufficient in isolation as a means for detecting faults (Fedrick, 2014). It must be remembered that the test sets were unable to replicate the environment (air conditions) or the faults (Khan et al., 2015). Furthermore, if the test set conducts asynchronous tests, a flaky test outcome may result, i.e., where the outcome can be “pass or fail on the same build” due to noise being introduced (Rehman and Rigby, 2021). This is further compounded by the engineers or process failing to identify a fault (Rehman and Rigby, 2021).

A forced rank structure was not identified as an issue but having to elevate a recurring fault to the hierarchy indicates the finely balanced engineering and aircrew structures in place. This needs to be considered when resolving how to reduce the impact of NFF on airworthiness.

The requirement to ‘check understanding’ was stated when reviewing the aircraft logbook and ascertaining how a fault was cleared. It was accepted as the captain’s responsibility. This was closely linked with understanding the engineers’ terminology. For information to be accurately exchanged, clarification is required (Bowers, Jentsch and Salas, 2000). This includes being able to recall the aircrew to provide more information about a fault, as expressed by one aircrew respondent. This point aligns with the engineers (Hockley, Lacey and Pelham, 2016) and an AAIB interviewee who observed that people usually remember more information after a period has passed.

5.5.12 Impact on the flight programme.

This section will analyse the data against the following subthemes: risk versus reward; repair time; cancelled/curtailed/amended profile flight; refusal to fly aircraft; and disinclination to report ongoing historical flight.

The main reward alluded to was engineers finishing the shift on time, even if they reduced the necessary diagnostics time. In a case such as this, a NFF was expected to be reported. However, aircrew not reporting faults increased the probability of the aircraft being available for the mission—this was more frequent

during operations—and reduced the maintenance conducted. The belief was the engineers would record NFF for minor faults. So, a subsequent reward was less rectification for the engineers.

Repair time was covered in the previous paragraph. The aircrew's view that complex faults recorded near a shift handover or late at night reduced the diagnostics conducted cannot be dismissed. This was cited by the interviewees as well. Furthermore, poor shift handovers were identified as impacting the flight programme, if only due to the limited diagnostics conducted.

The data confirms that the reappearance of the fault curtailed the flight and impacted the flight programme. Whilst the aircrew's safety was not at stake, it was perceived that the aircraft would be incapable of achieving the mission.

Furthermore, aircraft handling, airworthiness and air safety were affected. This supports the interviewees' observations. As previously noted, the acceptance of NFF and those that end in an abortive mission are not accepted by the Turkish Air Force (Ilarslan and Ungar, 2016). Also, as well as a mission abort, the NFF could result in an in-flight emergency (Steadman et al., 2005). The data concurs that the additional risk, workload and pressure were a concern for the aircrew.

Cancelled, curtailed and altered flight profiles were observed as a result of a NFF or intermittent fault. Nugatory hours were expended in planning for missions that were curtailed due to repetitive faults. In accord with the interviewees, the aircrew was similarly refusing to accept the aircraft with strong feelings expressed:

> "Immediate a/c [aircraft] change and refused to fly it until engines rejected."

> "Repeated NFF by engineers over many weeks until crew returned from another PTF and said they would not let anyone else fly it until something found."

The views were that either they were not believed and/or the engineers were not conducting sufficient diagnostics to find the fault. There was a perceived risk when flying the aircraft over and above any ALARP risk accepted by the Duty Holder. Establishing the number of flights curtailed indicates the seriousness of

the fault and the impact on capability (Copernicus, 2012). The examples provided by aircrew strongly support the concept that aircrew perceive a link exists between NFF and airworthiness.

Nevertheless, aircrew still chose not to report some faults, not always because they thought nothing would be investigated but reproducing the fault on the ground was virtually impossible and the engineers' effort and removal of the aircraft from the flying programme was not warranted. On operations, with a small pool of aircrew and engineers, this practice may become ‘acceptable’ but this hides the true aircraft ‘airworthiness’ state and was identified as a cause for concern by an AAIB interviewee.

Whilst only 44% stated that it did impact the aircraft handling, over 50% believed the reappearance of the fault did affect the airworthiness and air safety. This must be an ongoing concern for aircrew and provides an insight into why they have trust issues with the engineers when fixed faults reappear. The following quotes evidence that concern:

> “If the faults happened at critical phases of flight they could have more serious outcomes than when they reappeared to me.”

And

> “I am concerned (nearly lost friends to a frozen rad alt – we ought to spot it but 10-12hrs in a cab, reduced illume over desert, fatigued).”

5.5.13 Other – pressurize engineers

The data establishes that the aircrew did not perceive they pressurized the engineers, even though they needed to maintain their flying hours. These findings accord with the literature—the military engineers felt no overt pressure from the aircrew (Hockley, Lacey and Pelham, 2016, p.74). There was an exception for one platform but with the view that the engineers had done all possible to resolve the fault. This data found that the aircrew found the engineers to be under pressure and at times more so than the aircrew. This was evident when dispatching an aircraft. If the aircrew requested clarification of information, this

relieved the pressure on the engineers as they were no longer responsible for any delay. However, operational pressure was cited as a reason for any pressure. Further, it was acknowledged the pressure resulted in a higher number of NFF being recorded. No examples were given to support this observation.

5.6 Summary of analysis

The questionnaire has supported many views expressed by the interviewees and found within the literature. This methodological triangulation improves the validity of the research (Wilson, 2014, p.136) and “can reduce the risk of chance associations and of systematic biases” (Strauss,1987, cited in Wilson, 2014, p.180). Moreover, methodological triangulation is advantageous as it aids the reduction of flaws and research bias that results from reliance on a single research technique (Scribbr, 2023b). The sample was not skewed to a particular age or rank/status. Although most were male, RAF officers. The analysis indicates the aircrew perceives a strong relationship between NFF and intermittent faults and airworthiness, even though no specific training had been provided for the NFF phenomenon. This contributes to a positive answer to Research Question 2. Most had experienced intermittent faults and NFFs, became frustrated by them and would report any misgivings to the relevant hierarchy. However, they did not pressurize the engineers, even though for some there was concern that the skill set of the engineers was declining. As a result of the intermittent fault or NFF, flights had been cancelled, curtailed or had the profile changed and this consequently impacted the mission. The aircrew read the aircraft logbook but not all understood the engineers’ terminology and this was, for some, deemed essential as the aircraft captain should know the maintenance conducted on the aircraft. They could confirm the systems most likely to be subject to a NFF being recorded. The time to complete the PSED appeared low but there was evidence that more time would be taken for complex faults. Specific solutioneering was not provided but there was evidence of providing ‘guidance’ to where they perceived the fault to be. Trust is tenuous at times between aircrew and engineers and this impacts professionalism, communications and relationships, resulting in hierarchical management levels

having to intervene. Although a simple definition and explanation were provided and used to support this analysis, the topic of trust between the aircrew and engineers deserves dedicated research by a psychologist.

Any expected improvements since the publication of the ARNIC (2008) guidelines appear to be non-existent as there appears to have been no significant impact on the UK DAE, or specifically the RAF as most responses were from that military service and, therefore, more closely represent that population.

The key aspects found that should be targeted to reduce NFF occurrences are the following:

- Specific training on NFF, airworthiness and how to conduct a PSED.
- Improved understanding of engineering terminology by the aircrew.
- The experience of aircrew and engineers impacts the PSED and this should be monitored and measures put in place where this is evident.
- A classification and monitoring system for NFF and intermittent faults.
- Tracking of the main systems with high NFF occurrences.
- Reporting and analysing the frequency of curtailed/cancelled or changes to the profile of flights.
- A suitable document to record the PSED and clarify the aircrews' perception of impact on airworthiness.
- A hierarchical overview to monitor and manage the aircrew and engineers' training and experience and to monitor NFF occurrences to implement necessary changes when required.

The following quote from the data expresses the complication with resolving the phenomenon of NFF and the link to airworthiness due to the number of facets involved:

> "Better appreciation of NFF causes, especially the human ones (not all faults are aircrew fat fingers just as not all NFF are lazy / blind / deaf / dumb engineers!) would definitely aid things. Poor descriptions by aircrew, poor watch handovers and an unwillingness (or genuine inability) by

engineers to call and interrogate further with the crew are, I suspect, contributory factors; absence of spares may not help!"

It is asserted that Objective 3 has been achieved.

5.6.1 Limitations of the questionnaire

There are limitations with the questionnaire and the data provided.

Whilst the questionnaire was widely distributed the sample was small and skewed toward male, RAF aircrew. However, the combined military responses were greater than n=30, so the data can be used as an approximation of the population in general (Alder and Roessler, 1977; Wilson, 2014). However, this is the population of the RAF aircrew and not the aircrew population of the UK military or civil aviation. Consequently, the external validity, i.e., whether the findings "can be generalised to other relevant settings or groups" (Wilson, 2014, p.194), of the questionnaire results and analysis is valid for the RAF but not for the other UK military services and civil aircrew. Thus, no generalizability of the results can be proffered regarding aircrew in general. However, there are similarities between the RAF, Royal Navy and British Army aircrew training, operations, PSEDs and engineers so the outcomes should not be discounted entirely. To confirm any similarities between the three military aircrews' views on NFF and airworthiness it is recommended the questionnaire is conducted with British Army and Royal Navy aircrew.

Q33 was to be presented if a respondent answered Q32 negatively. Similarly, Q37 to Q39 should have been presented if respondents answered Q 36 Not sure or No. Q44 was to be responded if Q42 was answered positively. The logic of the questionnaire has been checked for all these questions and appears sound. A preview of the questionnaire indicates that they would have been presented as per the logic. So, there is no noticeable reason why these questions were not answered or the responses stored. However, it is acknowledged, there may have been a fault within the questionnaire that prevented these questions from being presented or the aircrew may have chosen not to provide the detail about the training provided. Not having these answers makes it difficult to make any

assumptions about the quality and usefulness of the training provided. Therefore, this ‘usefulness’ cannot be incorporated into a solution for reducing the occurrence of NFF. Similarly, understanding why insufficient time was allocated to the PSED or how far back the aircraft logbook was read cannot be addressed with evidence.

5.7 Conclusion

The questionnaire analysis was conducted to garner the viewpoint of aircrew using the template analysis themes. A strong link between NFF occurrences impacting airworthiness was established from the aircrew perspective. Additionally, the *criticality* of acknowledging the link was established as it impacts the risk to life of the aircrew. The majority of responses were from RAF aircrew and, therefore, more closely represent that population, so generalized statement regarding RAF aircrew population can be stated but not for aircrew in general. There is a close alignment between the interview and questionnaire responses. Key aspects have been identified with training, a dedicated PSED proforma, experience and communication, including terminology, identified as ways to reduce the impact on airworthiness from NFFs. These key aspects will be addressed in Chapter 6 – Analysis, to limit the number of NFFs and the impact on the airworthiness and risk to which the aircrew are exposed.

6 ANALYSIS

This chapter will holistically review the NFF phenomenon and the environment in which it sits with airworthiness. This analysis will be based on the findings from the literature review and survey, both the interviews and questionnaire analysis. The survey provided primary data and information on what was NFF, the aspects that contributed towards a fault being recorded as NFF and the effect NFF had on aircrew and engineers. Additionally, links were found between NFF and airworthiness and air safety. From this primary and secondary data, a rich picture, influence diagram, Bowtie analysis, FRAM, Fuzzy Logic inference and flow charts will be constructed and analysed. This analysis will demonstrate the impact of NFF on airworthiness and provide approaches to understanding and minimizing its impact.

6.1 Rich picture

A rich picture depicts the ‘as is’ *situation* of the problem being analysed. This problem is whether NFF had an impact on and link to airworthiness. Wilson (1984) accepts that the analyst drawing the picture cannot be neutral but to ease any bias, assumptions must be stated. As previously stated, the rich picture is based on this research’s primary and secondary data and the use of these sources should remove any of the author’s bias. A rich picture should contain subjective input from interested stakeholders, objective observation and develop the overarching view of the ‘as is’ situation and the new system in the context of the system environment (Tudor and Tudor,1995).

6.1.1 Rich picture explanation

The Airworthiness Bubble rich picture (Figure 6-1) makes sense to the creator but needs an explanation to others. The following is an explanation starting from the outside, 12 o’clock position and then moving in a clockwise direction from the central hub. The propulsion, airframe, weapon and electronic/electrical engineers (PAWE) are represented by red characters and the pilots by blue characters. The key for Figure 6-1 is in the bottom right-hand corner.

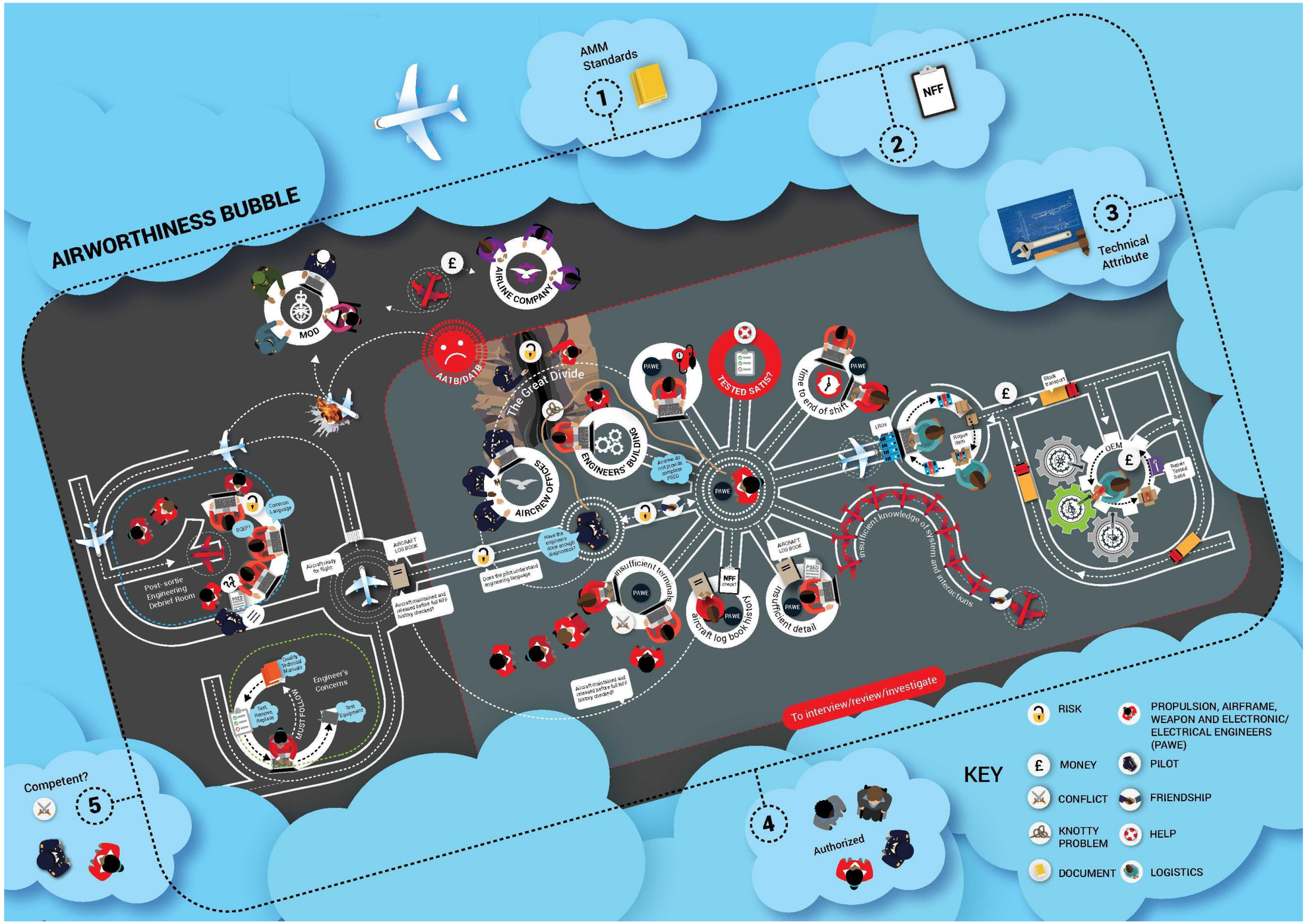


Figure 6-1: Airworthiness bubble rich picture

To aid the analysis the following is the airworthiness definition for this research:

> "Is the ability of an aircraft or other airborne equipment or system to be operated *in flight and on the ground* without significant hazard to aircrew, ground crew, passengers or to third parties*; it is a technical attribute of materiel throughout its lifecycle;"* ***it is to be undertaken*** **by competent and authorized individuals, according to approved procedures and instructions**. Adapted from: MAA (2015c)

From the airworthiness definition, the airworthiness bubble requires approved standards against which the aircraft is designed, built and maintained. It is the claim that NFF is linked to and impacts airworthiness. The airworthiness definition includes 'technical attribute' and this links to the inherent design, against which NFF is linked, as established in the Literature Review. To maintain an airworthy aircraft authorized personnel, engineers, pilots etc, are required and these people need to be competent.

The PAWE are located in the engineering building. They are under pressure (self-induced and real), look forward to the end of the shift and, thus, will take the quickest option to complete a task. They remove components from the aircraft, which are dispatched by the logisticians for repair at the OEM. These actions may be personality or experience-driven. The engineers maintain components as per the technical manuals and this may result in a 'tested satis' or NFF being recorded.

At the OEM, these components will usually be tested in one dimension (e.g., temperature, pressure etc.) some will be 'tested satis' and result in a NFF being recorded. Repaired serviceable components will be returned to the operator; some of these will be rogue items that will be available for engineers to fit into the aircraft. The engineers are perceived to have insufficient knowledge of aircraft systems and how they interact. The aircrew allegedly provides insufficient detail in the aircraft logbook and at the PSED. The engineers do not always check the aircraft history for recurring faults and NFF recordings. This is compounded by the engineers having too few computer terminals on which to record the maintenance or check the aircraft history. There is conflict, trust and support

between the pilots and the engineers. Again, this may be personality or experience-driven.

The aircrew's and engineers' offices may be in different buildings and thus contributes to the support and conflict. Aircrew are not always available when required, especially if more information is required about a flight. As such it is described as the *Great Divide*.

When the aircraft is ready for flight, the aircrew checks the aircraft logbook but not all understand the engineers' terminology detailing how a fault was rectified. As the aircrew does not understand how a reported fault has been fixed, there are concerns this adds to the conflict and lowering of trust. There is the aircrew perception that the aircraft has been maintained (fixed) as quickly as possible, without in-depth analysis and/or without a full history check being conducted. So, repeat faults are not unexpected.

The aircraft flies and in the worst-case scenario, it crashes. The accident will be investigated by the DAIB and the AAIB and will involve a review of circumstances, paperwork etc. This investigation may include a NFF investigation if there is any indication that a NFF was a cause or contributory factor. A discussion will also be held between the operator (e.g., the MOD - Figure 6-1) and the OEM (airline company).

For an aircraft that lands safely, a PSED will be conducted. Frequently an unsuitable location is used (noisy, with distractions and too small), the pilots and engineers may use unfamiliar terminology and may be neither adequately qualified, experienced nor competent to conduct the PSED. This results in insufficient information being recorded in the aircraft logbook and the PSED proforma.

This is compounded by the engineers' concerns that the technical publications they must use are not at the correct standard or quality or with sufficient detail, so the same maintenance is conducted that results in the same outcome. This may be 'tested satis' or NFF.

6.1.2 Rich picture outcome

The rich picture showed the '*as is*' problem regarding NFF, airworthiness, the aircrew, engineers and the environment. This problem will be further analysed using an influence diagram. Thus, a way to ameliorate the situation can be proposed. The rich picture includes the established link between NFF and airworthiness from the literature review and the aircrews' perception of a link between NFF and airworthiness.

6.2 Influence diagram

Where it is not possible to establish a cause and effect between factors an influence diagram can be used. An influence diagram gives a broad understanding of a system without any detail (Pidd, 2009, p.140). From the primary and secondary data and the rich picture, an influence diagram was created to further aid the analysis of the '*as is*' problem.

6.2.1 Influence diagram explanation

An influence diagram shows how one factor influences another but this does not mean there is a causal relationship between them (Waring, 1996, p.41). As one factor increases (e.g., Number of rogue items in stock) the influence on the next factor is determined (e.g. the Engineer's time decreases). The plus (+) symbol represents an increase in the factor's outcome, whilst the negative (-) symbol represents a decrease. Figure 6-2 was created from an analysis of the literature, the interviews, the questionnaire and the rich picture. The diagram depicts the influences present between the engineering, personality, quality and operational etc factors. Starting from the right-hand side of Figure 6-2, Table 6-1 explains how one factor influences another. The larger orange arrows (A+, B+) are discussed after Table 6-1.

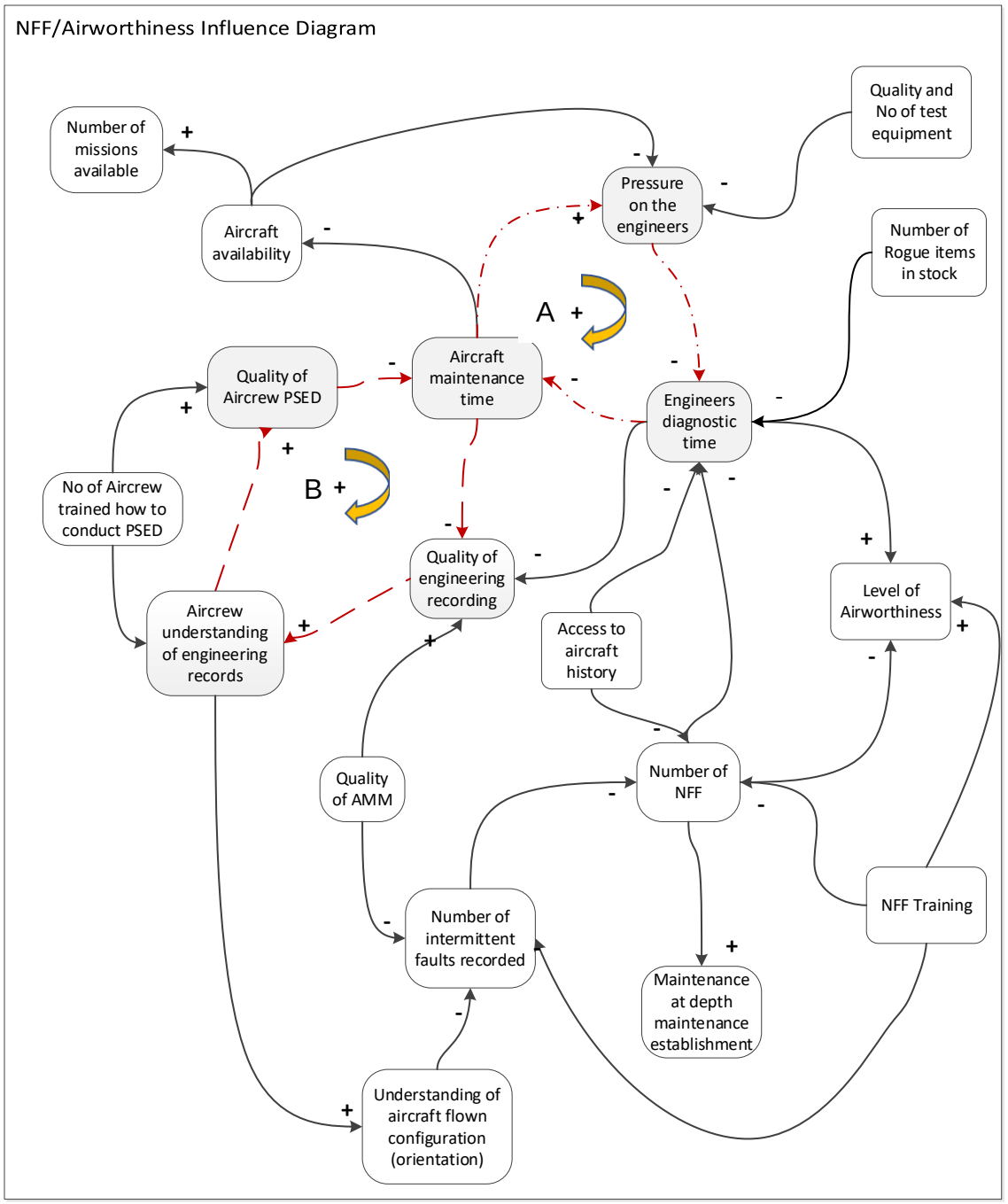


Figure 6-2: Influence diagram depicting the airworthiness and NFF problem

The influence diagram incorporates the aircrews' perception of NFF impacting airworthiness, as apparent when the number of NFF recorded decreases the aircraft's level of airworthiness. Additionally, when the engineers' diagnostic time increases, the level of airworthiness increases, i.e., improves. The aircrew perceived that at times insufficient time was allowed for diagnostics and maintenance time, especially nearing shift handover.

Table 6-1: Explanation of influence diagram

Factor increasing	Links to	Factor influenced	Influence direction	Comment
Aircraft availability	→	The Number of missions available	Increases	More available aircraft means more missions are possible.
Aircraft availability	→	Pressure on the engineers	Decreases	There is less work for the engineers to do. Available aircraft means serviceable aircraft.
Pressure on the engineers	→	Engineers' diagnostic time	Decreases	Less time to complete one or more diagnostic tests, in-depth or otherwise.
Engineers' diagnostic time	→	Aircraft maintenance time	Decreases	If the diagnostic time increases the causes of the fault can be identified more precisely (or quicker) and this reduces the time required for maintenance (overall this reduces the number of intermittent faults and NFF recorded so reduces maintenance time)
Aircraft maintenance time	→	Pressure on the engineers	Increases	The pressure on the engineers to find the cause of the fault and rectify it increases.
Quality and number of test equipment	→	Pressure on the engineers	Decreases	Better test equipment should provide more accurate results and, therefore, reduce the pressure on the engineers as diagnostic time is reduced.
Number of rogue items in stock	→	Engineers' diagnostic time	Decreases	If the number of rogue items in the stock increases these will be fitted to aircraft, possibly producing more (intermittent) faults and, therefore, reducing the time to conduct diagnostics.

Engineers' diagnostic time	→	Level of airworthiness	Increases	Less time for diagnostics will impact the level of airworthiness (risk)
No of NFF recorded	→	Level of airworthiness	Decrease	A greater number NFF recorded should reduce the level of airworthiness.
No of NFF recorded	→	Maintenance at depth establishment	Increases	More components are sent for maintenance at a depth facility (e.g., an OEM).
No of NFF recorded	→	Engineers' diagnostic time	Decreases	More faults are being investigated, so less time is available for diagnostics.
Access to aircraft history	→	Engineers' diagnostic time	Decreases	The additional aircraft, system and maintenance history provides the engineers with the background required to better identify the fault. This additional knowledge permits the engineers to focus on the diagnostic effort.
Access to aircraft history	→	No of NFF recorded	Decreases	Better access to the aircraft history allows a check to be conducted for previous NFFs or intermittent faults. This knowledge will lead to focused diagnostics/maintenance and reduce the number of NFF recorded.
Aircraft maintenance time	→	Aircraft availability	Decreases	Longer time spent conducting the maintenance reduces the time the aircraft is available for flights.
Aircraft maintenance time	→	Quality of engineering recording	Increase	It is assumed that the maintenance time includes the time to complete the engineering paperwork. As such more detail should be written to explain the diagnostics and work conducted. If a NFF is recorded it should be clear why from the detail provided and the documents referred.

Quality of engineering recording	→	Aircrew understanding of engineering records	Increases	Higher quality recording of how faults are cleared will improve the aircrew's understanding.
Quality of the technical publications	→	Quality of engineering recording	Increases	Higher quality publications mean the maintenance conducted can be recorded more accurately.
Quality of the technical publications	→	Number of intermittent faults recorded	Decreases	Higher quality (detailed) publications lead to improved diagnostics and maintenance and a reduced number of intermittent faults occurring.
Number of intermittent faults recorded	→	No of NFF recorded	Decreases	Faults are recorded as intermittent and not NFF.
NFF training	→	No of NFF recorded	Decreases	Training on NFF highlights the phenomenon and awareness leads to improved understanding and improved maintenance. Therefore, fewer NFFs are recorded.
NFF training	→	Number of intermittent faults recorded	Decreases	As above but for intermittent faults.
No of Aircrew trained how to conduct PSED	→	Quality of aircrew PSED	Increases	Aircrew trained in how to conduct and complete the PSED improves the quality of the fault information imparted to the engineers.
No of Aircrew trained how to conduct PSED	→	Aircrew understanding of engineering records	Increases	From the PSED training, the aircrew’s knowledge of the engineering terminology will be increased, so they will be better able to recognize the engineering conducted and recorded.

Aircrew understanding of engineering records	→	Quality of aircrew PSED	Increases	If the aircrew's understanding of the engineering terminology increases (from training), they can better recognize engineering conducted and recorded and align the PSED accordingly.
Aircrew understanding of engineering records	→	Understanding of aircraft flown configuration	Increases	As the aircrew's understanding of the engineering records develops their knowledge of the aircraft's as-flown configuration is increased. They can better understand what engineering has been conducted and the outcome. Without this understanding, misinformation could later be imparted to the engineers.
Understanding of aircraft flown configuration	→	Number of intermittent faults recorded	Decreases	More detailed information is provided to the engineers on the aircraft's orientation. This improves the knowledge of how a fault was presented and aids the engineering conducted. This reduces the number of intermittent faults as the fault is found quicker.

6.2.2 Influence diagram loops

In an influence diagram, a loop is categorized as a positive loop if the number of minus arrows (-) is zero or an even number. A positive loop is non-adaptive and will verge towards either a rapid increase or a rapid decrease in the system stability (Waring, 1996, p.44). There will be instability. In contrast, a negative loop, one with an odd number of minus arrows (-) is adaptive and stable; it is self-maintaining (Waring, 1996, p.44). Within Figure 6-2, there are no negative loops but there are four positive loops, two of which are indicated by the orange arrows, the dotted lines and are annotated A and B. There are two more, larger loops (Figure 6-3 and Figure 6-4).

Positive loop A, (Figure 6-2) indicates instability. The more pressure there is on the engineers, the less time there is for diagnostics and so there is an impact on the aircraft maintenance time. The pressure on the engineers, self-induced or otherwise, needs to reduce, or the aircraft maintenance or diagnostics time needs to increase.

For positive loop B (Figure 6-2), there is instability and this is influenced by the quality of the aircrew PSED, their understanding of the engineering terminology and records, as well as the quality of the engineers' records for the work conducted. If the maintenance time increases, the allocation of time for the completion of engineering records needs to increase accordingly. This would turn this non-stable loop into a negative, stable and adaptive loop, i.e., self-maintaining.

For the larger positive, unstable, loop (Figure 6-3), if the number of intermittent faults is correctly recorded as NFF the negative (-) sign going in 'Number of NFF' would become a plus (+). This would cause the loop to become negative and stable. However, this is still masking the problem. There are two ways to improve the outcome and change the loop to negative. Firstly, if the time to complete the engineering record is increased relative to the engineering diagnostics time, this would create a negative, stable loop. Secondly, an option would be to increase

the engineering diagnostics time relative to the number of NFFs. Both would create the correct influence without masking the problem.

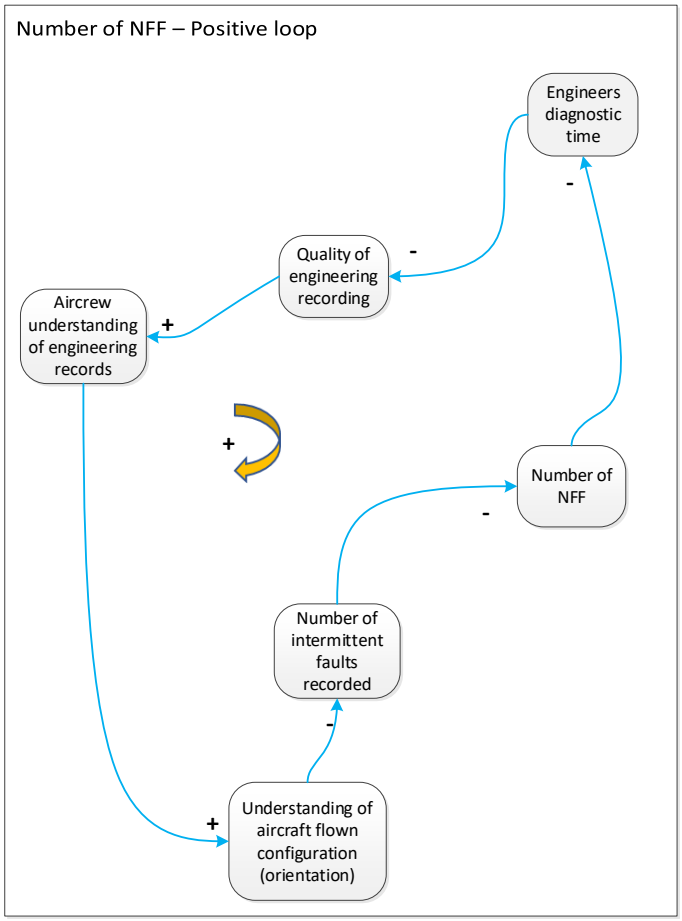


Figure 6-3: Number of NFF - positive influence loop

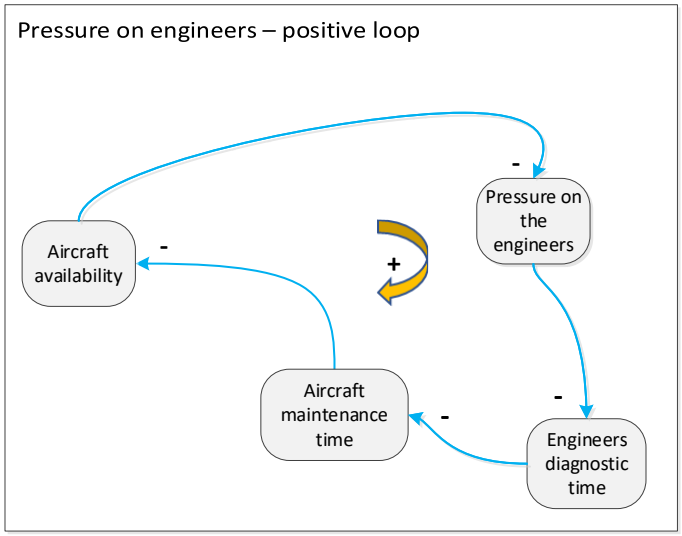


Figure 6-4: Pressure on engineers - positive influence loop

For Figure 6-4, to change from a positive unstable loop to a negative stable loop, will on the face of it still reduce the availability time. There are two options the management could permit. Firstly, permit the engineers to have more diagnostics time and an associated increase in aircraft maintenance time. Secondly, as the pressure on the engineers increases permit more time for diagnostics. If either of these options was instigated the loop would become stable and self-maintaining.

6.2.3 Influence diagram outcome

The influence diagram could be taken as a snapshot or over a longer period. If assessed over 24 hours or for a particular fault then a snapshot is valid. If over a longer period, longer maintenance time could lead to more aircraft availability as aircraft should have fewer faults as better diagnostics could be conducted. However, changing the influence of one factor on the next will depend on the managers, engineers and aircrew behaviours and approaches to the situation. This is a limitation of influence diagrams. Moreover, they do not present the full picture as they only consider the influence of the preceding factor. Functional Resonance Analysis Method (FRAM) considers upstream and downstream coupling, how to dampen or influence the outcome, the internal and external potential outcome and indicates how these may be manifest (Hollnagel, 2012). The likely output variability is identified to enable some potential corrective action to be considered.

Taking the relationship from the influence diagram, Bowtie and FRAM diagrams were conducted.

6.3 Bowtie

A Bowtie is viewed as a tool for different purposes depending upon one's perspective. For some, it is a means to aid the identification and management of risk (CAA, 2015d). Others view them as a means to describe and analyse the route of risk from the causes of the event to the consequences (BSI, 2019). This analysis will initially use the Bowtie to represent the risks identified in the rich picture and the influence diagram and ways to mitigate the effect that could cause the hazard.

6.3.1 Bowtie analysis

For a threat to be valid, it should have the ability to cause the Top Event. Table 6-2 explains how the NFF and airworthiness Bowtie threats, the Hazard '*Operating an aircraft in the air or on the ground*' could cause the Top Event '*Engineering diagnostics resulted in NFF being recorded (Release of aircraft with FNF)*' (Figure 6-5) to materialize. For completeness, Table 6-2 also indicates the source of the Bowtie input (literature review, interviews or questionnaire). The focus of the analysis has been on the Threats and not the 'Consequences' if the Top Event happened. However, eight Consequences are shown. Appendix C provides details for the origin of the Threats and the Consequences presented in Figure 6-5.

As the term NFF implies the fault **is not there—**it cannot be found, it is recommended that NFF should be replaced with *Fault Not Found* (FNF). This small change in terminology has a much larger impact. It indicates the fault may still be there, it just was not found when diagnostics were conducted. This may cause aircrew to pay more attention to what engineering work was conducted and ensure they prepare for any eventuality if the fault reappears. It is still acknowledged that even with a NFF the aircrew accepts the fault may appear and wish to prepare for that event in controlled conditions rather than when under pressure in the flight. For those aircrews who understand and accept a NFF, the use of FNF instead may alert them to the fact that the fault may still be present and may reappear and it allows them to prepare for that event, which they may have not previously done.

Note that whilst the threats and barriers are drawn sequentially, they do not act sequentially but may act in parallel.

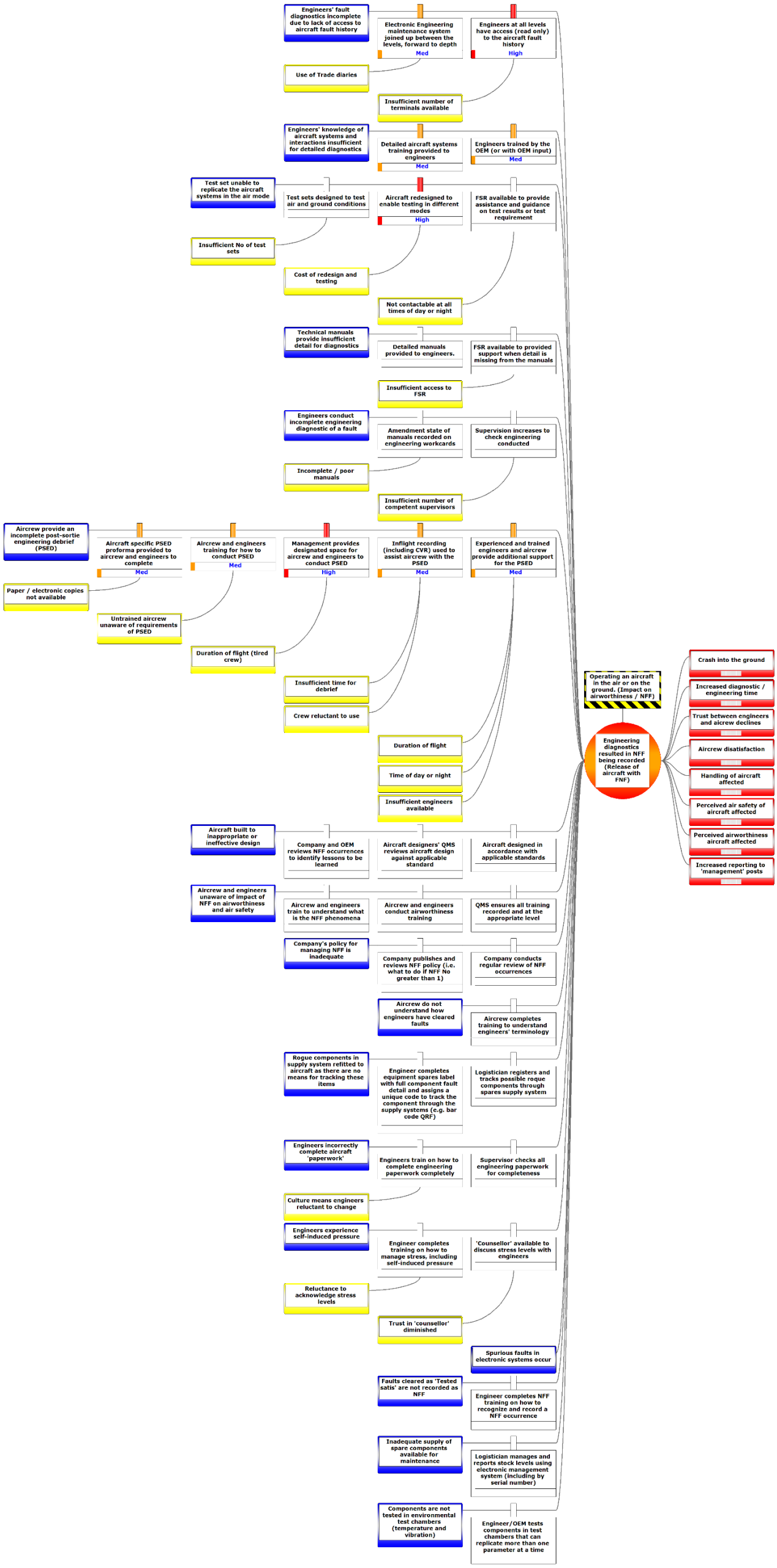


Figure 6-5: Bowtie of NFF and Airworthiness

Table 6-2: How the Threat would cause the Top Event to happen

Threat	How would it cause the Top Event to happen?	Source
Engineers' fault diagnostics incomplete due to lack of access to aircraft fault history	Engineers repeat maintenance previously conducted as they do not know what has been conducted, the frequency, when, what was tested and which components were changed. This could be unnecessary repeat maintenance.	Literature Review AAIB Interviews
Engineers' knowledge of aircraft systems and interactions insufficient for detailed diagnostics	Not knowing how the systems interact, even across a data bus, there will be unavoidable ignorance that may result in ineffective maintenance or testing taking place that results in a NFF being recorded, or components changed on spec that do not resolve the problem but appear to show that the engineers have done some work.	Interviews Questionnaire
Test set unable to replicate the aircraft systems in the air mode	A full test of the system is not possible as the flight conditions cannot be replicated on the ground. The fault is cleared with terminology such as ‘re-test ok’, which is effectively a NFF.	Literature review Interviews Questionnaire
Technical manuals provide insufficient detail for diagnostics	The technical manuals are incomplete or state to repeat the same process numerous times (up to three) until a positive result is recorded. Without fully detailed up-to-date manuals engineers are unable to complete full diagnostics of the system.	Literature review
Engineers conduct incomplete engineering diagnostic of a fault	Without complete manuals or knowledge, experience and competence the engineers are unable to do full diagnostics of a fault. This may also be due to engineering attitude, culture, or external or internal pressures.	Interview Questionnaires
Aircrew provide an incomplete PSED	Full fault details, flight conditions, and configuration are not passed onto the engineers or recorded in the aircraft logbook. Engineers attempt the diagnostics with incomplete fault information.	Literature review

Aircraft built to inappropriate or ineffective design	Systems are designed with *unknown* dormant (intermittent) faults. This implies the design has not been tested fully for all configurations and flight conditions. This is more likely for electronic and software systems than mechanical systems. The system design is not fully appreciated, which results in the production of incomplete technical manuals and ineffective test sets.	Literature review
Aircrew and engineers unaware of the impact of NFF on airworthiness and air safety	Limited knowledge of NFF and its link to airworthiness and air safety means a culture exists of accepting NFF and conducting limited diagnostics to clear the fault. This is also impacted by limited resources and ineffective test sets being available	Literature review? Questionnaire?
Company's policy for managing NFF is inadequate	NFF is not monitored either within or outside an organization. This has been allowed to permeate without consideration of the impact on capability, cost, and morale. Serial numbered components repetitively removed for testing are returned and refitted without query.	Literature review (Hockley, Lacey and Pelham, 2016)
Aircrew do not understand how engineers have cleared faults	Engineers' terminology, e.g., 'cleared IAW AMM 123' means the aircrew does not know what work was carried out and this affects their confidence in the aircraft and engineers. Without understanding how a fault has been cleared they are unable to know what to monitor or report when the fault reoccurs. Also, they cannot prepare for a repeat occurrence.	Questionnaire (Hockley, Lacey and Pelham, 2016, Q42, Q46 and Q48)
Rogue components in supply system refitted to aircraft as there are no means for tracking these items	The supply chain does not track all components by serial number. Components tested at depth maintenance (e.g., OEM) are returned to stock holdings when the test results in a NFF. Some items are fitted repeatedly and then removed due to a fault but when retested result in a NFF. Tracking (against specific aircraft) and removal of these items from stock will reduce unnecessary	Literature review

	repeat maintenance and testing and the number of NFF occurrences.	
Engineers incorrectly complete aircraft 'paperwork'	Incomplete paperwork that fails to detail all the maintenance work means a review and analysis of the aircraft's faults, or a specific fault, cannot be undertaken with any confidence. The full work completed needs to be detailed otherwise repeated NFFs cannot be found.	Literature review (Hockley, Lacey and Pelham, 2016)
Engineers experience self-induced pressure	Engineers' pressure (self-induced or otherwise) means they only do the fault diagnostics sufficient to make the aircraft serviceable. The intermittent fault may still be there. Thus, the engineers may record it as NFF after only limited diagnostics.	Literature review (Hockley, Lacey and Pelham, 2016)
Spurious faults on electronic systems occur	Spurious (intermittent) faults can be a result of dormant faults from design or an aircraft condition that may not be reproducible on the ground, or a test bench. When the component is tested, the result is NFF or similar working being recorded.	Literature review (Hockley, Lacey and Pelham, 2016)
Faults cleared as 'Tested satis' are not recorded as NFF	Companies need to accept that terms such as 'tested satis', 'cause not found' and 'no defect apparent' are all terms that mean the fault has not been found, so a NFF. Acceptance and understanding of these terms will highlight the true extent of NFF and, once ascertained, full analysis of the fault and system will permit a review of resources to be undertaken, or full diagnostics of the system to find the fault or a redesign of the system to eliminate the fault.	Literature review (Hockley, Lacey and Pelham, 2016)
Inadequate supply of spare components available for maintenance	Limited stock supplies mean LRUs are changed based on whether they are in stock. If a test set indicates one of three LRUs is the probable cause of the fault the easiest LRU to change is replaced or the one that is in stock. Better stock supplies would reduce the incorrect LRU being replaced. The LRU removed may be bench-tested and declared NFF. The fault may still be on the aircraft but in a	Literature review Questionnaire

	different LRU or the wiring and cables.	
Components are not tested in environmental test chambers (temperature and vibration)	Engineers at forward and depth maintenance are unable to reproduce flight conditions (pressure, temperature, humidity etc.) on the ground. This results in tested components being declared as a NFFs. The test sets able to test in more than one parameter need to be designed and produced. This relates to the overall aircraft design and knowing how all the systems interact and operate under all conditions.	Literature review Questionnaire

The 'prevention control' barriers to remove the threat or prevent the threat from developing into the Top Event events are shown in Figure 6-5.

6.3.2 Bowtie outcome

The Bowtie analysis has shown how the threats can lead to the Top Event occurring and the barriers to prevent it from happening, namely *Engineering diagnostics resulted in NFF being recorded (Release of aircraft with FNF)*. The acknowledgement of the threats and the implementation of the barriers provide a means to prevent the Hazard from occurring. These will contribute to reducing the risks a NFF will have on the aircraft's airworthiness and reduce the risk to the aircrew. This links with the aircrew's perception that NFF does contribute to airworthiness and does put their safety at risk. The Bowtie is a means to communicate risk to the users, namely the engineers, aircrew, logisticians and organizational management. However, it is like any tool, it is only of use if it is used, reviewed and updated. It should be considered a *Live* document. It needs the acknowledgement of the stakeholders involved and its limitations.

The benefit of a Bowtie is that the barriers whilst depicted sequentially will act in parallel. However, the Bowtie analysis will not cater for faults occurring without clearly recognized causes unlike FRAM (Hollnagel, 2012). Therefore, FRAM was implemented to consider any upstream function variability on a downstream function variability and any function's internal and external variability, such as 'to explain the engineer's terminology' to the aircrew.

A review of the original Bowtie (Figure 6-5) was conducted after the FRAM analysis to highlight those risks (threats) and barriers deemed to carry the most weight (criticality) and require focused attention (Section 6.4.2).

6.4 FRAM Analysis

The use of FRAM was explained in Section 3.10.4. The advantages of FRAM are that it focuses on normal daily activities, does not require an obvious cause to be stated and accepts that outcomes will not necessarily be triggered by linear events (Hollnagel, 2012). It was for these reasons it was selected to further analyse the relationship between NFF and airworthiness. Additionally, FRAM can be used to analyse *work-as-done* and also *work-as-imagined* (Hollnagel, 2012), so thereby making it suitable for combining current and future activity (the breakdown of processes). The current activity (Functions in FRAM terminology) to be considered are those that exist in current aviation operations and maintenance activities. The future functions are those proposed as a result of this analysis. FRAM considers functional resonance (i.e., tending to reinforce or prolong) because the variability of a socio-technical system's performance will not be completely random, as it will be due to people and an organization's "approximate adjustments" that are evident daily (Hollnagel, 2012, p.29).

Full details of the five FRAM steps applied during this research are available in the FRAM book (Hollnagel, 2012, pp.136-138); a short explanation will be given for each step. The FRAM model presents the Function and the Aspects. Functions are not detailed tasks but the action to be performed. The FRAM model does not include arrows from one function to another, as in principle they can be placed anywhere. However, each function can be characterized by up to six Aspects (Table 6-3). For clarity within the narrative, the Aspects will be presented with a capital letter.

Table 6-3: Aspects of a FRAM Function Adapted from: Hollnagel (2012)

Letter	Aspect	Description of Aspect
C	Control	“How the function is monitored or controlled”
O	Output	The result of the function – an entity or state change
P	Precondition	“The condition that must be met before the function can be carried out”
T	Time	A temporal constraint on the function. i.e., a start or end time or a duration
I	Input	That which starts the function or the function processes or transformations
R	Resource	That which is required for the function to be carried out.

6.4.1 FRAM implemented

The implementation of FRAM resulted in the instantiation of the FRAM model for the NFF and airworthiness case and the analysis of the sources of variability for the functions.

FRAM step 0 and 1 are to “determine the purpose and scope of the analysis” and then “identify and describe the functions” (Hollnagel, 2012, p.136). This includes allotting the Aspects. Step 0 is to determine the NFF and airworthiness relationship for an aviation company. It does not expand to consider the OEM or the design of the aircraft. An example of the outcome of Step 1, a Function with the associated Aspects, is shown for Function 1 – To conduct PSED– with the associated Aspects (Figure 6-6). Not all Aspects have to be completed (Hollnagel, 2012, p.60). The full FRAM model (Figure 6-10) shows all the Functions with the links to the associated Aspects detailed in Appendix D, D.2. The Functions and Aspects were created from the previous analysis and the author's experience.

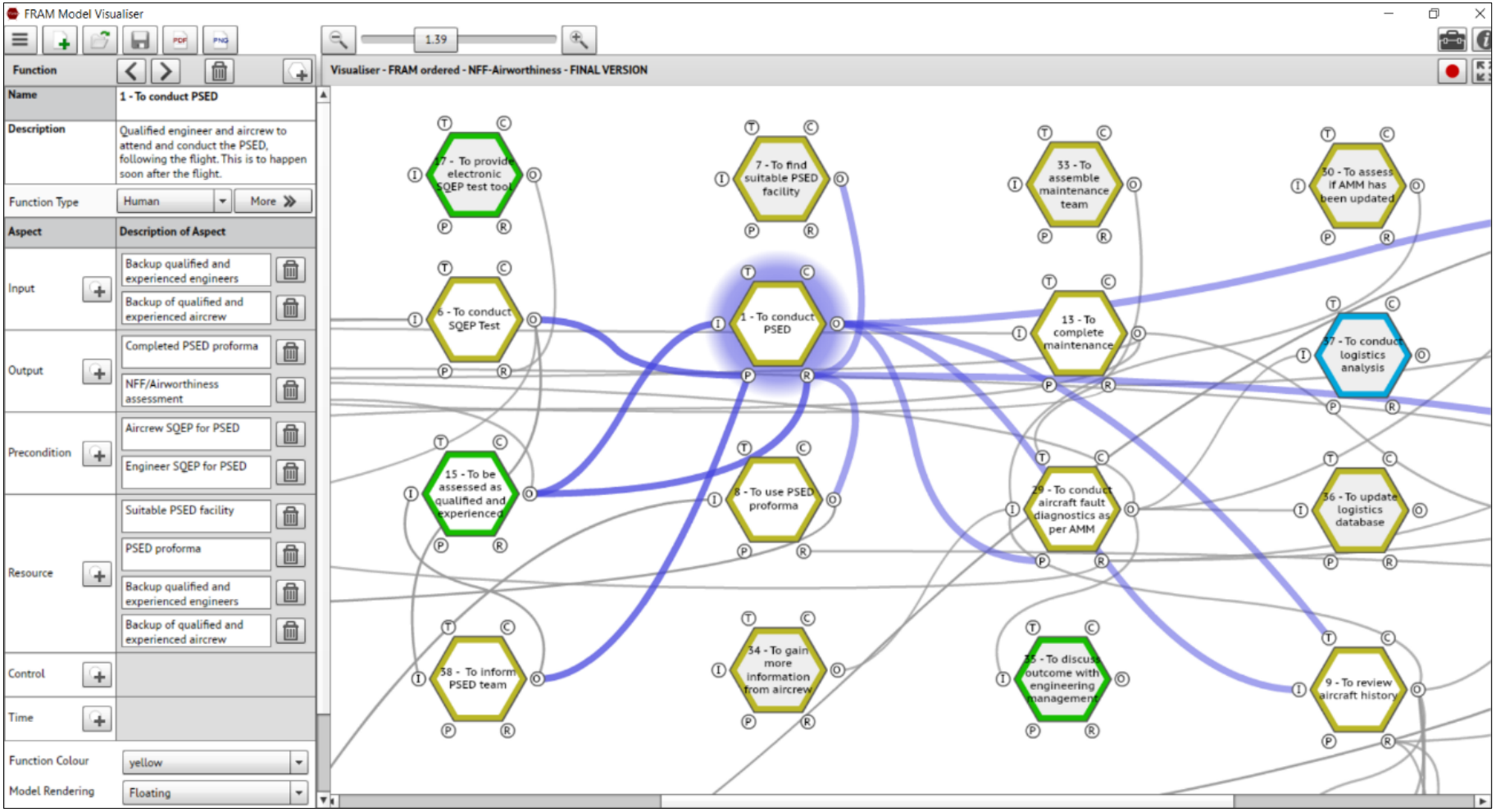


Figure 6-6: FRAM Model - Function 1 with Aspects

FRAM step 2 is to “describe the potential and actual performance variability” of the functions possible for everyday norms and extreme variations (Hollnagel, 2012, p.137). There are three possible reasons for the variability:

- Internal function (endogenous) variability of the output, as a result of the nature of the function.
- External function (exogenous) variability of the output, as a consequence of the environment.
- Upstream/downstream coupling, is how the variability of an upstream Function influences the downstream function. (Hollnagel, 2012, p.64).

The type of Function variability was also selected from the options of Human, Technological or Organization, which are deemed the most widely used Function categories (Hollnagel, 2012, p.65) (Figure 6-7). Function 1 was assessed as a Human Function as this is a function performed by small groups of humans and is likely affected by their variability.

1	Step 1 - Identify and describe the Functions		Step 2 - Identification of Output Variability		
			Type of Function	Internal Variability	External Variability
	Name of function	To conduct PSED	Human		
	Description	Qualified engineer and aircrew to attend and conduct the PSED, following the flight. This is to happen soon after the flight.	Carried out by engineers and aircrew - individually or in small groups. Those involved with relevant PSED.	Relatively high degree of potential variability for human factors reasons: fatigue, circadian rhythm, attention, boredom, working conditions, morale.	Variation due to: Social/cultural factors such as normalised behaviours. Group pressure. Environmental Factors where PSED being conducted - lighting, climate, facility. Organizational Factors - Availability of qualified personnel required. Operational pressure may cause delay or limitation of information imparted.
	Aspect	Description of Aspect			
	Input	Backup qualified and experienced engineers			
		Backup of qualified and experienced aircrew			
	Output	Completed PSED proforma			
		NFF/Airworthiness assessment			
	Precondition	Aircrew SQEP for PSED			
		Engineer SQEP for PSED			
	Resource	Suitable PSED facility			
		PSED proforma			
		Backup qualified and experienced engineers			
		Backup of qualified and experienced aircrew			
	Control	*Not described initially*			
	Time	*Not described initially*			

Figure 6-7: FRAM Model Step 2 - Function 1 with function type and description of possible internal and external variability

The first part of Step 2 is to consider the internal variability, that is how the function may vary due to the internal workings of the function type (Hollnagel, 2012, p.67). This could be due to human physiological or psychological reasons, not knowing

the inner workings of technology or poor communication within organizations. Function 1 was a human type and so the causes of variability are due to the engineers and aircrew and for Output Aspect ‘complete PSED proforma’ the most likely dimension was Sequence with an *omission* (Figure 6-8). Applying the FRAM guidance (Hollnagel, 2012, p.6), the frequency of Function 1 variability was assessed as *high* with the amplitude of the performance variability likely to be *large* (Hollnagel, 2012, p.68). One step of the function could be omitted and the potential performance indicator would be incorrect fault diagnostics or maintenance being conducted. Both of which would affect a NFF being recorded.

For the external variability, the ‘elaborate solution’ was performed using the failure modes or phenotypes categories to describe the variability of the Function outcome or output (Hollnagel, 2012, p.71). The external variability considers what external factors could cause variability of the Function output. The possible causes of external variability for Function 1 are shown in Figure 6-8. The possible Function failure modes were concerning speed, distance, sequence, object, force, duration, direction and timing (Hollnagel, 2012, p.72) but as these link closely to upstream/downstream coupling, they will be explained in Step 3.

Steps 3 and 4 are closely linked. Step 3 considers the “aggregation of [the] performance variability” (Hollnagel, 2012, p.137) when the upstream and downstream functions are coupled. As FRAM considers variability and resonance, it is acknowledged that the progression may not be linear. The route is not predefined as it is a socio-technical system subjected to human factors, organizational management and technical outputs. It further depends on each instantiation. This is to analyse how the variability of an upstream function can decrease (dampen), increase (resonance) or have a neutral influence on the downstream function. The coupling (Step 3) allows for everyday performance variability to be considered rather than focusing on failures and breakdowns. It considers emergent properties and outcomes and aims to provide damping measures to keep the system stable, to reduce resonance. Ways to mitigate any influence are proposed. The focus is on the variability and not the probability.

1	Step 1 - Identify and describe the Functions		Step 2 - Identification of Output Variability						Part 4 - Consequence of the Analysis
			Internal Variability	Outputs	Most Likely Dimension of Output Variability	Description of Most Likely Output Variability	Frequency of Output Performance Variability	Amplitude of Output Performance Variability	Potential Performance Indicators
	Name of function	To conduct PSED							
	Description	Qualified engineer and aircrew to attend and conduct the PSED, following the flight. This is to happen soon after the flight.	Relatively high degree of potential variability for human factors reasons: fatigue, circadian rhythm, attention, boredom, working conditions, morale.						
	Aspect	Description of Aspect							
	Input	Backup qualified and experienced engineers							
		Backup of qualified and experienced aircrew							
	Output	Completed PSED proforma		Completed PSED proforma	Sequence	Omission	High	Large	Incorrect fault diagnostics completed, resulting in incorrect maintenance outcome
		NFF/Airworthiness assessment		NFF/Airworthiness assessment	Timing/duration	Too early - output incomplete or inaccurate.	High	Large	1. Repeat NFF recorded as the seriousness of fault not recorded. 2. Quality manager of the supervisor spots the error and has to recall the aircrew.
	Precondition	Aircrew SQEP for PSED							
		Engineer SQEP for PSED							
	Resource	Suitable PSED facility							
		PSED proforma							
		Backup qualified and experienced engineers							
		Backup of qualified and experienced aircrew							
	Control	*Not described initially*							
	Time	*Not described initially*							

Figure 6-8: FRAM Model Step 2 - Function 1 and internal variability analysis

Step 4 is to monitor the performance outcome and any dampening of the proposed indicators being monitored. Dampening is an intervention in the process for the organization's management to make developments to improve the system promptly. The consequence of the upstream variability on the downstream variability is assessed as causing an increase, decrease or no change.

Steps 3 and 4 are not analysing a specific event but adopting an analytical approach—they consider how the *potential* variability of each function could become an actual variability. For this research, this could be lessons learned from the literature review. Figure 6-9 shows the potential FRAM upstream/ downstream coupling aggregation of variability for the combined frequency and amplitude of the upstream variability with the damping factor (Steps 3 and 4). Scoring determined the effect of the upstream/downstream coupling on the downstream output variability (Table 6-4, Table 6-5 and Equation (6-1)). The scoring was as follows (Tomczynski, 2014):

Table 6-4: FRAM upstream/downstream coupling rough scoring matrix

	Description and scores	High	Medium	Low
A	Frequency of Upstream Output Performance Variability	3	2	1
		Large	Medium	Low
B	Amplitude of Upstream Output Performance Variability	3	2	1
		Increase	No change	Decrease
C	Possible effect on this (downstream) Function Output Variability	3	2	1

The upstream/downstream Rough score was calculated as follows:

$$Rough\ Score = A\ x\ B\ x\ C \qquad \textbf{(6-1)}$$

Table 6-5: Rough scoring potential effect on downstream variability

Potential upstream output is likely to have -		
Minimal effect on downstream functional variability	A medium effect on downstream functional variability	A major effect on downstream functional variability
0-9	9<>18	18<>27

on downstream function output

The accuracy of any model, including the FRAM model, is dependent on the creator and is prone to biases being introduced. To reduce any of the researcher's bias the FRAM model and analysis (Appendix D, D.1) were reviewed by four SMEs with knowledge of current aviation systems (See Section 3.9.4 and Appendix D, D.3 - Task 1). Their analysis and proposed corrections were considered and implemented as necessary. This SMEs' review provide reliability such that the analysis would yield consistent findings, transparency and support the claim that similar findings would be made (Saunders, Lewis and Thornhill, 2016). Therefore, the FRAM model-final solution (Figure 6-10) is a *Live* document and should be used, reviewed and updated as improvements are made to the system. There were six major and 25 medium potential effects of the upstream/downstream coupling (Table 6-6).

Table 6-6: Potential FRAM upstream/downstream coupling aggregation of variability

The Rough score of 27 - Potential upstream output is likely to have - A major effect on downstream functional variability		
Upstream number and function	Downstream number and function	Coupled Aspect
6 - To conduct Suitably Qualified and Experienced Person (SQEP) Test	1 - To conduct PSED	Aircrew SQEP for PSED
6 - To conduct SQEP Test	1 - To conduct PSED	Engineer SQEP for PSED
7 - To find suitable PSED facility	1 - To conduct PSED	Suitable PSED facility
9 - To review aircraft history	1 - To conduct PSED	Completed PSED proforma
10 - To analyse NFF assessment	9 - To review aircraft history	NFF fault assessment
11 - To analyse intermittent fault assessment	9 - To review aircraft history	Intermittent fault assessment
The Rough score of 18 - Potential upstream output is likely to have - A major effect on downstream functional variability		

Upstream number and function	Downstream number and function	Coupled Aspect
13 - To complete maintenance	3 - To understand engineering terminology	Closed engineering workcard
4 - To explain engineer's terminology	3 - To understand engineering terminology	Inexperienced aircrew
8 - The aircrew and engineers are to be trained in how to use the PSED proforma	5 - To book training	Engineers requiring refresher training
3 - To understand engineering terminology	5 - To book training	Aircrew requiring training
6 - To conduct SQEP Test	5 - To book training	Engineers requiring training
4 - To explain engineer's terminology	5 - To book training	Aircrew requiring refresher training
8 - To use PSED proforma	5 - To book training	Aircrew requiring refresher training
14 - To fly the aircraft	6 - To conduct SQEP Test	Aircrew requiring Q&E test
3 - To understand engineering terminology	12 - To read aircraft logbook	Aircrew content with engineering terminology
3 - To understand engineering terminology	14 - To fly the aircraft	Aircrew content with engineering terminology
12 - To read aircraft logbook	14 - To fly the aircraft	Signed aircraft logbook
4 - To explain engineer's terminology	14 - To fly the aircraft	More knowledgeable aircrew
12 - To read aircraft logbook	14 - To fly the aircraft	Read aircraft logbook
13 - To complete maintenance	16 - To provide electronic searchable aircraft maintenance database	Updated electronic aircraft logbook
10 - To analyse NFF assessment	23 - To be a functioning NFF/Airworthiness group	Report for NFF/Airworthiness working group
1 - To conduct PSED	23 - To be a functioning NFF/Airworthiness group	NFF/Airworthiness assessment
9 - To review aircraft history	23 - To be a functioning NFF/Airworthiness group	NFF fault assessment

9 - To review aircraft history	24 - To assess if fault is intermittent	History of fault description/equipment serial number
9 - To review aircraft history	25 - To assess if fault occurred before	History of fault description/equipment serial number
34 - To gain more information from aircrew	29 - To conduct aircraft fault diagnostics as per AMM	Improved PSED information
9 - To review aircraft history	29 - To conduct aircraft fault diagnostics as per AMM	History of fault description/equipment serial No
30 - To assess if AMM has been updated	29 - To conduct aircraft fault diagnostics as per AMM	AMM amendment state
1 - To conduct PSED	29 - To conduct aircraft fault diagnostics as per AMM	Completed PSED proforma
6 - To conduct SQEP Test	38 - To update logistics database	Engineer SQEP for PSED
6 - To conduct SQEP Test	38 - To update logistics database	Aircrew SQEP for PSED

1	Step 1 - Identify and	Step 3 - Aggregation of Variability																				Part 4 - Consequence of the Analysis
		Upstream Function			Most Likely Form of Upstream Variability	Description of Most Likely Upstream Variability	Frequency of Upstream Performance Variability	Amplitude of Upstream Performance Variability	Possible effect on this (downstream) Function	Possible effect on this (downstream) Function Output Variability [increase, decrease, remain unchanged]	Frequency			Amplitude			Total	Damping			Rough Downstream Function Variability Score	Potential Damping Factors to counter upstream-downstream coupling
	Name of function	No	Name	Aspect							H	M	L	H	M	L	T	I	N	D		
	Description																					
	Aspect																					
	Input	15	To be assessed as qualified and experienced	Backup qualified and experienced engineers	Wrong object	Incorrect assessment made	Low	Large	To be unable to conduct PSED until back-up engineers arrive or possible misinformation imparted during PSED.	Increase	0	0	1	3	0	0	3	3	0	0	9	Keep up-to-date records of suitable engineers to reduce probability of unsuitable person being allocated the task initially. Have back-up pre-empted.
		15	To be assessed as qualified and experienced	Backup of qualified and experienced aircrew	Wrong object	Incorrect assessment made	Low	Large	To be unable to conduct PSED until backup aircrew arrive or possible misinformation imparted during PSED.	Increase	0	0	1	3	0	0	3	3	0	0	9	Keep up-to-date records of suitable aircrew to reduce probability of unsuitable aircrew being mis-assessed. Have back up pre-empted.
	Output																					
	Precondition	6	To conduct SQEP Test	Aircrew SQEP for PSED	Wrong object	Wrong assessment outcome from test	High	Large	If aircrew are not SQEP the PSED may be delayed until the arrival of back-up aircrew. This will reduce the maintenance time available	Increase	3	0	0	3	0	0	9	3	0	0	27	Keep up-to-date records of suitable aircrew to reduce probability of SQEP test error going undetected. Conduct periodic test of SQP Test system.
		6	To conduct SQEP Test	Engineer SQEP for PSED	Wrong object	Wrong assessment outcome from test	High	Large	If engineers are not SQEP the PSED may be delayed until the arrival of back-up engineers. This will reduce the maintenance time available	Increase	3	0	0	3	0	0	9	3	0	0	27	Keep up-to-date records of suitable engineers to reduce probability of SQEP test error going undetected. Conduct periodic test of SQP Test system.
	Resource	7	To find suitable PSED facility	Suitable PSED facility	Wrong object	Unsuitable facility used/proposed	High	Large	If a suitable facility is not found for the PSED the debrief may be cut short, misinformation provided, or misheard. May result sin doing the wrong maintenance or having to call aircrew back to obtain more information.	Increase	3	0	0	3	0	0	9	3	0	0	27	Pre-book room for debrief or have suitable rooms allocated for debriefs.
		22	To provide PSED proforma	PSED proforma	Timing/duration	Too late - provided too late for PSED being conducted	Low	Large	If a PSED proforma is not provided the PSED will be delayed starting. This may impact the time available for maintenance to be conducted.	Increase	0	0	1	3	0	0	3	3	0	0	9	1. Ensure PSED is allocated to engineer ground crew at start of see-in crew allocation. 2. Have PSED stored in suitable PSED facility.
		15	To be assessed as qualified and experienced	Backup qualified and experienced engineers	Wrong object	Incorrect assessment made	Low	Large	To be unable to conduct PSED until back-up engineers arrive or possible misinformation imparted during PSED.	Increase	0	0	1	3	0	0	3	3	0	0	9	Keep up-to-date records of suitable engineers to reduce probability of unsuitable person being allocated the task initially. Have back-up pre-empted.
		15	To be assessed as qualified and experienced	Backup of qualified and experienced aircrew	Wrong object	Incorrect assessment made	Low	Large	To be unable to conduct PSED until backup aircrew arrive or possible misinformation imparted during PSED.	Increase	0	0	1	3	0	0	3	3	0	0	9	Keep up-to-date records of suitable aircrew to reduce probability of unsuitable aircrew being mis-assessed. Have back up pre-empted.
	Control																					
	Time																					

Figure 6-9: FRAM Steps 3 and 4 - Upstream/downstream coupling for Function 1

6.4.2 FRAM and Bowtie alignment

The Bowtie was updated with the resonance identified in the FRAM model and analysis. This aids the identification of the barriers which could have the greatest impact on reducing the Top Event from occurring—*Engineering diagnostics resulted in NFF being recorded (Release of aircraft with FNF)*—if implemented. Those that scored 27 in the FRAM analysis were updated as high criticality and those identified as 18 were identified as medium criticality (Table 6-6). All other criticalities were removed from the BowTie (Figure 6-11). In line with CAA recommendation (CAA, 2022) the threats and barriers were reordered to show those with the potential to have a major-to-medium impact on a downstream Function output. The combined FRAM and Bowtie analysis identifies to the organization's management where attention should be focused. Targeting these couplings, and checking the damping factors have worked, will decrease the potential for the resonance to occur and reduce the likelihood of the Top Event. However, this is dependent on a management team and users applying this analysis to the task of reducing the impact of NFF on airworthiness. To aid this flow charts were created to identify key processes, documents and reviews to be undertaken.

The influence diagram (Figure 6-2) indicated the effect of pressure on the engineers, the time to complete the diagnostics and maintenance, the time to complete the engineering paperwork and the requirement for the aircrew to understand the engineer's terminology. By applying a different analysis method, new aspects are raised as key areas on which to focus to reduce any impact on NFF being recorded and airworthiness. The different approach looking at more than just influence provides the Duty Holder and the organization with specific areas to consider, including the barriers in the BowTie analysis.

The combining of FRAM and Bowtie is original analysis. It was implemented to provide a focus for the organization's management teams.

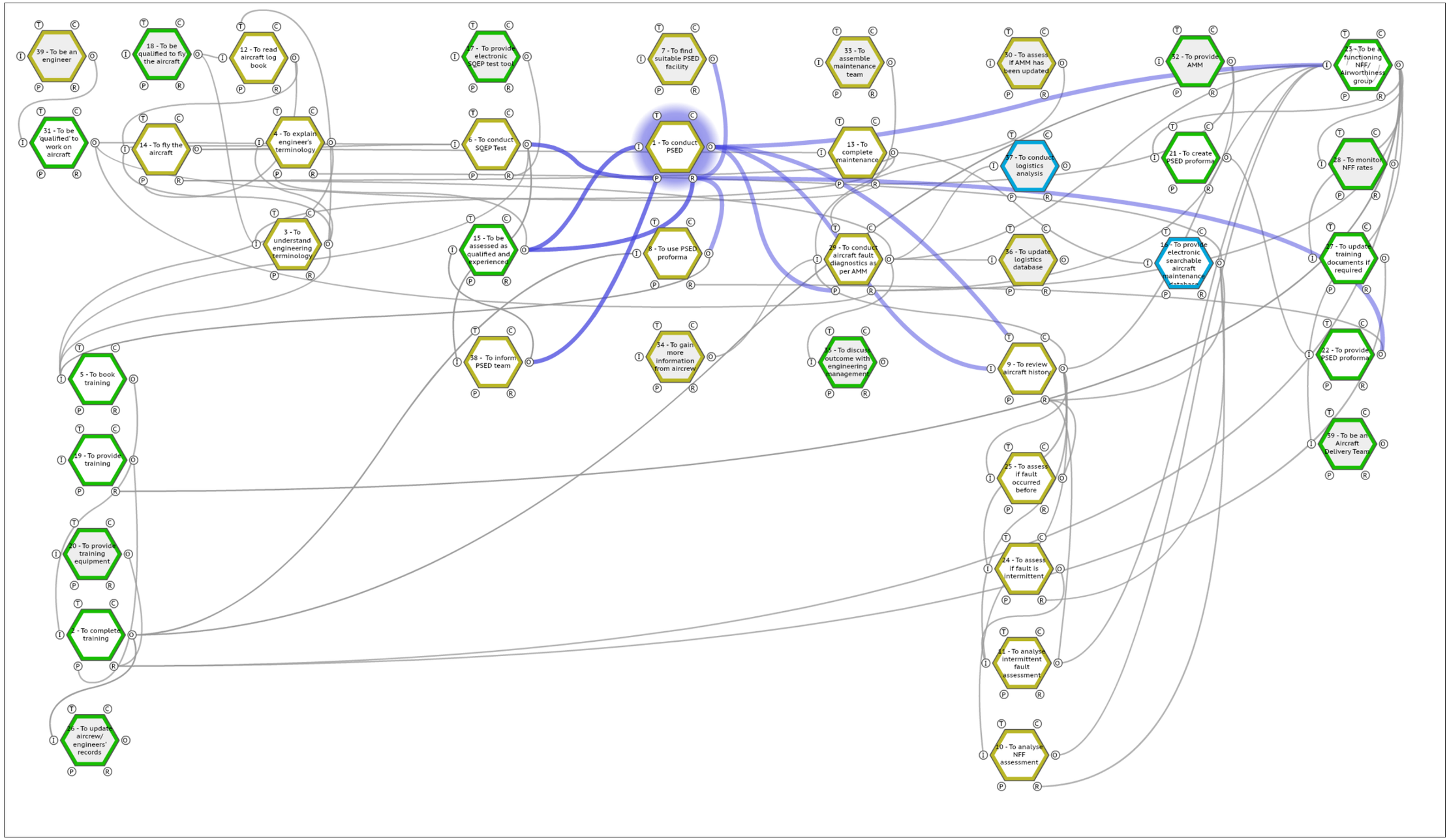


Figure 6-10: Full FRAM NFF and Airworthiness Model

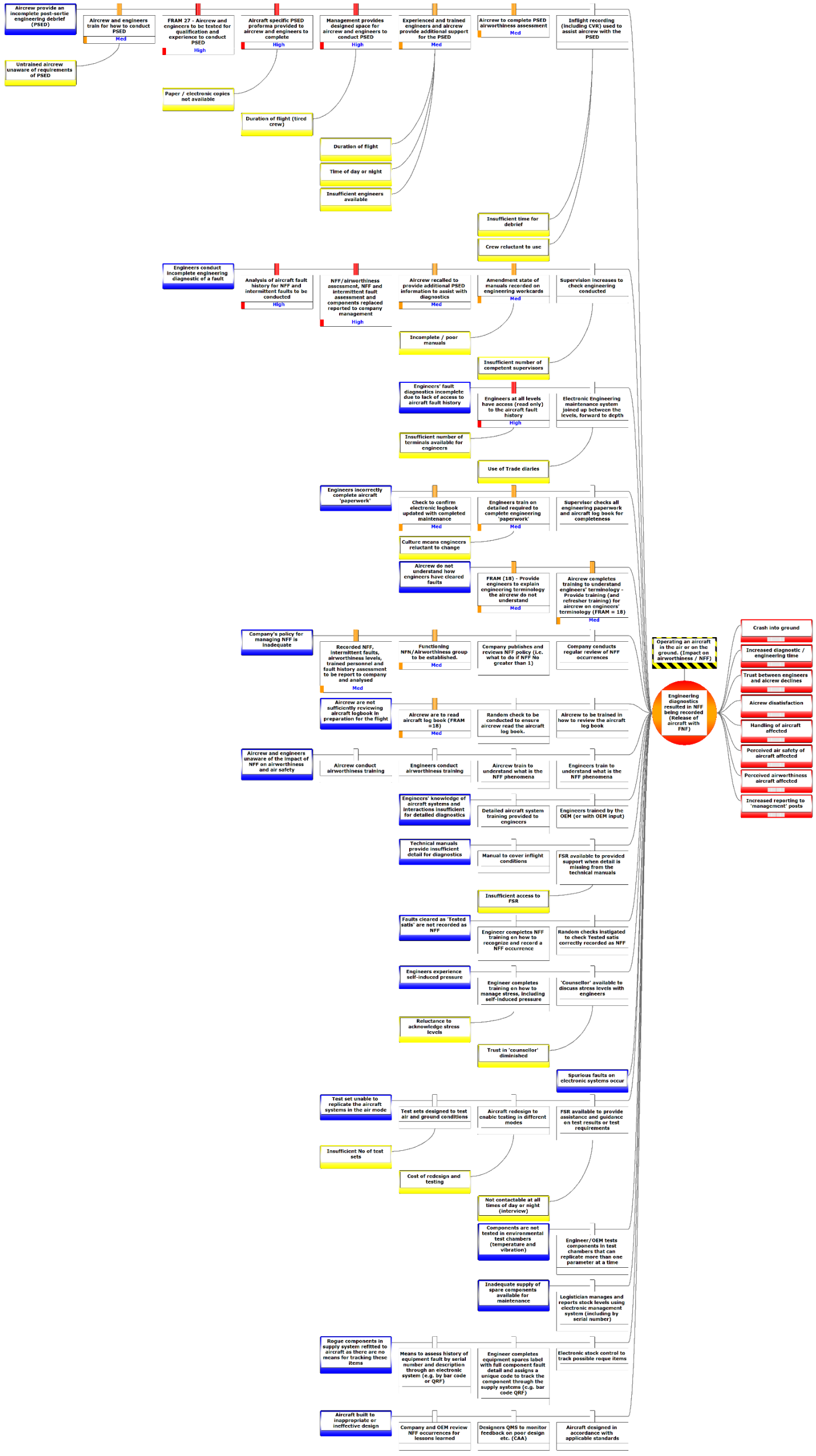


Figure 6-11: Revised NFF and airworthiness Bowtie post-FRAM analysis

6.4.3 External Validity of FRAM analysis

The FRAM analysis was based on the results and analysis of the literature review, the interviews, the questionnaire and the creation of the rich picture, influence diagram and Bowtie. Internal validity was assessed as being achieved (Section 3.9.4). However, as most of the questionnaire results were from male RAF aircrew (88%) any generalizable outcomes are more relevant to that context. Additionally, the SMEs used to review and verify the analysis were male RAF engineering officers (serving and retired). These SMEs did assess the FRAM model and analysis (Excel spreadsheet) but their knowledge of civil operations and other military forces operations was limited. These organizations probably adopt different procedures for the PSED and NFF reporting and analysis. The two civil pilots ' interviews (Appendix A, A.1 and A.4) provided some insight but this was insufficient to support generalized outcomes for aviation operators. Therefore, external validity is limited to the context of RAF operations and engineering practices and procedures unless further data is acquired via interviews or the questionnaire yields results from other aviation operators or maintenance organizations. Therefore, it "will be necessary to replicate the study in that other context, or contexts, to be able to establish such statistical generalisability" (Saunders, Lewis, and Thornhill, 2016, p.194). Further, external validity could be achieved by assessing the FRAM model against an aviation maintenance company to assess how closely it aligns with the processes and procedures in place. Moreover, the FRAM model and analysis could be applied to one section of the organization and then compared against another section of the organization. This would enable any benefit from the FRAM NFF and airworthiness analysis to be established, critiqued and assessed. This approach would provide evidence that the introduction of the FRAM model had a positive impact on the NFF rate, i.e., the number of occurrences was reduced, and airworthiness remained at a high level.

6.5 Fuzzy logic inference analysis

The use of fuzzy logic was explained in Section 3.10.5. The following will explain the advantages of using the Sugeno Fuzzy Logic approach, the analysis conducted, the findings and their implications for establishing a link between NFF and airworthiness (Research question 1 – Section 2.17.1). The aim was to combine aircrew and engineers' perceptions of an aircraft's airworthiness level to provide an assessment of the true value of the aircraft's airworthiness to aid management in deciding the appropriate action to be taken. In doing so, it supported the second research question of establishing the aircrews' perception of an engineering link between NFF and airworthiness (Section 2.17.1) and meeting Objective 4. The aircraft's airworthiness is assumed to include all aircraft's systems. The fuzzy logic analysis will link with the flow charts (Section 6.7). The analysis was conducted using the MATLAB Fuzzy Logic Toolbox.

6.5.1 Fuzzy logic inference explanation

"The fuzzy principle states that everything is a matter of degree", it blurs boundaries and moves from bivalence to multivalence (Kosko, 1994, p.18). The solution is not binary, one of two things [e.g., true or false, or zero or one] but three or more (Kosko, 1994, p.19). A fuzzy logic system is a way to encode experience-based knowledge in the form of logical rules and it infers a relationship between a vague thought or concept and a value (Douglas, 2021). For example, it provides a set of rules to classify the notion of small, medium or large based on numerous views. A fuzzy inference system is a form of artificial intelligence that uses human interpretable rules rather than more abstract mathematics (Douglas, 2021). An advantage of a fuzzy inference system is that no model is required and thus is suitable for complex systems "whose underlying mechanisms are not fully known" but "experience and intuition of the system" must be known to allow the rules to be developed (Douglas, 2021).

A plot with a "spike means the number belongs 100% to the set" (Kosko, 1994, p.124). This would be valid if everyone were identical or if a machine was making the selection. However, with the complexity of sociotechnical systems, such as

aviation with aircraft, aircrew and engineers, each human would view the world differently based on skill, experience, influences and bias and this *Weltanschauung* or worldview (Waring, 1996, p.7) will contribute to the multivalence outputs.

The following explains some key terms relevant to Fuzzy Logic Inference Systems.

Fuzzy Set - A *fuzzy set* is defined where the members belong to that set to some degree otherwise the member would be classified as a standard or nonfuzzy set (Kosko, 1994, p.292), e.g., all numbers defining *small* would be in the *small* fuzzy set.

Linguistic variables - A linguistic variable is a variable whose value is expressed as words or sentences rather than numbers in natural or artificial language and “serve as a means of approximate characterization of phenomena which are too complex or ill-defined to be susceptible of description in precise terms” (Zadeh, 1975, p.201). They are usually adjectives used to describe a fuzzy set. For example, *Height* is a linguistic variable and could have various linguistic values, such as *small, medium* or *tall*. Airworthiness (x, y and z) would be classified as a linguistic variable with linguistic values of negligible, minor, major and severe effect.

Membership functions - The Membership functions for each of the linguistic variables are described by the shape of the plotted curves that define how each input point is mapped to the membership function, i.e., its location beneath a curve. One method to garner the shape of the membership functions is to poll a sample of the relevant population. A specific input value could belong to more than one membership function depending on how it was viewed by the sample polled.

Fuzzification – The process of taking a value and assigning it to a linguistic variable based on the sample polled.

Defuzzification – The process of taking the output from the *Inference* process and turning a linguistic variable into a value.

Inference – This is the process of "using logical statements to infer what the output should be" (Douglas, 2021). It uses fuzzy logic operators that are akin to binary counterparts, AND, OR. A fuzzy AND becomes the minimum of two variable inputs, whereas a fuzzy OR becomes the maximum of the two variable inputs.

Sugeno Fuzzy Inference – The Takagi-Sugeno-Kang fuzzy inference applies fuzzification to the two inputs and applies a fuzzy operator. It always applies the "product implication method" (Mathworks, 2022) in doing so it does not calculate the centroid of an area, like Mamdani, but uses the crisps spike outputs to calculate the overall output using the following rule:

IF x is A and y is B THEN Z = f(x,y).

The output membership functions are either linear or constant with the typical rule applying Equation (3-1). (MathWorks, 2022):

Where for this analysis:

x = Aircrew's PSED airworthiness level selected

y = Engineers' aircraft airworthiness level.

z = Aircraft's overall airworthiness level = output level

The consequence of each rule is stipulated by a "fuzzy singleton" (a spike). For this analysis, Sugeno and the AND rule were used with the membership functions for the two inputs identified as F1(x), F2(y) (see Figure 3-4, Figure 3-5, and Equations (3-1) (3-2) and (3-3)).

By applying the weighted averages (Equation (3-3), the overall output using the Sugeno approach removes the defuzzification process used in the Mamdani approach (Hamarsheh, n.d.). This is an advantage of the Sugeno approach. As it uses weighted averages or weighted sums of only some data points (the spikes), it is computationally efficient compared with the Mamdani approach (MathWorks, 2022).

So, the first step is to ascertain the degree each input belongs to each of the fuzzy sets by the use of the membership functions (MathWorks, 2022). This is the fuzzification process.

6.5.2 Fuzzy logic inference implemented

The implementation of the Sugeno fuzzy logic was based on an assessment of the aircraft's airworthiness level by aircrew and engineers. Airworthiness was the linguistic variable.

Input x was based on whether the airworthiness level of the aircraft, from an aircrew perspective, had moved from one level to another. The four impact levels (linguistic values) were as follows:

- Level 1 – Negligible to none (N)
- Level 2 – Minor (Mi) effect
- Level 3 – Major (Ma) effect
- Level 4 – Severe (S) effect

These are detailed in Section 3.9.5 and Appendix E, E.1. On a range of zero to four, a sample of 100 aircrew from the population would state when they assessed the aircraft's as-flown-condition airworthiness level to cross a boundary. So Aircrew1 may state the boundary between Level 1 (Negligible) and Level 2 (Minor) was at 1.8. Whereas Aircrew2 could state 1.5. The results for the range for each level would be summed, normalized and used for input x. to form the membership function, i.e., the curve shape. As there was no access to the aircrew, a normal Gaussian distribution was used. (See Section 3.12 for the limitations of this approach). It is recommended to improve the fuzzy logic analysis a sample of 100 aircrew from the population is polled for views of what would be the boundary between the linguistic values, Negligible to Severe. However, this approach demonstrated the suitability of using fuzzy logic to assess the airworthiness of an aircraft.

Input y was based on the engineers' perception (See Task 2 Appendix E, E.1) There were 11 engineering SME submissions for Task 2. Their results were evaluated in Excel (Appendix E, E.2) and normalized. Again, this is another

limitation. To reinforce the analysis, it would be advantageous to repeat Task 2 to gain a sample of 100 engineers' views from the population. This would minimize the influence of any outliers.

Table 6-7: Task 2 Engineers' criteria for the levels of aircraft airworthiness

Level	Description
Negligible	The aircraft is fully airworthy or there is minimal change to the overall airworthiness level. There is a negligible hazard to the aircrew, ground crew and third parties.
Minor	The aircraft's overall airworthiness level has been affected. There is a minor hazard to the aircrew, ground crew and third parties. The situation is to be monitored.
Major	The aircraft's overall airworthiness level has been affected. There is a major hazard to the aircrew, ground crew and third parties. An investigation is required to assess the cause and impact.
Severe	The aircraft is unairworthy. There is a significant hazard to the aircrew, ground crew and third parties. The aircraft is completely unairworthy. A detailed investigation is required before the aircraft can fly.

To demonstrate the process, Figure 6-12, Figure 6-13, and Figure 6-14 show for One Month the membership function inputs x and y. The Designer view has two inputs, the Aircrew (x) and Engineers' (y) airworthiness assessments (yellow boxes), the Sugeno fuzzy logic inference based upon the rules (white box), with the overall aircraft airworthiness level (z) (blue box) (Figure 6-12). The Membership Function Editor (Figure 6-13) shows the four Gaussian membership function curves for the aircrew input of N, Mi, Ma, and S effect on airworthiness. From 0 to 1, the aircrew airworthiness level would be negligible to none, with a straight line from 0 to 1 before following a Gaussian curve down to 2. The Minor and Major inputs peak at 2 and 3 respectively and follow a Gaussian curve. The Severe input peaks at 4 but starts from 3, indicating that all aircrew would not access the aircraft airworthiness level to be severe just at point 4. It would be 'vague' and follow the Gaussian curve.

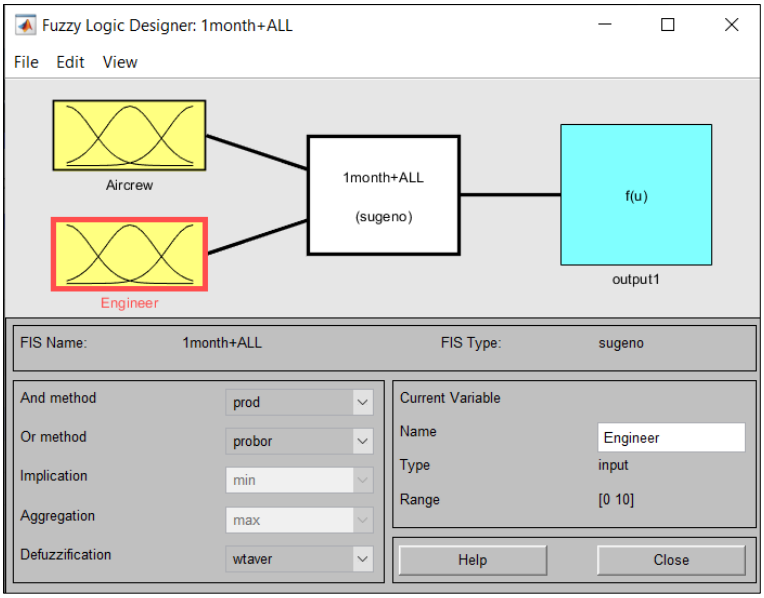


Figure 6-12: One month fuzzy logic designer

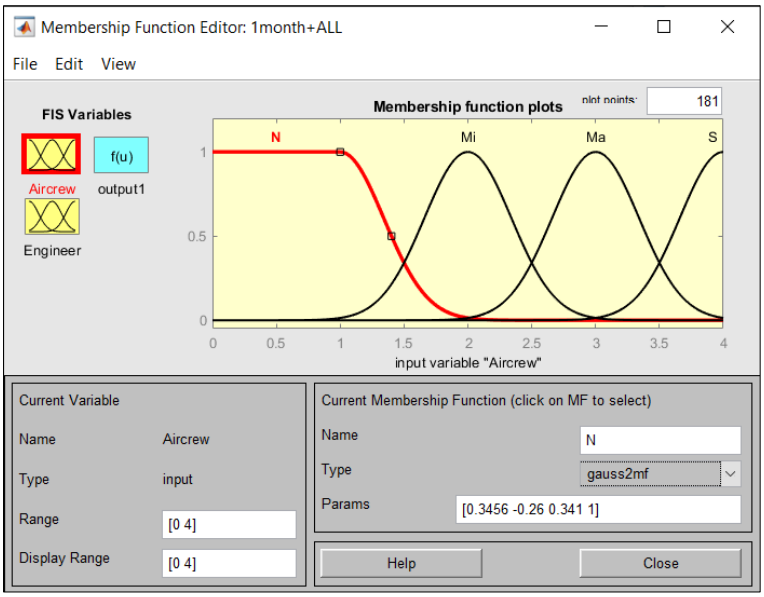


Figure 6-13: One month X input - aircrew airworthiness level assessment

There were four engineer membership function curves (N, Mi, Ma and S) for each Aircrew airworthiness assessments levels (N, Mi, Ma and S) (Figure 6-14). So, each input y had 16 membership functions (4 aircrew levels x 4 engineering levels). Where a membership function did not align precisely to a triangle, trapezoid or Gaussian line available in the fuzzy logic toolbox, a best-fit approach was implemented (Appendix E, E.2). For some inputs, one best-fit line was not acceptable, so the membership function was split into two, for example instead

of one Gaussian line, a triangle and a trapezoid were used. This equates to 17 or 18 membership functions being evident in the rules (Appendix E, E.4).

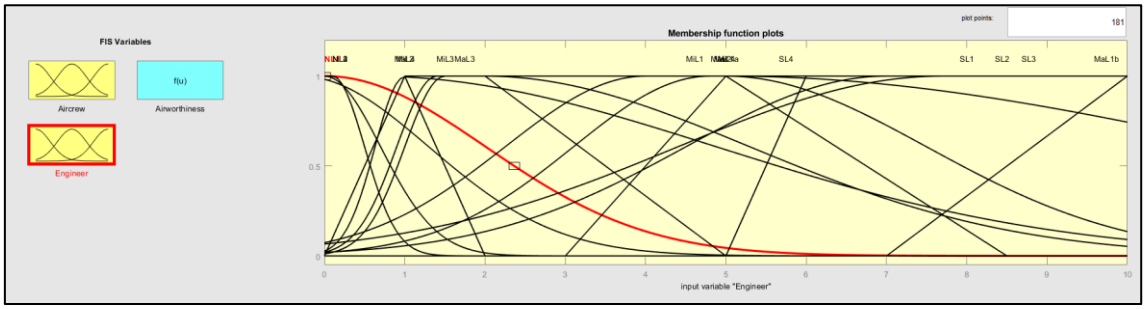


Figure 6-14: One month Y input - engineers' airworthiness assessment

The two airworthiness risk matrices (Table 6-8 and Table 6-9) were based on the addition and then the multiplication of the aircrew and engineering levels respectively. This was to demonstrate the impact of the applied matrix on the airworthiness output (z). severely

Table 6-8: Airworthiness risk matrix 1 - by addition

		Engineer			
		Negligible	Minor	Major	Severely
Aircrew		1	2	3	4
Negligible	1	2	3	4	5
Minor	2	3	4	5	6
Major	3	4	5	6	7
Severely	4	5	6	7	8

Table 6-9: Airworthiness risk matrix 2 - by multiplication

		Engineer			
		Negligible	Minor	Major	Severely
Aircrew		1	2	3	4
Negligible	1	1	2	3	4
Minor	2	2	4	6	8
Major	3	3	6	9	12
Severely	4	4	8	12	16

Figure 6-15, Figure 6-16 and Figure 6-17 show the rule editor, the rules viewer and the resulting surface plot for One month applying the rules from Risk Matrix 1 (Table 6-8). The rules are of the type If-Then (Figure 6-15). So as an example:

If (Aircrew is Mi) AND (Engineer is SL2) THEN (Airworthiness is Serious Review)

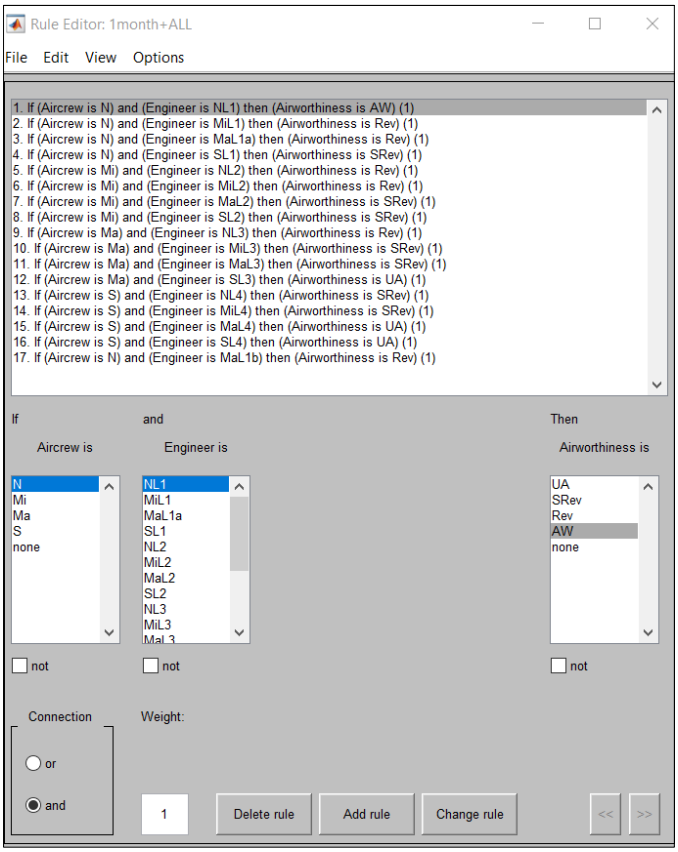


Figure 6-15: Rule editor for 1 month – risk matrix 1 applied

Figure 6-16 visually shows the curves for the aircrew and engineering membership functions. Setting the inputs for aircrew level 2 (Mi) and engineering input 5, resulted in an output airworthiness level of 4.22 out of a range of 10 (airworthy) to 0 unairworthy (Figure 6-17). The degree to which the different rules that meet the input criteria (Rules 6, 7 and 8) are shown as dark blue spikes in the Airworthiness results area, with red line being the overall aircraft Airworthiness result (Figure 6-16), calculated from the weighted averages (Equation (3-3)).

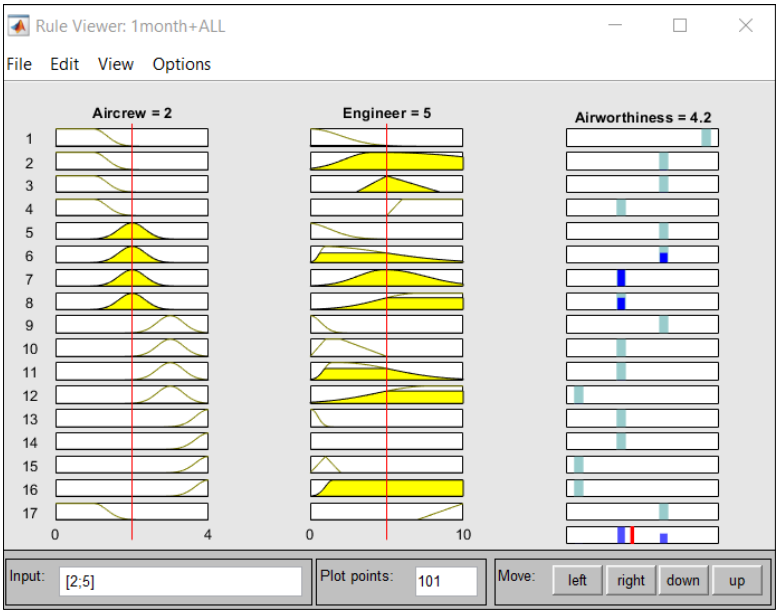


Figure 6-16: Rule viewer - 1 month, risk matrix 1, for aircrew level 2 and engineering level 5 inputs

The surface plot for the combined rules applied for the One-month membership functions, adhering to risk matrix 1, reveals the non-linear outcome (Figure 6-17). This is expected as the fuzzy logic smoothly flows from the dominance of one rule to another, and this prevents sharp creases (MathWorks, 2022). The axis for the Aircrew's PSED assessment represents the aircrew input membership functions, from 0 to 4 and these align with the aircrews' airworthiness assessment of the aircraft following the flight. The descriptions are based on negligible to severe impact, with the latter focused on surviving the flight (Task 2). This would reflect the aircrews' selection for when they assessed the aircraft's as-flown-condition airworthiness level to cross a boundary from one level to another; this would not be linear but varied based upon the differing views. The engineers' assessment axis is the engineers' membership function input, from 0 to 10 and this is related to how many aircrew PSED airworthiness assessments would be required before the engineers perceived that the aircraft's airworthiness level moved from one boundary to another within the range of negligible to severe. This outcome is based on the 11 engineering SME's submissions for Task 2 (Appendix E, E.1). The Airworthiness axis is the output from the fuzzy logic inference based upon the rules (Figure 6-15). The output ranges from 0, unairworthy, to 10, airworthy, with boundaries and the likely system/technical

outcome applicable for each level (Table 6-11). Point A is where Aircrews' PSED assessment of 2 and Engineers' assessment of 5 meet, with the overall airworthiness level being 4.2 (Table 6-10). This is categorized as Major and would warrant an investigation to assess the cause, impact and remedial action. The aircraft has experienced technical NFF or recurring NFF that has not been resolved and, thus, the NFF issue has a major effect on the aircrew operation of the aircraft.

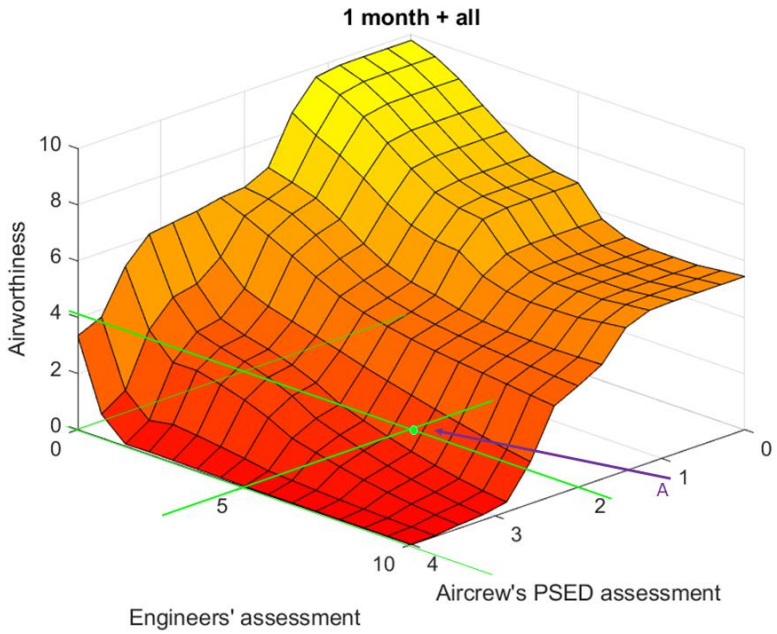


Figure 6-17: 1 month surface plot for risk matrix 1

Figure 6-18 and Figure 6-19 show the surface plots for all four periods for risk matrices 1 and 2 respectively. The effect of the different risk matrices is evident when comparing the surface plots. Risk matrix 2 plots have a plateau at an aircrew input of 0 to approximately 2.5 and an engineers' airworthiness level 0 to 1. Also, Risk matrix 2 plots have a more stepped fuzzy logic inference airworthiness output, evident for all aircrew inputs and an associated engineers' input level 10.

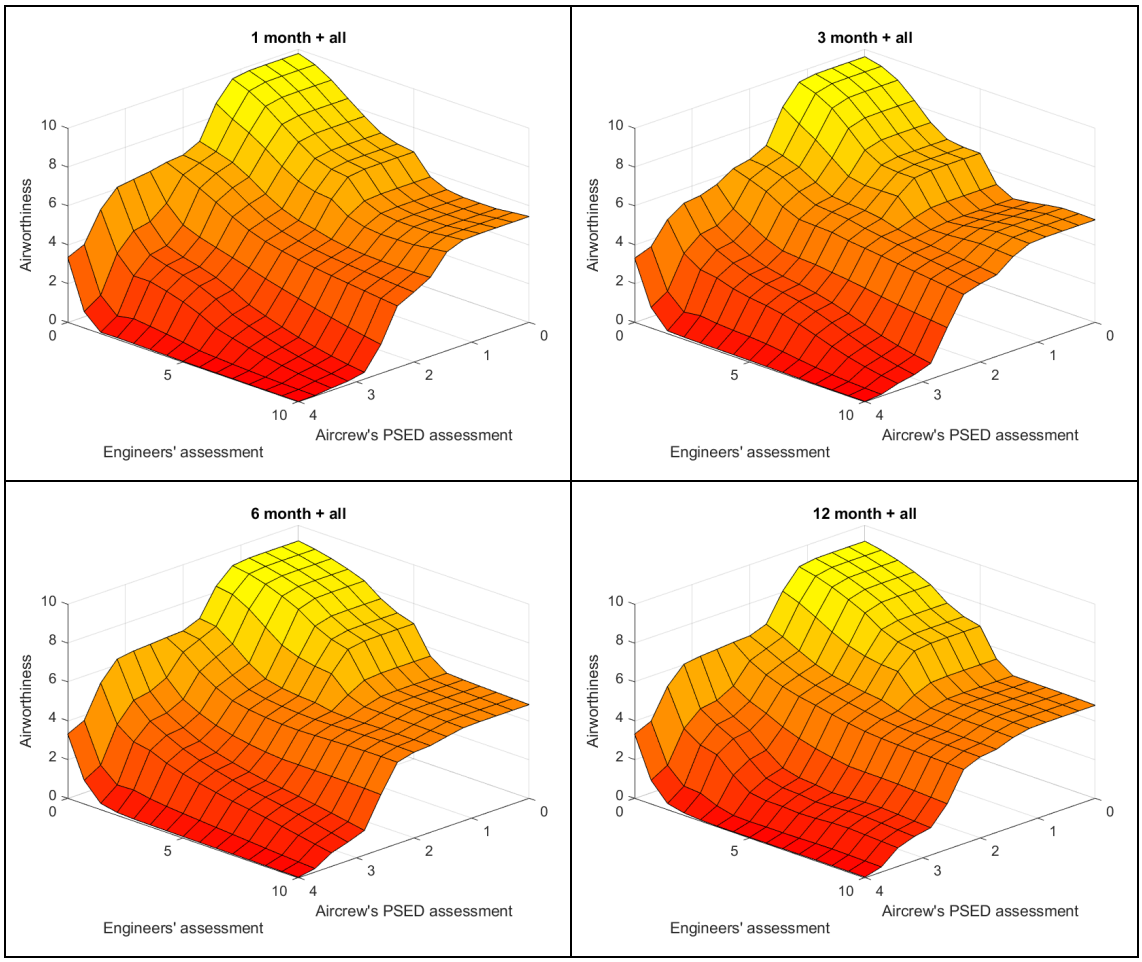


Figure 6-18: Airworthiness level surface plots for 1-, 3-, 6- and 12-month periods for risk matrix 1

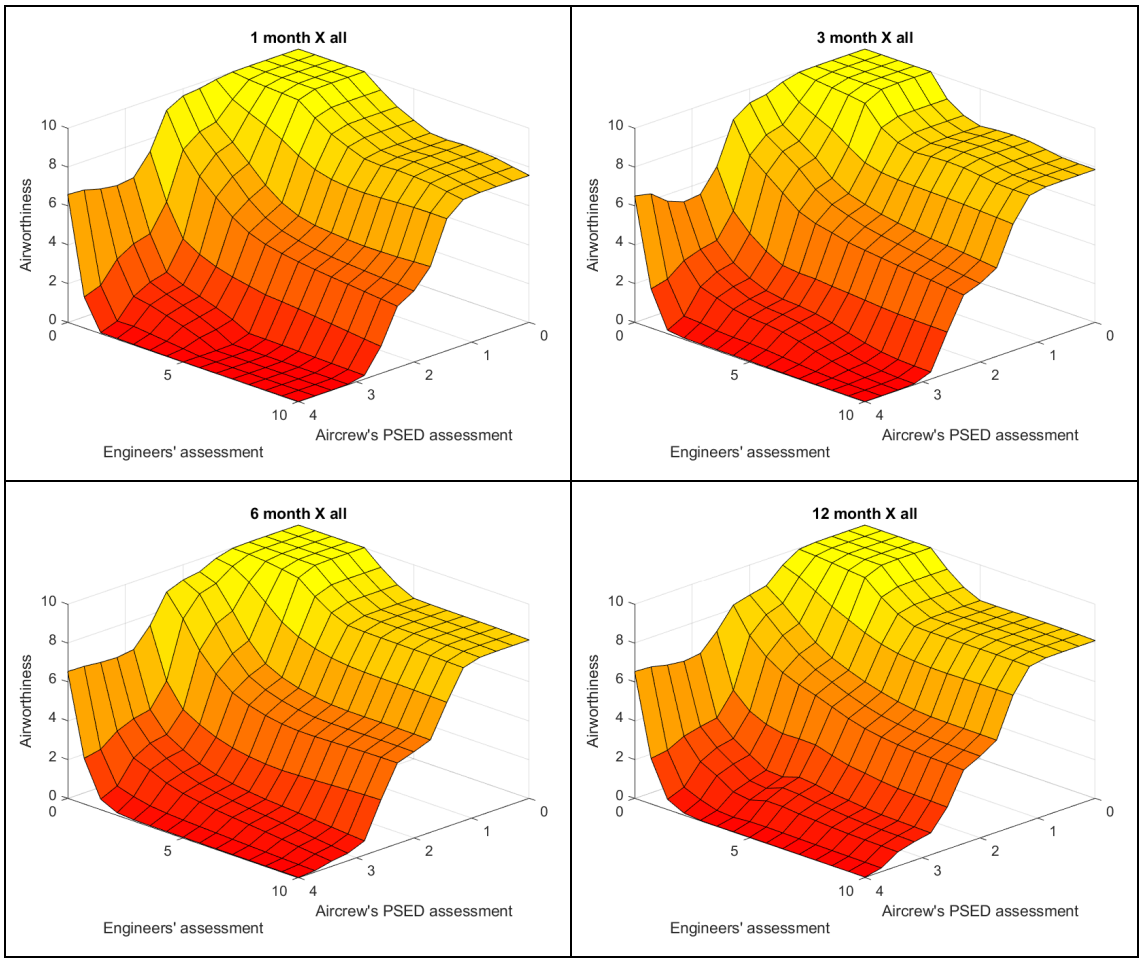


Figure 6-19: Airworthiness level surface plots for 1-, 3-, 6- and 12-month periods for risk matrix 2

Applying the rules for the two risk matrices results in different airworthiness output values (*z*) for the combination of Aircrew and Engineering airworthiness levels (Table 6-10). This shows the variation caused by applying a different risk matrix and the effect of the changing engineers' assessed airworthiness levels for the related aircrew PSED airworthiness level across the four periods. This combined approach is a way to remove the bias or influence that an individual could have when establishing if the aircraft is 'airworthy' or whether more scrutiny of the engineering approach should be adopted. As the surface plot varies for each period (1, 3, 6 and 12 months) it demonstrates the aircrew and engineers' view that based on the number of NFF recorded the airworthiness level is not binary (0 or 1). It reduces as the number of NFF increases and the aircrew's perception of the aircraft's airworthiness level becomes more Severe. This indicates that just following the AMM, which may produce the same results, is no longer justified

and a more detailed investigation is required. This is further emphasised by the SMEs' justification for the Task 2 results.

Table 6-10: Change in airworthiness level across periods for two airworthiness risk matrices

Risk approach	Risk matrix 1				Risk matrix 2			
	Period in months				Period in months			
Membership function input levels	1	3	6	12	1	3	6	12
Aircrew =1, Engineer = 5	6.7	6.6	6.91	6.8	8.3	8.0	8.2	8.1
Aircrew =2, Engineer = 5	4.2	4.9	4.4	4.5	4.2	4.9	4.6	4.8
Aircrew =3, Engineer = 5	1.6	2.3	2.16	1.4	0.1	1.2	1.1	1.4
Aircrew =4, Engineer = 5	0.03	0.07	0.07	0.03	0.0	0.04	0.03	0.03

Table 6-11: Description of aircraft airworthiness level and potential outcome

Level	Description	Fuzzy Logic Value	Outcome if flown - Likely system/technical outcome
Negligible	The aircraft is fully airworthy or there is minimal change to the overall airworthiness level. There is a negligible hazard to the aircrew, ground crew and third parties.	10 - 7.5	Repeat technical NFF has a negligible effect on aircraft. NFF technical fault has a negligible effect on the aircrew operation of aircraft. Negligible change to the airworthiness level of aircraft.
Minor	The aircraft's overall airworthiness level has been affected. There is a minor hazard to the aircrew, ground crew and third	7.5 <>5	The technical NFF or recurring NFF has a minor effect on aircraft. NFF technical fault has a negligible effect on the aircrew operation of aircraft. No requirement to resort to reversionary modes. Any

	parties. The situation is to be monitored.		aircrew actions are minimal and within their capability. Automatic backup systems will accommodate the reoccurrence of the fault during the flight. Some additional attention to the flight plan is required. There is a Minor change to the airworthiness level of aircraft.
Major	The aircraft's overall airworthiness level has been affected. There is a major hazard to the aircrew, ground crew and third parties. An investigation is required to assess the cause, impact and remedial action. The OEM and NFF/Airworthiness Working Group is required to support the investigation.	2.5 to >5	The aircraft has experienced a technical NFF or recurring NFF that has not been resolved. This NFF has a major effect on the aircrew operation of aircraft. Flight planning requires additional attention and scrutiny. Automatic backup systems are insufficient to accommodate the reoccurrence of the fault during the flight. There is a requirement for the aircrew to resort to reversionary modes, and the crew workload is increased. There is a Major change to the airworthiness level of aircraft. The likelihood of an accident or incident increases but is not yet beyond an acceptable level.
Severe	The aircraft is unairworthy. There is an extremely significant hazard to the aircrew, ground crew and third parties. The aircraft is completely unairworthy. A detailed investigation is	0 to >2.5	Repeat technical NFF has a Severe effect on aircraft. NFF technical fault has a severe effect on the aircrew operation of aircraft. Extreme increase in the aircrew workload – survival mode implemented. Automatic backup systems are insufficient to accommodate the reoccurrence of the fault during the flight. The use of reversionary modes is insufficient for an acceptable

	required before the aircraft can fly.		level of capability and the ability to maintain safe flight. There is a Severe change to the airworthiness level of aircraft. The likelihood of an accident or incident has increased beyond an acceptable level. Extremely high likelihood of the technical fault reoccurring that could or will result in an accident. High probability of Catastrophic outcome for the asset.

The following are examples of the SMEs' differing justification for the engineering airworthiness levels chosen for Task 2.

"Task 2 should be undertaken for the number of sorties and not over a specified period". written

"Any repeat arising (>=2) in a month would demand immediate investigation, therefore "S" designation since the aircraft is unairworthy."

- Level 1 occurrence:

  "No impact on the sortie and is of no hazard to 1st/2nd or 3rd parties is inconvenient but does not affect airworthiness. After a few occurrences then the fault should be monitored to gather further data and to ensure that it does not worsen regardless of elapsed period/number of sorties."

  "More likely to promote complacency and thus increase overall airworthiness risk without it being recognised. The fault becomes a 'Norm' and is ignored and accepted which could lead to unintended actions and consequences."

  "Aircraft …[X] works on 'cycles' of a maximum of 6 flights before engineering data MUST be analysed after being downloaded from the aircraft. Therefore, justification for Level 1 arisings being moved to minor is set at 6. Where no fault can be reproduced by the engineering team but

there is a known repeat of a minor 'irritation' then it is likely that discussion with the (pilot) duty authorising officer about raising an acceptable deferred fault would take place. This is because whilst it could be argued that there is no impact to airworthiness, due to the workload on the pilot any distraction could have serious air safety implications."

"The fault is a negligible fault, but any repeat occurrence should be considered as an airworthiness hazard requiring monitoring/tracking and follow-up mitigation should be minimal difference between months 6 and 12."

- Level 2/3 occurrences:

  "Would generally accept two occurrences before deciding airworthiness was affected and escalating a response, often the first occurrence would be a 'wait and see if it's a trend' and the second would be a 'conduct a System BIT [built-in test] or similar'."

  "Will eventually escalate from Minor (Monitor), and then Major (Investigate) due to the need to be seeing to doing something to try and rectify the intermittent fault. Usually (as the easiest option), this is likely to be an LRU change for the next sortie and, if not rectified, a more in depth investigation (ie wiring connectors / harnesses etc) prior to the next sortie. Consequently, the pace of escalation is often dictated by what could be done (from a maintenance perspective) as opposed to what should be done (from a risk management perspective) – ie the engineers would be unwilling to tear the aircraft apart when it could just be a badly seated LRU."

- Level 3 occurrence

  "Poses a significant hazard to parties and would require immediate action, which could result in a limitation if the operational situation dictates, regardless of number of occurrences. However, if the number of occurrences increases then deeper investigation is required. As the duration/number of sorties between occurrences increases then the

probability of the risk lessens, so an additional occurrence could be accepted before investigation."

- Level 4 occurrences

  "Requires resolution before next flight regardless of how often the fault occurs."

  "By definition the aircraft is not airworthy and the level is severe."

This further supports the fuzzy logic inference approach. Whilst the Duty Holder (HSE, no date-a; MAA, 2021) is the accountable person, being presented with an advisory tool that presents an unbiased outcome will aid the decision-making process. With the viewpoints of the 11 SMEs combined, any bias has been reduced or even eliminated.

This fuzzy logic inference method provides some smoothing and combining of the various views. The variety of reasons for moving from one level to another is interesting and the reasons could be many, such as the individual, experience, history, training and moods. However, they support the view that the level of airworthiness that is acceptable and the work to remedy a NFF varies across individuals and/or organizations. This approach will be of benefit to those assessing the implications of NFF and airworthiness and should be incorporated into an organization's NFF policy.

6.5.3 Analysis of the 3-month fuzzy logic surface plots

The 3-month Risk matrix 2 surface plot has a dip at aircrew level 3 and engineers level zero (Figure 6-19). This dip is caused by the combination of rules being applied, namely rules 4, 5 and 8-12. As the aircrew level moves from 2.5 towards 3.5, *more than one Gaussian membership function is activ*e (Figure 6-20). These are for Minor and Major aircrew inputs, rules 4 to 8 and rules 9 to 12 respectively for the two risk matrices (Table 6-8 and Table 6-9).

The outcomes for rules 4 and 11 are different for the two risk matrices. For Risk matrix 1, rule 4 with the aircrew = 2.6 (Minor) and engineer = 0.1 (Negligible), the output would be Review airworthiness level – Minor. Likewise for the same inputs

but applying Risk matrix 2, the output would be Airworthy – Negligible (Table 6-11). Also, for the same input values, rule 11 would result in Risk matrix 1 being Serious review and Risk matrix 2 would result in Unairworthy. This results in the dark blue spikes being located in different places (Figure 6-20). However, due to the product implication method (Equations (3-2) and (3-3)) rules 4, 5 and 8-12 all combine to contribute to the overall outcome (Figure 6-20) and it is the different weighting that results in the surface plot dip.

The limitations caused by being unable to precisely match the engineering normalized data input with the curves available in the Fuzzy Logic Toolbox will also contribute to this feature.

The surface plots make it appear more dramatic than when looking at aircrew input values between 2.5 and 3.2 for a constant engineering input of 0.1. Figure 6-20 shows the rules views for both risk matrices. The aircraft airworthiness level descends steadily from 5.75 to 5.07 when applying Risk matrix 1; a drop of 0.68. Whereas when applying Risk matrix 2, the aircraft airworthiness levels drop from 6.99 to 5.14 before rising again. A drop of 1.85 in the airworthiness level before it rises again to 5.87 for an engineer's input of 0.1 (Figure 6-20, Figure 6-21, Table 6-12). However, this indicates the importance of the membership function curves, the rules and the product implication method.

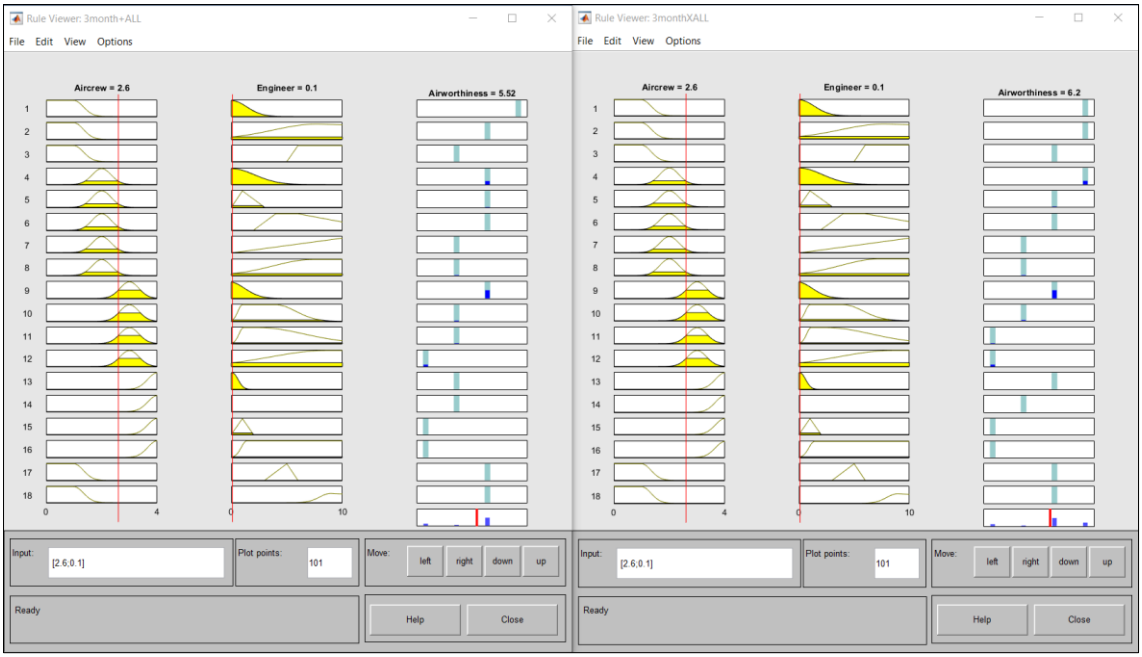


Figure 6-20: 3-month rules view for Risk matrix 1 and Risk matrix 2 for aircrew = 2.6 and engineer = 0.1

Table 6-12: 3-month aircraft airworthiness level for varied aircrew membership function input and Risk matrix 1 and 2

	Aircraft airworthiness level applying	
Aircrew level	Risk matrix 1	Risk matrix 2
2.5	5.75	6.99
2.6	5.52	6.20
2.7	5.36	5.65
2.8	5.27	5.35
2.9	5.23	5.21
3.0	5.19	5.15
3.1	5.15	5.14
3.2	5.07	5.15

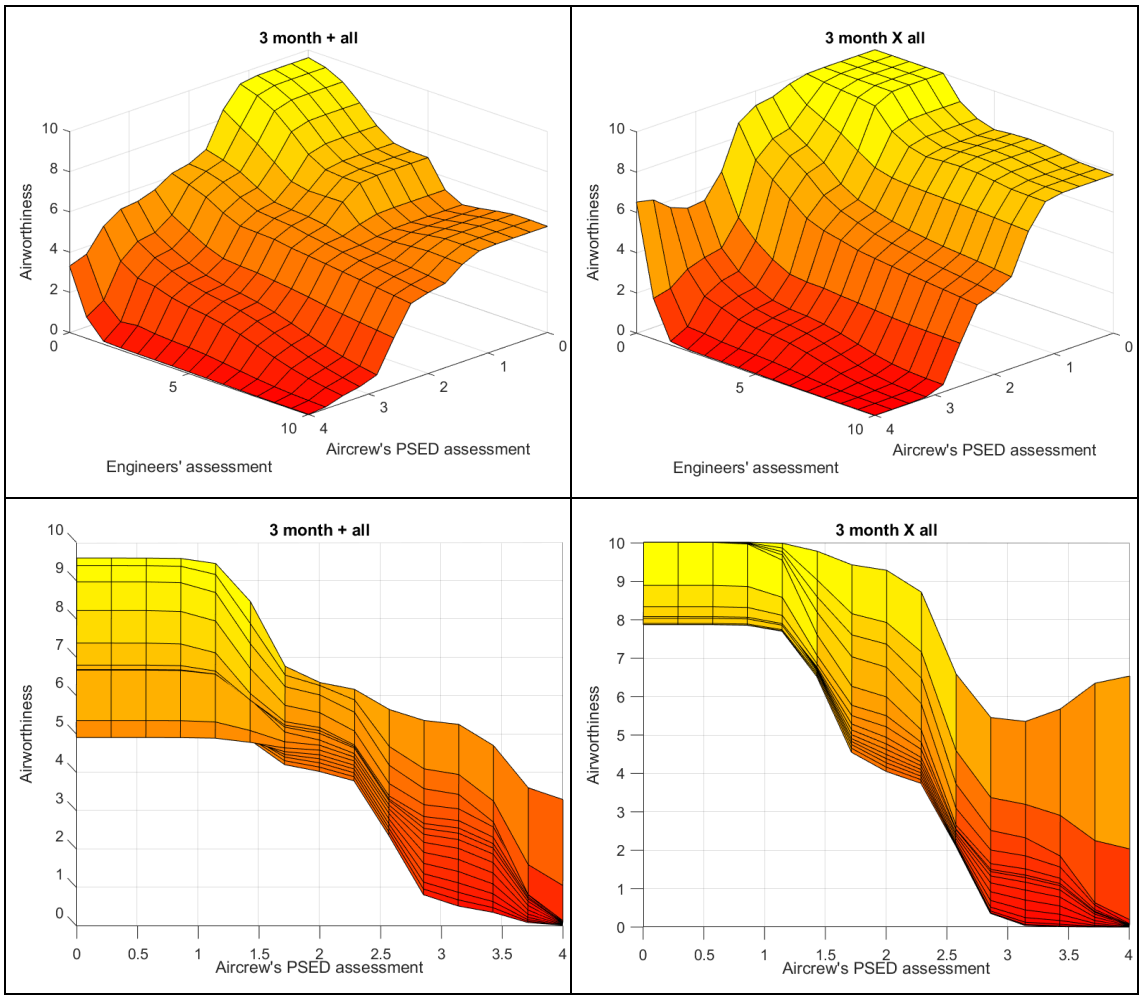


Figure 6-21: 3-month surface plots and side view surface plots for Risk matrix 1 and Risk matrix 2

6.5.4 Validity

Internal validity was addressed in Section 3.9.5 and assessed as being met. Additionally, a university professor with MATLAB and fuzzy logic experience reviewed aspects of the analysis for accuracy of design, implementation and results, such as the best-fit lines and the fuzzy logic 3D plots, which contributed to the internal construct validity. External validity is concerned with the generalizability of the results and whether they are applicable to other settings (Wilson, 2014). Task 2 was completed by SMEs who were male RAF engineering officers. This may inadvertently result in bias in the analysis as it is based on their operational environments and experience. Therefore, any generalized statements are weighted towards that context—RAF operations. The

airworthiness training for UK military engineering officers is very similar (Cranfield, 2023) as is the operating environment. Hence, a general statement of validity may be applicable to those groups. However, the civil operating construct for maintenance with engineers required to be licenced (CAA, 2023) is different as is the relationship between the aircrew and engineers (See Interview 1 and 4, Appendix A). Therefore, the external validity of the fuzzy logic analysis only extends to RAF operations and engineering. To extend the external validity to other organizations, further analysis and primary data will be required. There are some options, such as the following:

- Task 2 should be completed by SME engineers from other organizations to establish whether there is any similarity with the RAF SME engineers' views. If strong similarity exists, then this supports external validity.
- The fuzzy logic results and analysis should be applied to other aviation organizations and used as an advisory tool. This can be used to assess the credibility of the overall aircraft airworthiness level.

6.5.5 Fuzzy logic analysis summary

This fuzzy logic approach has combined possible aircrew views of an aircraft's airworthiness level with real views from aviation engineers. Combining the two views, with a risk matrix, to produce an overall aircraft airworthiness level demonstrates that airworthiness is not binary. Moreover, it demonstrates that the severity varies as time progresses across one, three, six or 12 months. For some engineers, the view was that six and 12 months held the same risk. The approach demonstrates that fuzzy logic can be adopted as an advisory tool to combine both aircrew and engineers' view of an aircraft's airworthiness level to aid the duty holder with the decision-making process. Applying the relevant risk matrix and incorporating the description of the state of the aircraft and the likely outcome if flown better identifies the risk for the duty holder but more importantly for those directly linked to the airworthiness definition, aircrew and engineers, and the NFF occurrences. The distraction to the aircrew was previously stated by the aircrew during the interviews and the questionnaire. Now, the engineers are highlighting

it as a concern, along with complacency by the engineers. Again, this complacency was identified during the interviews and questionnaire.

Moreover, the engineers' views contribute to answering Research Question 1 (Section 2.17.1). From the responses to Task 2 (Appendix E, E.1) the engineers established a link between NFF and airworthiness. Their views were not based solely on the outcome of the maintenance conducted or directed as per the AMM. They acknowledged that over a set period if the number of Aircrew PSED airworthiness levels recorded for a fault related to a NFF or intermittent fault increased, they used engineering judgement to establish that a different approach was required to resolve or investigate the NFF **and** that the overall aircraft airworthiness level had changed. This established link between NFF and airworthiness can be categorized as *impactful* and *critical*. Impactful as it has "a powerful effect on a situation or person" (Cambridge Dictionary, 2023a). The maintenance situation was changed; the engineer decided that the airworthiness of the aircraft had changed. It was critical as it was "of the greatest importance to the way things might happen" (Cambridge Dictionary, 2023b). The engineers had changed how the diagnostics or investigation would change, as evidenced by the narrative supporting their selections.

A limitation of the analysis is that the SMEs were all RAF engineering officers. This impacts the external validity and to widen the external validity Task 2 is recommended to be completed by SME from different aviation establishments.

6.6 Aviation company data analysis for NFF

The following details the analysis of an aviation company's maintenance data for NFF recordings within a small fleet of aircraft over the period 2009 to 2022. The aim was to establish the number of NFF recordings in total and for specific systems. For the same aviation company, it also includes oversight of the OEM data for correct and incorrect NFF recordings for the period 2018 to 2022, 39 months in total. As this data is classified as commercial in confidence it has been withheld (Cranfield University, 2022). It is not available via Cranfield Research

Online Data (CORD). The reliability of the data was addressed as credible (Section 3.8.3).

6.6.1 Analysis of a company's NFF data

The frequency of NFF recorded over this period was analysed for the key aircraft systems prone to NFF as established from the interviews and questionnaire (Table 6-13), namely navigation, communication, AFCS, fuel and instruments. As the fleet was growing during this period the average values were established. The total number of maintenance cards raised during these 14 years was almost 50,000. The fuel system encountered the highest number of faults recorded (1031). The highest average NFF/year recorded was for the navigation system. The greatest percentage of NFF overall was for the navigation system, closely followed by the autoflight system (Table 6-13). So, the number of maintenance cards raised for a system needs to be considered against the percentage of NFF recorded. It is evident that the number of NFF has increased over these 14 years (

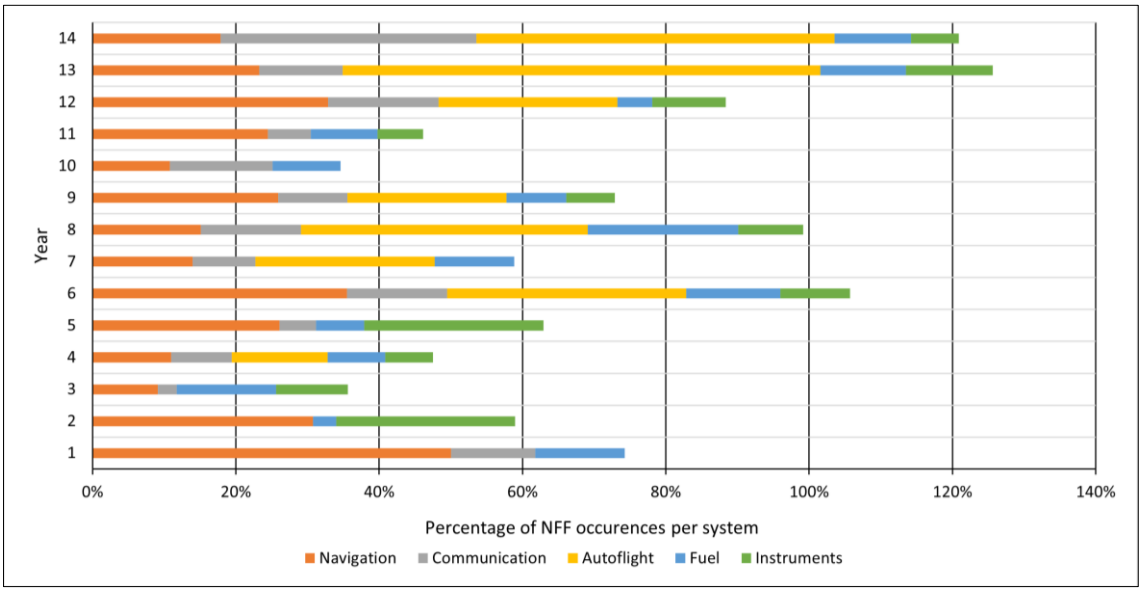


Figure 6-22 and Figure 6-23). No explanation has been provided by the aviation company for this increase but it might be due to an increase in flying hours or a change in environmental conditions. However, the NFF for the navigation system appears more pronounced for the earlier period. In the last two years, the autoflight system NFF greatly surpasses that of the other systems with a peak of

67% in year 13 and zero recordings in periods 10 to 11 (

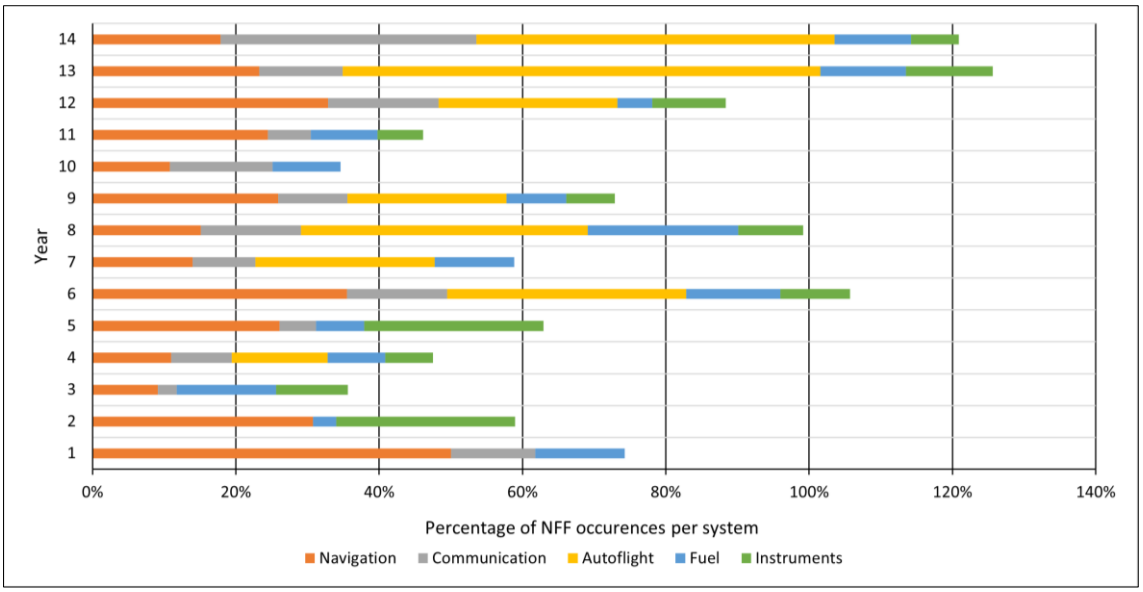


Figure 6-22 and Figure 6-23). So the results of the analysis suggest that the NFF for the navigation system have been resolved but an issue for the autoflight system has developed. Whilst the number of autoflight work cards raised per year is low, the percentage resulting in NFF is high and might warrant further investigation to establish the cause of the sharp increase.

Table 6-13: Aviation maintenance data for the period 2009 to 2022

	System				
	Navigation	Communication	Autoflight	Fuel	Instruments
Total no. cards raised	710	623	86	1031	366
Average no. cards raised/year	50.7	4.9	6.1	73.6	25.4
No of NFF	161	68	19	108	31
Average NFF/year	11.5	4.9	1.4	7.7	2.2
% NFF	23	11	20	10	10

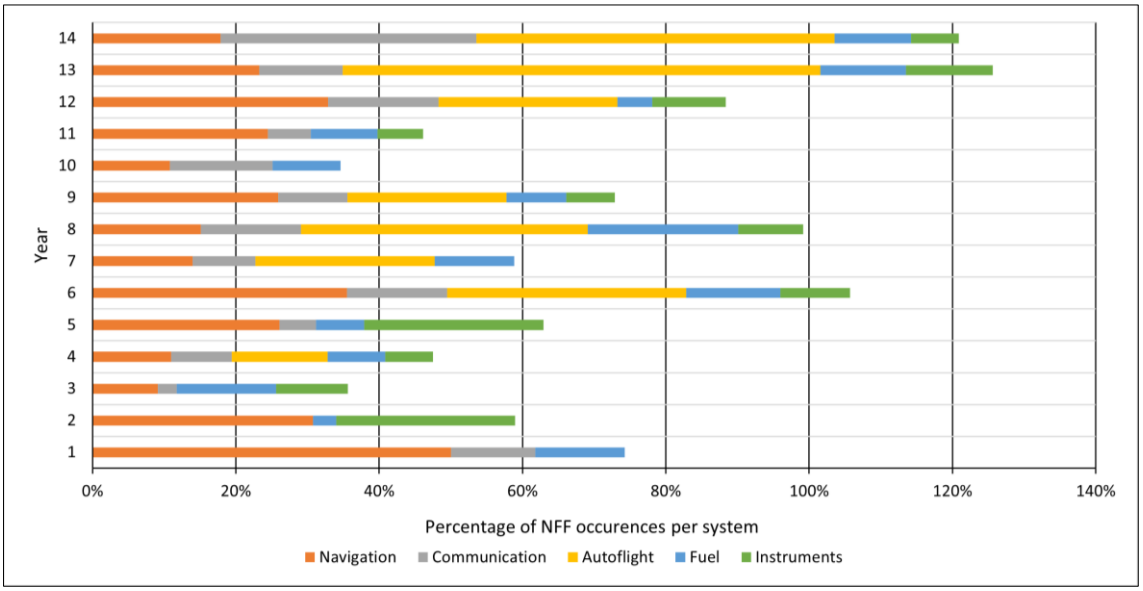


Figure 6-22: Total percentage of NFF recorded for the navigation, communication, autoflight, fuel and instruments over a 14-year period

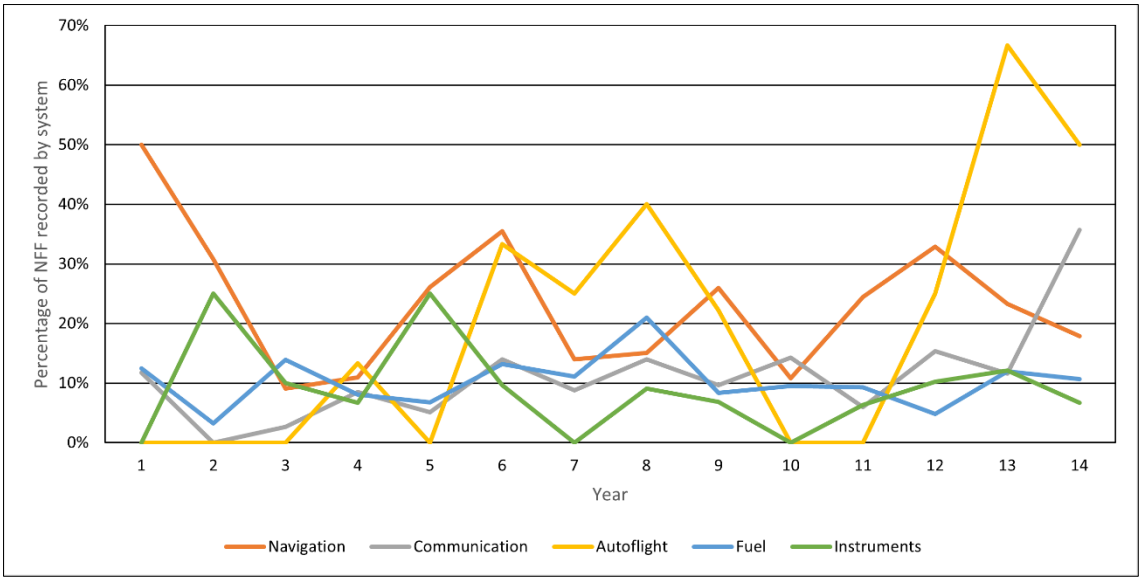


Figure 6-23: Percentage of NFF recorded per aircraft system over a 14-year period

This information is key for any company, military or commercial, analysing the impact of NFF on airworthiness, the aircrew and the engineers. Analysing the maintenance and NFF data for trends will support any communication with the aircrew regarding the airworthiness of the aircraft. It will engender better trust between all parties; a requirement for good working relationships and cooperation (Psychology Today, 2023). This was an issue identified from the interview and questionnaire.

Any aviation company needs to identify when the NFF recorded increases above the average. Using the aviation maintenance data, the average number of NFF recorded per year was used to establish the impact if this average occurred over condensed periods, namely 6, 3 and one months (Figure 6-24 to Figure 6-28). Assessing the actual count rather than a percentage makes it easier to assess if the number of NFF recorded has increased. This can be seen as a rolling 12 months. Any increase needs to be assessed for cause, impact and correlation with the aircrew PSED assessment of the aircraft's airworthiness. If these indicated the impact is major or severe an investigation needs to occur. It is important to assess this against the fuzzy logic airworthiness level to check for any correlation.

Whilst it does indicate the effect of NFF on maintenance it also shows the top NFF system for the five systems was navigation and then the autoflight. These were two of the top systems identified by the aircrew for being prone to NFF.

The organization needs to take action. How this action can be implemented is presented in flow charts (Section 6.7). Analysing a rolling 12-month period would have highlighted the large increase in the autoflight NFF recordings during year 13 (2021). Once spotted, greater scrutiny with the aircrew PSED airworthiness level assessment should have been completed. From this, remedial or recovery action would have been possible. Any detrimental impact on airworthiness would have been identified early. The Duty Holder informed so the risk could be better assessed. A similar action could have been conducted for the early navigation peaks.

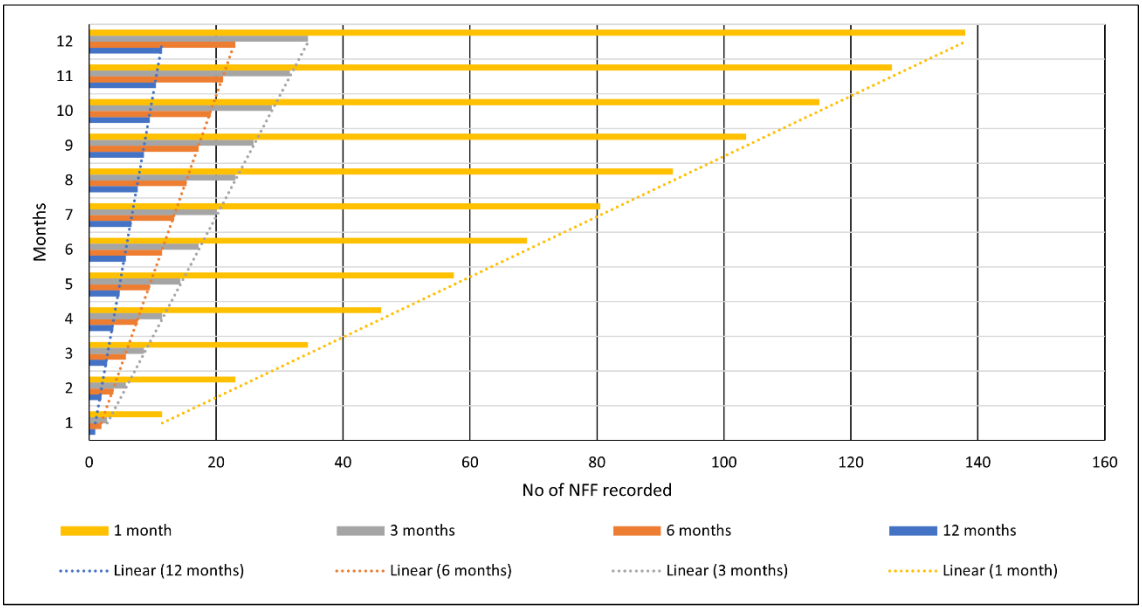


Figure 6-24: Cumulative effect of a year's average NFF occurring in shorter periods of 1, 3 and 6 months for the navigation system

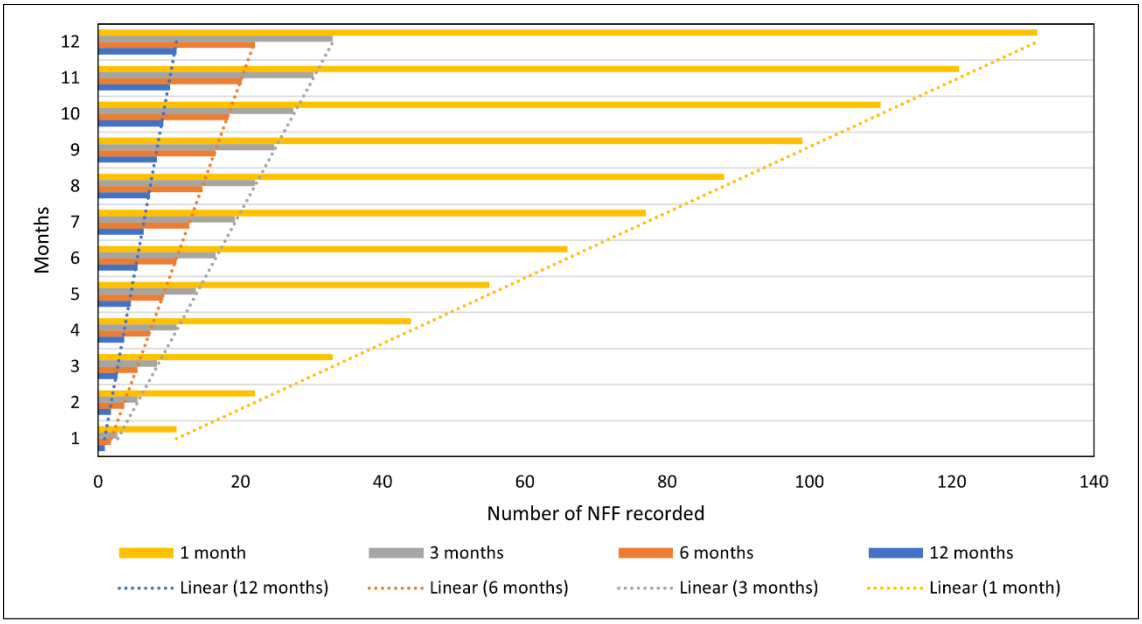


Figure 6-25: Cumulative effect of a year's average NFF occurring in shorter periods of 1, 3 and 6 months for the communication system

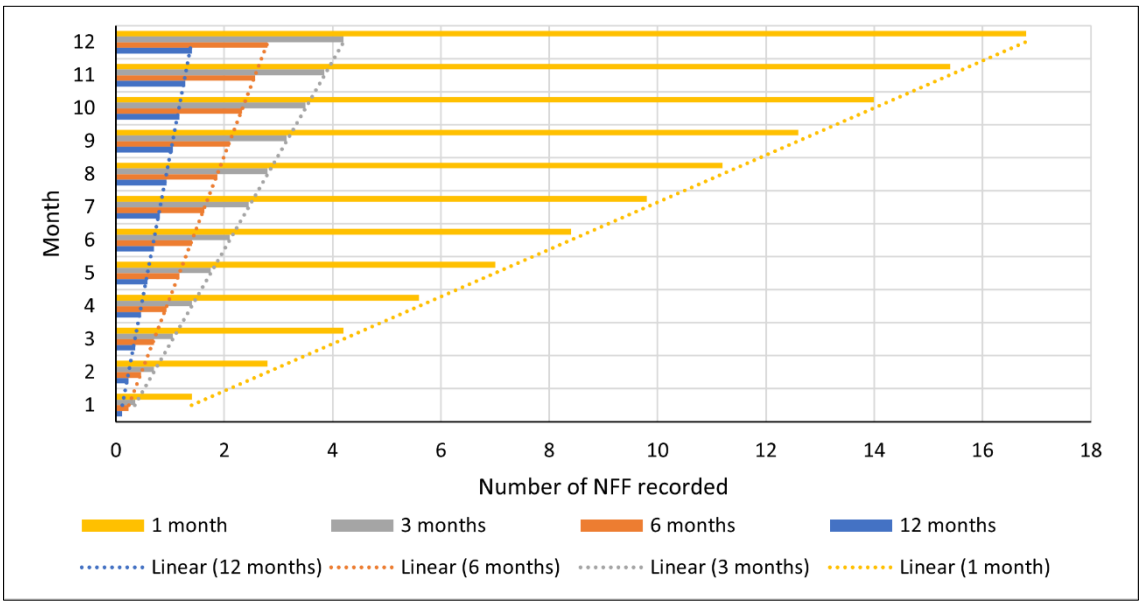


Figure 6-26: Cumulative effect of a year's average NFF occurring in shorter periods of 1, 3 and 6 months for the autoflight system.

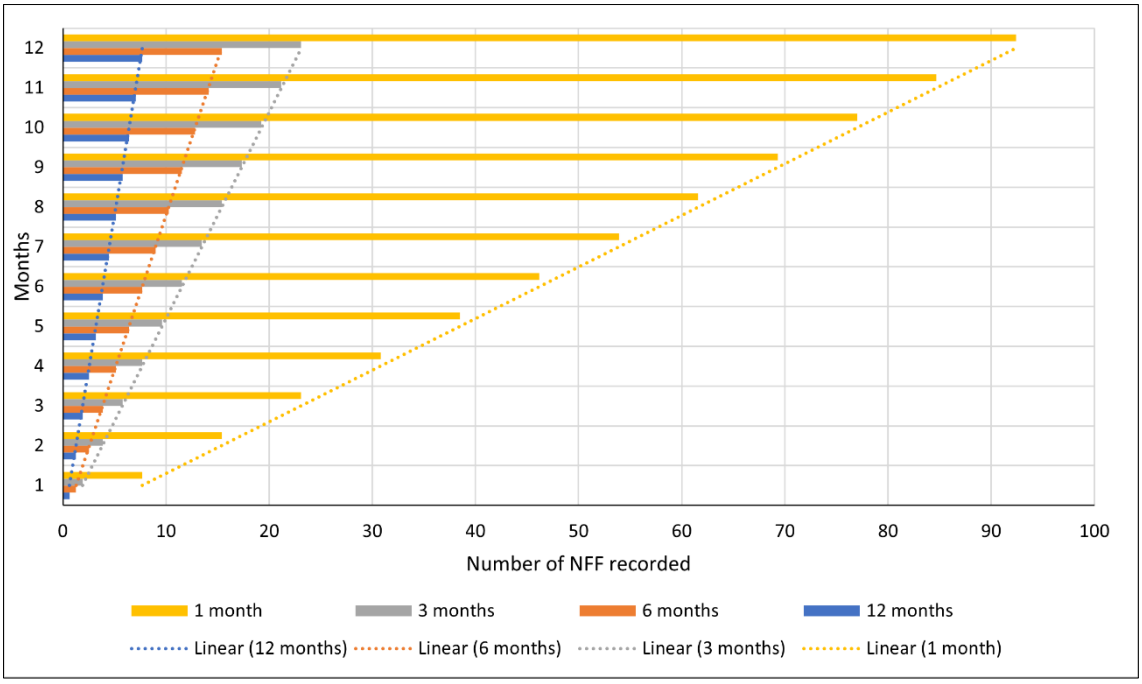


Figure 6-27: Cumulative effect of a year's average NFF occurring in shorter periods of 1, 3 and 6 months for the fuel system

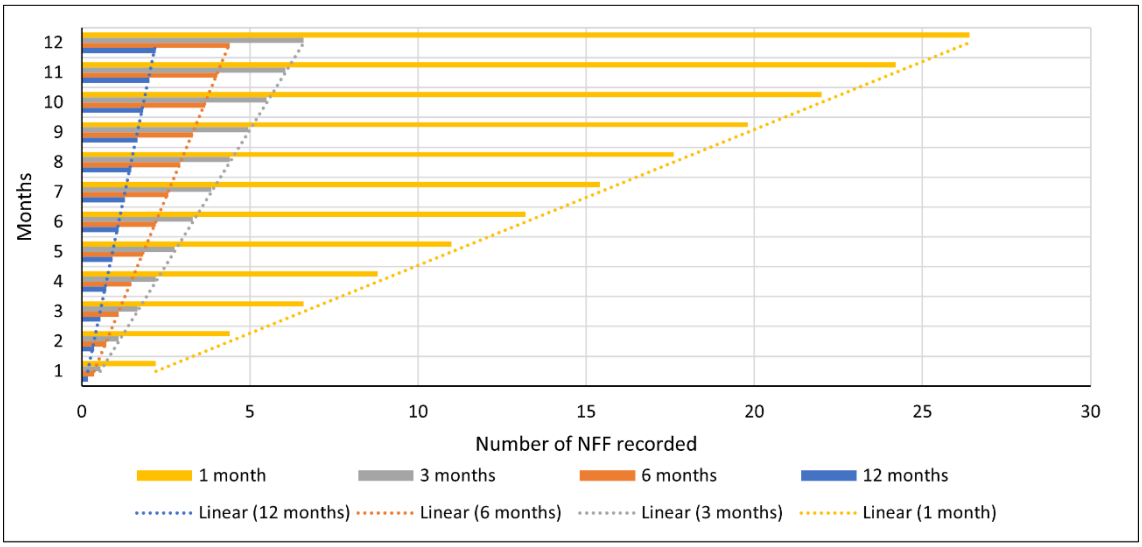


Figure 6-28: Cumulative effect of a year's average NFF occurring in shorter periods of 1, 3 and 6 months for the instrument system

6.6.2 Different ways of recording NFF

An issue previously identified was the numerous ways for recording a NFF. Consequently, when analysing the aviation data a check was conducted for the different terms used. In total there were 18 ways (Table 6-14). Consequently,

when analysing the data, it is essential to know all the permutations to search for. Having a consistent and agreed approach for the terminology to be used within and between different organizations, such as the operator and the OEM, will improve the analysis of NFF and counter its impact on airworthiness. Also, the aircrew's understanding of the engineering terminology will be improved. This will benefit communication and trust.

Table 6-14: Different ways NFF was recorded in the aviation data

Number	Term
1	No fault after check/test
2	Found satis no defects.
3	NFF
4	No fault
5	No fault after test
6	No fault apparent
7	No fault found
8	No fault found after – explanation to follow
9	No fault found during invest.
10	No fault found on ground
11	No faults after check/test
12	No faults apparent after test
13	No faults apparent at this time
14	No faults at this time
15	No faults found
16	No faults observed
17	Unable to reproduce
18	Unable to reproduce fault

6.6.3 OEM NFF data analysis

Maintenance data regarding NFF reporting was provided from the Aviation company OEM covering 2018 to 2022, 39 months. The data was for those work cards correctly and incorrectly recording the maintenance activity as NFF. In total there were 496 work cards submitted that claimed the maintenance resulted in a NFF. Of these, 333 correctly and 163 incorrectly recorded the maintenance as NFF. Examples of incorrectly recorded NFF were for ‘aircraft battery panel removed for access’ or ‘fuel filter requires replacement.’ The second example

would have been part of scheduled maintenance. This indicates that almost a third of all maintenance was incorrectly recorded as NFF. This demonstrates the engineers either do not know what is a NFF or are choosing to incorrectly record the maintenance.

Analysing the data for the five main systems prone to NFF occurrences, the result shows that almost half (45%) of the fuel system NFFs were incorrectly recorded, with a quarter (26%) being misrecorded for the navigation system (Table 6-15). This strongly suggests that for those systems, especially the fuel system, the engineers do not know what is a NFF. This might be due to inadequate training as indicated by Hockley, Lacey and Pelham (2016), inadequate diagnostics—as promoted by the interview and questionnaire responses—or wishing to complete the maintenance before a shift handover—as advocated from the interviews and questionnaire responses. This makes it more difficult to assess the true impact of NFF on airworthiness. A distinction needs to be made between scheduled maintenance and a true NFF. Specific NFF training would improve this miss-recording.

Table 6-15: OEM's analysis of Aviation company's NFF recordings

	NFF Correctly recorded	NFF incorrectly recorded	NFF Percentage incorrectly recorded
Navigation	38	10	26
Communication	31	3	10
Autoflight	7	0	0
Fuel	20	9	45
Instruments	5	0	0

6.6.4 Aviation data consequences

There are numerous consequences for this NFF recording. As established for navigation and fuel systems the recording of NFF is incorrect. This will indicate a great impact on airworthiness than is reality. It impacts the logistic system as a greater number of items are incorrectly being sent for depth maintenance. These may become classified as 'rogue items'. This is an unnecessary organizational cost. This analysis and evidence need to be regularly analysed and discussed for improvement between the aviation company management, engineers,

logisticians and the OEM. Reducing this erroneous NFF recording will provide a better understanding of the true impact of NFF. From this, the impact on airworthiness can be determined, when combined with the aircrew PSED reports and the engineering management assessment.

It has been known that components removed as part of unscheduled maintenance, as a result of fault diagnostics, are frequently recorded as NFF by the OEM or repair company (Suciati and Suwondo, 2019). This is usually from diagnostics that indicate the fault could be in one of three components, so the easiest or the one in stock is changed, or numerous components are changed concurrently to save time to declare the aircraft serviceable ((Hockley, Lacey and Pelham, 2016). This presents false reliability figures for the component and the possible 'rogue' components are installed on aircraft (Suciati and Suwondo, 2019) and this perpetuates the NFF problem and the negative impact on airworthiness.

Figure 6-24 to Figure 6-28 should be updated once the recording of the NFF occurrences has been improved following NFF training and review by a dedicated team focused on reducing the impact of NFF on airworthiness.

6.7 Flow charts analysis

The previous analysis has considered the '*as is situation'*, the survey analysis, how the NFF/airworthiness relationship can be observed and, for the Bowtie analysis, what barriers can be used to reduce the possible recording of further NFF. Additionally, the FRAM model and analysis considered the potential resonance and variability that is contained within an aviation organization. The following flow charts (Figure 6-32 to Figure 6-36) draw this information together and suggest a means for management to address and minimize the NFF occurrences and the impact on airworthiness. Key aspects of the flow charts will be explained.

The aircrew and engineering pre-post-flight flow chart (Figure 6-32) includes key findings from the literature review and survey, namely whether the engineers and aircrew are SQEP for the PSED, the need for a dedicated location in which to

hold the PSED, a check for whether the aircrew understands the engineers' terminology, the requirement for a PSED proforma designed to consider NFF, systems used and aircrews' perceived level of airworthiness following the flight.

This links with the training requirements (Figure 6-32) that focuses on the need for training to ensure the aircrew and engineers understand airworthiness, NFF, engineering terminology used, how to use the PSED proforma and how to use the SQEP calculation tool. Combined, these aspects have been raised as causes for NFF, misunderstanding and trust issues between the aircrew and engineers, misinformation between both parties, and not being SQEP for the tasks required. The aim of implementing this training is to reduce the risk to airworthiness and it links directly to the Bowtie and the FRAM model where the upstream/downstream Rough score was rated as 27 to 18—key contributors to the link between NFF and airworthiness—and requiring specific action to dampen any resonance (Table 6-6).

The maintenance flow chart (Figure 6-31) addresses the issue of repeat maintenance being conducted as the engineers were not considering previous maintenance conducted or were completing the minimal maintenance before a shift handover (as detailed in the interview and questionnaire analysis). A focused check of the aircraft history for intermittent or NFF reports will aid any diagnostics and if evident should be reported to the NFF/Airworthiness working group to consider as part of the organization's NFF policy. Further, it requires the AMM issue or amendment numbers to be recorded to ensure the latest procedures are being used. This will aid any trending to establish if the NFF recorded was reduced after any amendment was incorporated. Moreover, this will aid identification of those AMM that are not being updated swiftly.

The SQEP calculator tool (Figure 6-32) is simple to use and only requires the aircrew and engineers to input their training (qualifications) and the number of years of experience on the aircraft. This was created in Excel (Appendix F). The training to be required will be established by the organization but should include PSED training, aircraft system training etc. Importantly, this SQEP calculator tool must be reviewed and used in relation to the complexity of the air system. For

training aircraft, such as the Grob 120TP Prefect, the complexity of the systems is much less than that for a new combat aircraft, such as F-35B Lightning II, or a commercial aircraft, e.g., Boeing 737 Max. This will impact the depth of knowledge and experience required for both aircrew and engineers. Additionally, if the aircraft system has an electronic monitoring system this may also impact the SQEP grading of red, amber and green. It may reduce the SQEP level required due to this inbuilt health assessment and feedback available to the engineers. However, it should be remembered that the engineer and aircrew will have to be conversant with the plethora of codes and the integration of the systems. This lack of knowledge was raised by the aircrew during the interview and the questionnaire. The SQEP calculator tool aims to identify if additional training is required or whether support is required for the PSED or understanding the engineering terminology. This aspect should be included in the organization's NFF policy.

The PSED reporting proforma (Figure 6-33, Figure 6-34 and Appendix G) was based on the findings from the literature review, interviews, and questionnaire. All highlighted limitations or weaknesses with the current '*as is situation*' that affect the PSED and consequently the outcome of engineering faults, specifically intermittent faults and NFF outcomes. If the overall modal time for the PSED remains at approximately five minutes (Q34) then it needs to be focused and of value. The starting point was the 7 Squadron Fault Debrief form (Hockley, Lacey and Pelham, 2016, p.152). It was expanded to include questions regarding repeat intermittent faults and NFF, handling, airworthiness, air safety, and specific guidance regarding the flight condition when the fault appeared. Importantly, it contains descriptions of the airworthiness levels the aircrew will select for the aircraft post the flight. This was included in Task 2 to aid the engineers in making their assessment of the airworthiness level (Appendix E, E.1 and Appendix G).

The penultimate flow chart is for the logisticians (Figure 6-35). Implementing this is aimed at reducing the policy of changing the aircraft's most accessible LRU identified in the AMM for the fault, the LRU in stock and fitting 'rogue' components that are fitted to different aircraft but are being returned from the OEM as NFF.

This could also apply to a component that was being refitted to the same aircraft and producing the same fault, leading to it being removed again and sent to depth maintenance. This requires the logisticians and engineers to accurately update the electronic databases. A current and correctly populated database enables the logisticians and engineers to assess whether a component/LRU has a history of being intermittent or NFF (Figure 6-32).

For consistency, the term NFF will continue to be used but it is recommended that the term FNF be used instead of NFF. This focuses the emphasis on the fact the fault has not been found. The fault may still be present but dormant or intermittent (Avižienis, Laprie and Randell, 2001). With this revised terminology, the severity of NFF and the impact on airworthiness can have the focus needed.

The NFF/airworthiness working group (Figure 6-36) is the crux for reducing the NFF occurrences and their impact on airworthiness. It needs to be incorporated into the NFF organization's policy. The inputs to the working group are all the reports indicated in the other flow charts. Additionally, it includes the FRAM and Bowtie model analysis and the fuzzy logic inference outputs. These all need using, reviewing and updating as improvements or changes are made to the aviation system. They are *live* documents. The outcome of the NFF/airworthiness working group reviews will be updates to these documents, feedback to key users (e.g., the logisticians) and an assessment of the aircraft's airworthiness level from the fuzzy logic pertinent information to aid the Duty Holder with the assessment of whether the aircraft is ALARP and tolerable with the NFF occurrences and impact on airworthiness.

The following details those stakeholders who should comprise, contribute to and support the NFF/airworthiness working group. Without full support at the relevant level, the link between NFF and airworthiness will remain unknown, and unacknowledged, a risk to life and a safety issue.

Stakeholders/members of NFF/Airworthiness Working Group

- Duty Holder
- SQEP Aircrew

- SQEP Engineers
- Aircrew management
- Engineering management
- Logisticians
- OEM/Design Organization
- ‘Delivery Team’ (procurement agency/body)
- Quality control
- Trainers
- Information Technology personnel
- Nominated Chairperson (with dedicated staff)

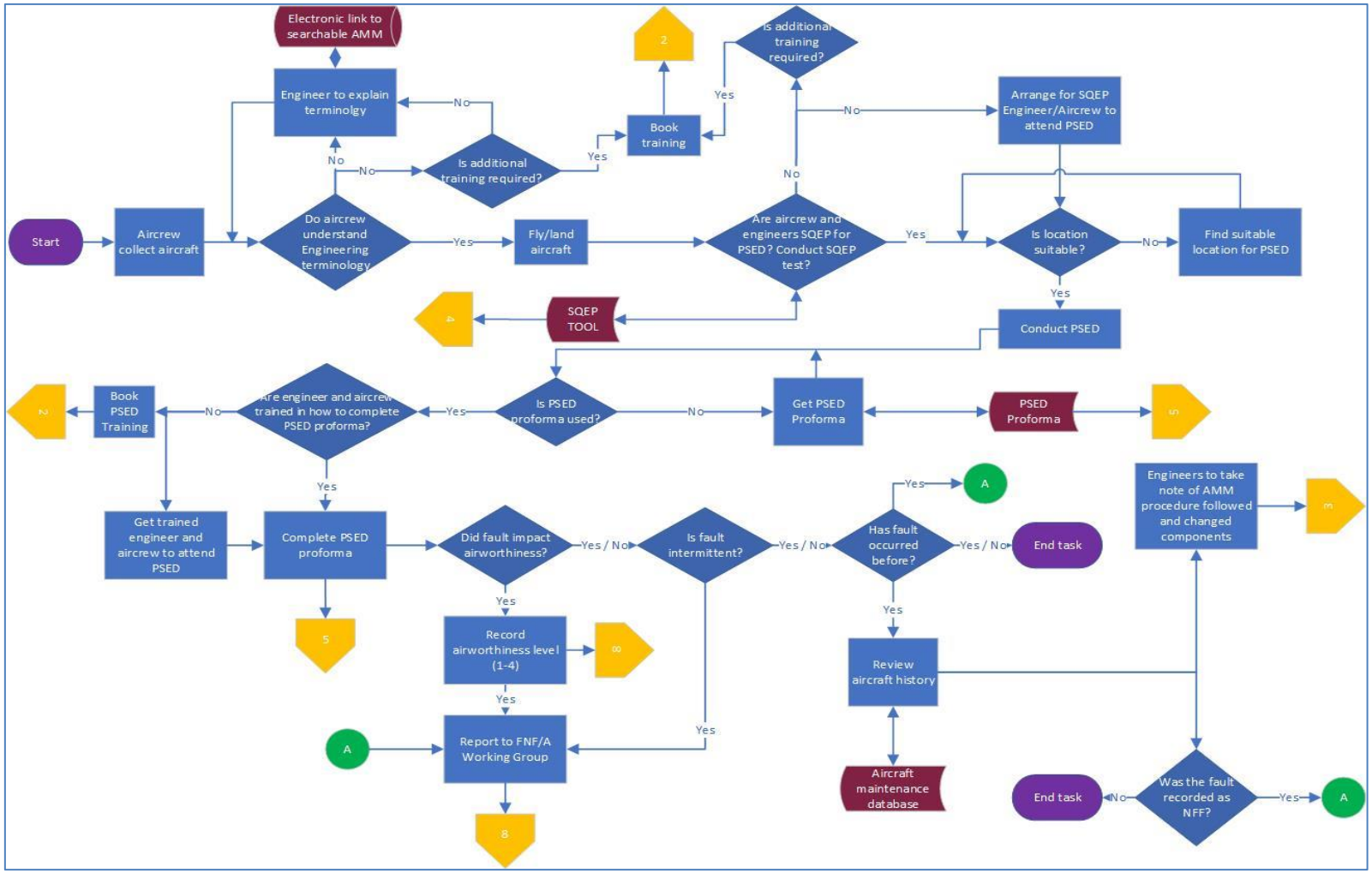


Figure 6-29: Aircrew and engineering pre-post-flight flow chart

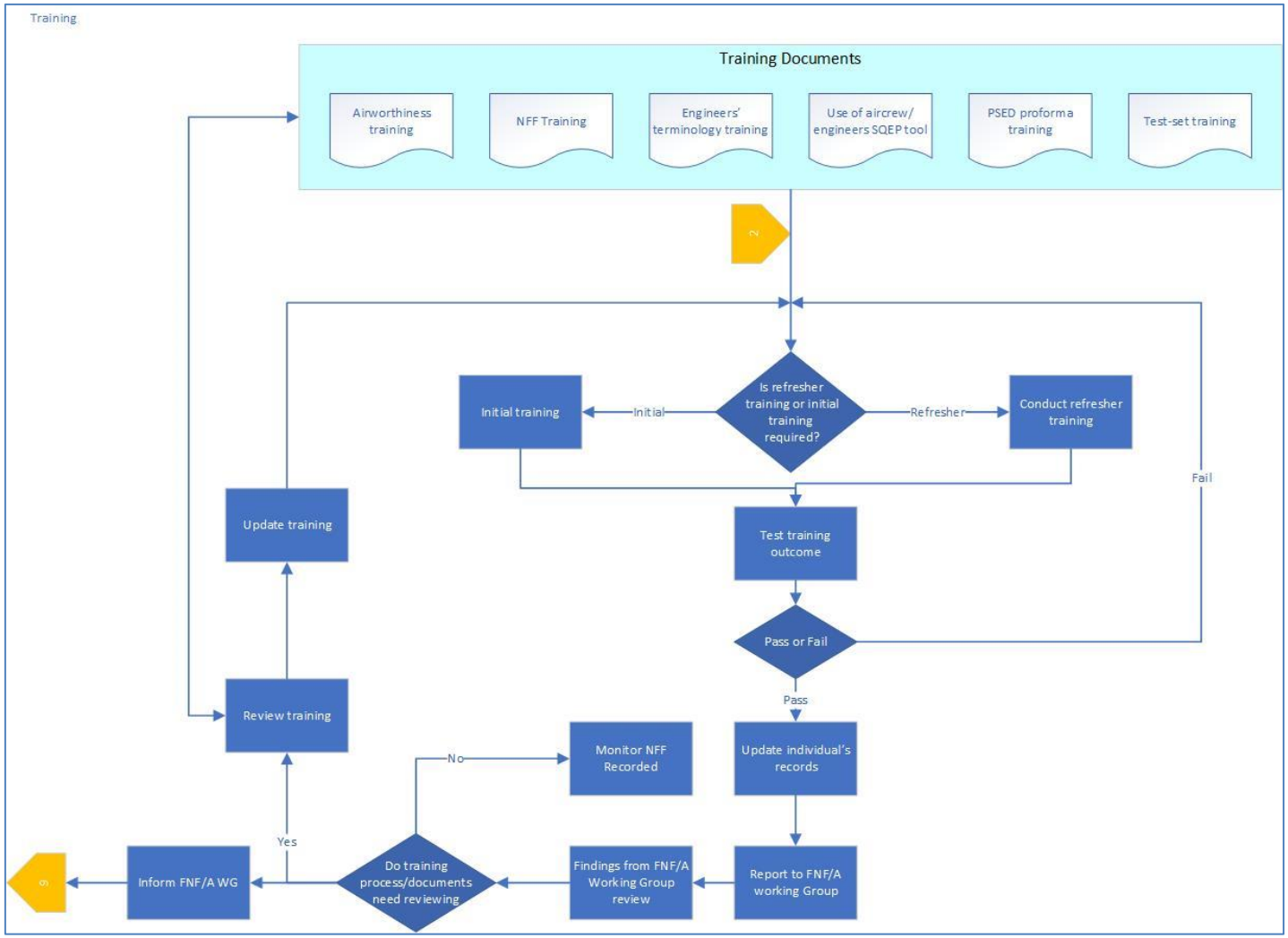


Figure 6-30: Aircrew and engineering training to reduce NFF occurrences

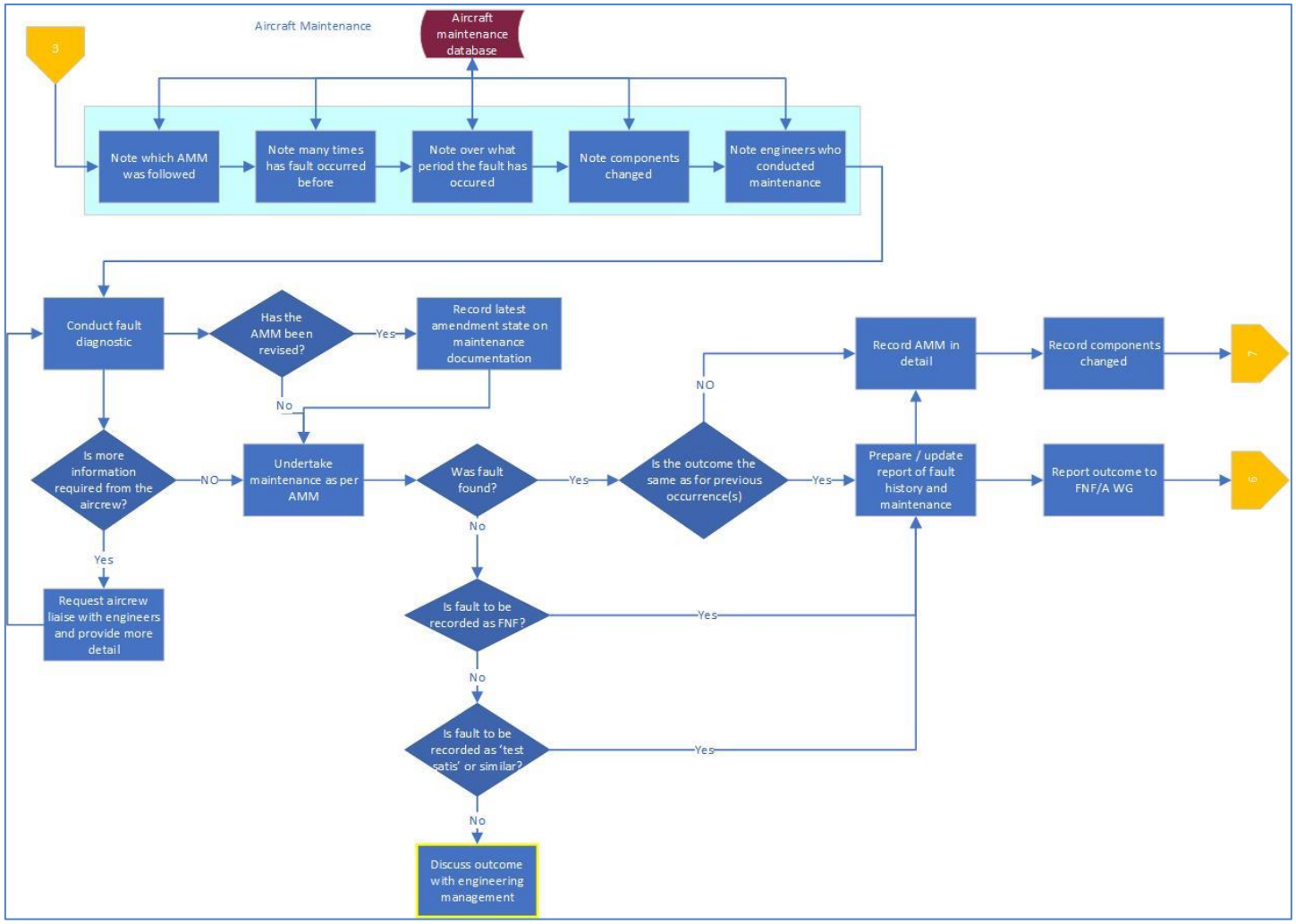


Figure 6-31: Reducing NFF occurrences via an improved engineering approach

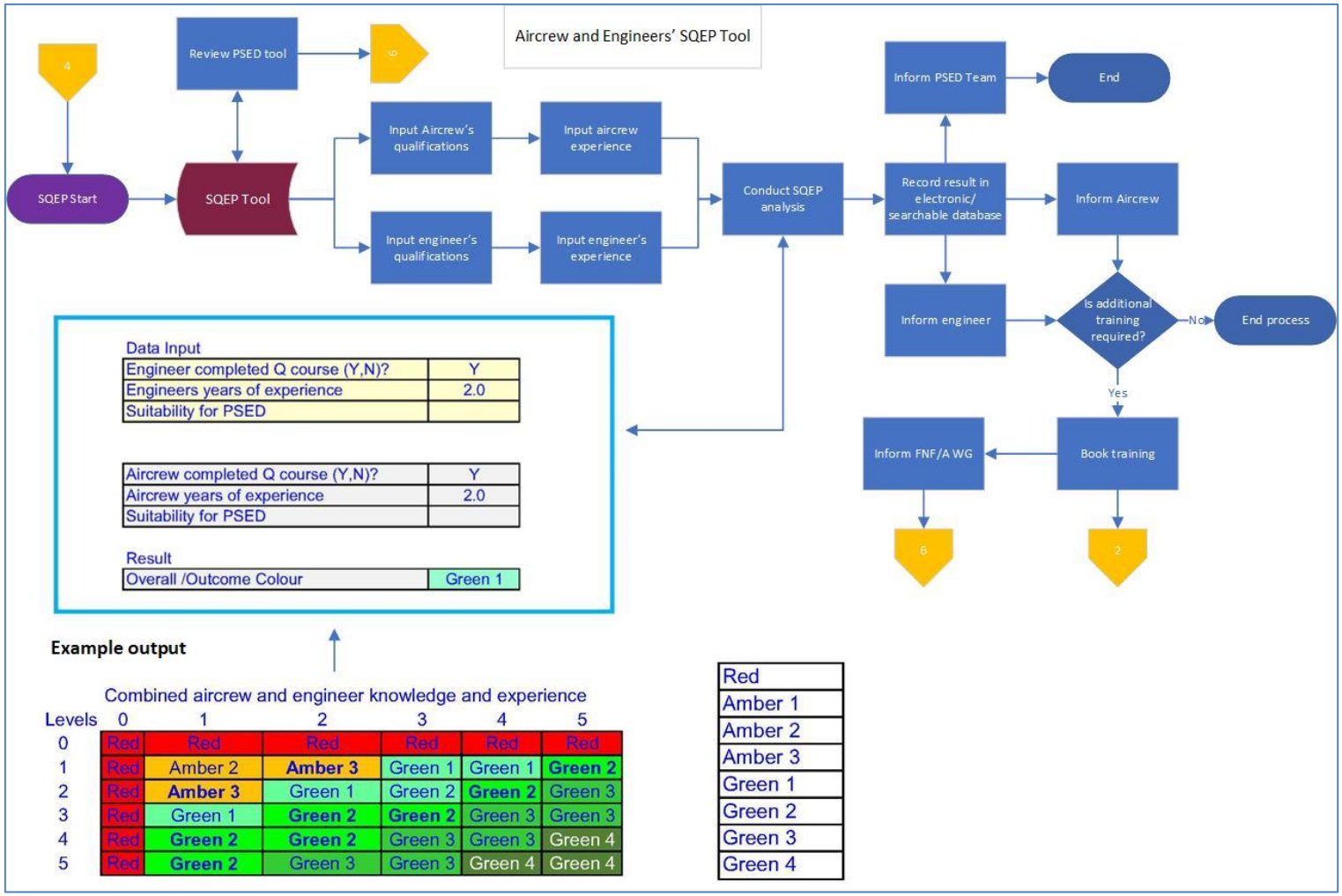


Figure 6-32: Aircrew and engineering SQEP tool

Post-sortie engineering debrief reporting proforma

1. Date:	2. Start Time: End time:	3. Aircraft No:
4. Aircrew reporting:	5. Engineer(s) attending PSED:	6. Work number:
7. Description of fault:		
8. Observed symptoms: provide as much detail as possible, including the following: I. Time within flight. II. Cockpit indications III. Aircraft orientation IV. Speed V. Control surfaces (position, feel) VI. Altitude VII. Vibration, noise, smell?		
9. Description of the flight conditions (when fault occurred)		
10. Were symptoms intermittent?	Yes ☐	No ☐
11. What actions did you take?		
12. Did the situation improve / degrade, following your actions? Explain how	Yes ☐	No ☐

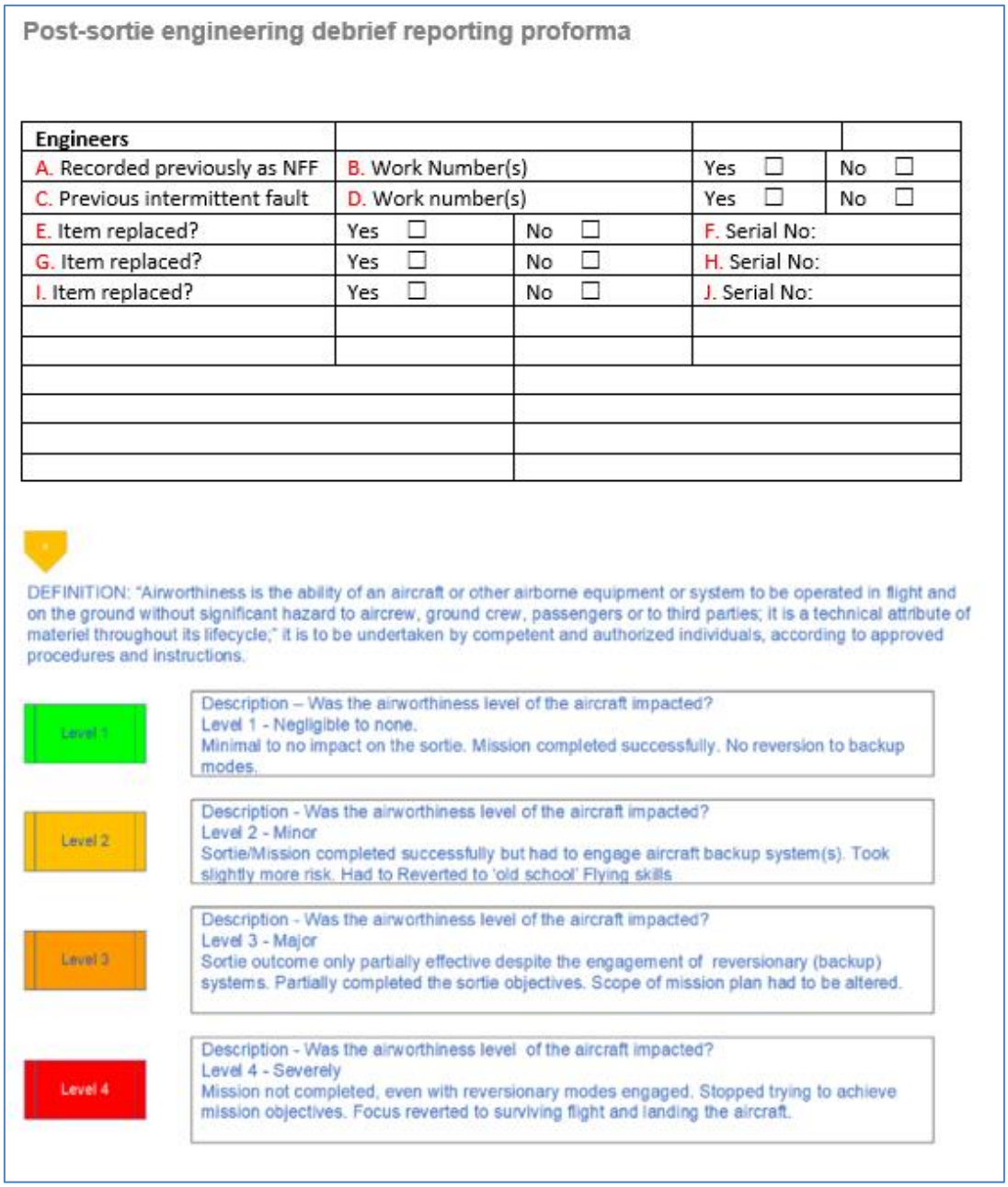
13. Systems(s) – Select those that apply								
1	Avionics	☐	5	Engine	☐	9	Hydraulics	☐
2	Communication	☐	6	Fuel control	☐	10	Navigation	☐
3	AFCS	☐	7	Electronic warfare	☐	11	Electrical power	☐
4	Instrumentation	☐	8	Armament	☐	12	Radar	☐
Others system - state								

14. Did you make a mark on the CVR/tape at the time of occurrence?	Yes ☐	No ☐
15. How was the sortie impacted?		
16. Did the fault affect the aircraft handling?	Yes ☐	No ☐
17. Did the fault affect the airworthiness[1]? State airworthiness level post flight – 1 – 4	Yes ☐ Level 1 - 4	No ☐
18. Did the fault affect the air safety[2]?	Yes ☐	No ☐
19. Similar fault recorded previously as NFF?	Yes ☐	No ☐
20. Similar faults previous intermittent fault?	Yes ☐	No ☐

[1] "Is the ability of an aircraft or other airborne equipment or system to be operated *in flight and on the ground* without significant hazard to aircrew, ground crew, passengers or to third parties; *it is a technical attribute of materiel throughout its lifecycle;*" ***it is to be undertaken*** **by competent and authorized individuals, according to approved procedures and instructions.** (Adapted from: MAA, MAA02 Glossary, 2020).

[2] Air safety "*the state of freedom from unacceptable risk of injury to persons, or damage, throughout the life cycle of military Air Systems.*" (MAA, MAA02 Glossary, 2020).

Figure 6-33: PSED proforma – Page 1



Post-sortie engineering debrief reporting proforma

Engineers				
A. Recorded previously as NFF	B. Work Number(s)		Yes ☐	No ☐
C. Previous intermittent fault	D. Work number(s)		Yes ☐	No ☐
E. Item replaced?	Yes ☐	No ☐	F. Serial No:	
G. Item replaced?	Yes ☐	No ☐	H. Serial No:	
I. Item replaced?	Yes ☐	No ☐	J. Serial No:	

DEFINITION: "Airworthiness is the ability of an aircraft or other airborne equipment or system to be operated in flight and on the ground without significant hazard to aircrew, ground crew, passengers or to third parties; it is a technical attribute of materiel throughout its lifecycle;" it is to be undertaken by competent and authorized individuals, according to approved procedures and instructions.

Level 1

Description – Was the airworthiness level of the aircraft impacted?
Level 1 - Negligible to none.
Minimal to no impact on the sortie. Mission completed successfully. No reversion to backup modes.

Level 2

Description - Was the airworthiness level of the aircraft impacted?
Level 2 - Minor
Sortie/Mission completed successfully but had to engage aircraft backup system(s). Took slightly more risk. Had to Reverted to 'old school' Flying skills

Level 3

Description - Was the airworthiness level of the aircraft impacted?
Level 3 - Major
Sortie outcome only partially effective despite the engagement of reversionary (backup) systems. Partially completed the sortie objectives. Scope of mission plan had to be altered.

Level 4

Description - Was the airworthiness level of the aircraft impacted?
Level 4 - Severely
Mission not completed, even with reversionary modes engaged. Stopped trying to achieve mission objectives. Focus reverted to surviving flight and landing the aircraft.

Figure 6-34: PSED proforma – Page 2

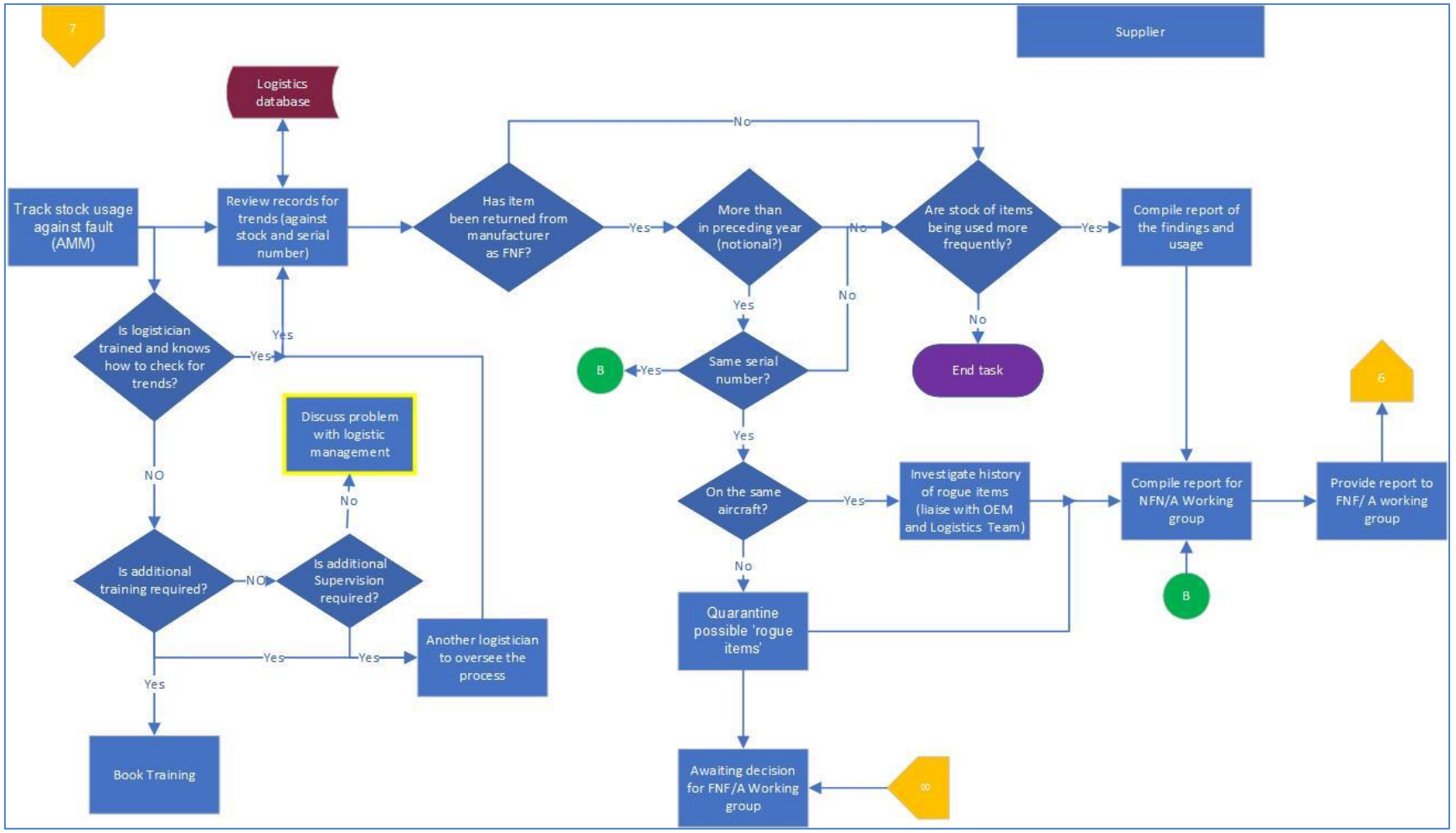


Figure 6-35: Logistic flow chart

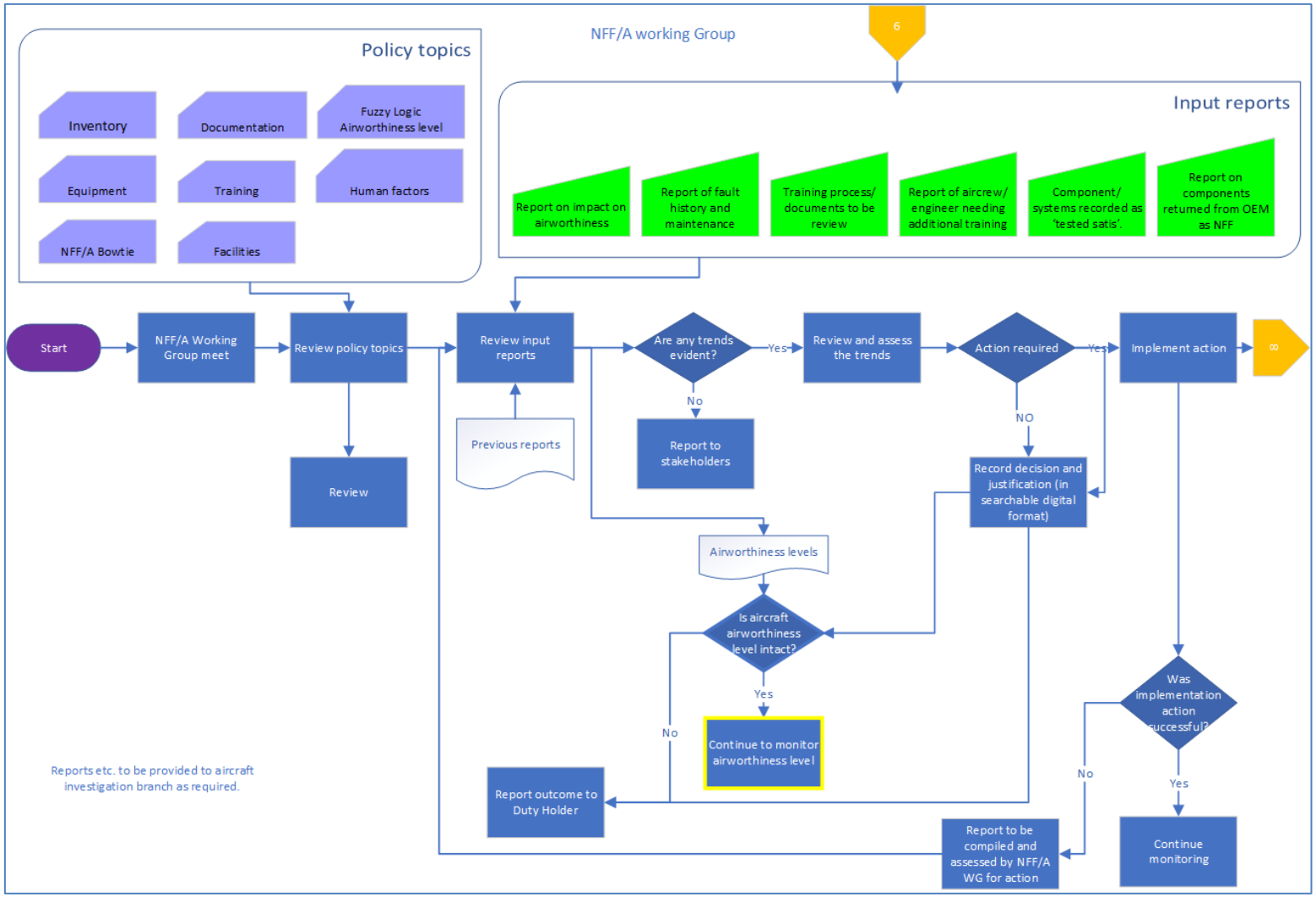


Figure 6-36: NFF and airworthiness working group

6.8 Summary

This chapter has holistically analysed the NFF phenomenon relative to the airworthiness environment. It has been based on primary and secondary data from the findings from the literature review, interviews, questionnaire and aircraft maintenance data. In doing so the complexity of the socio-technical systems has been evident. The '*as is situation'* was the starting point for understanding the problem with addressing the impact of NFF on airworthiness. This included the key stakeholders, such as the aircrew, engineers, logisticians and management. The influence diagram, Bowtie diagram and FRAM model with the analysis all demonstrate the influences of training, a dedicated space for the PSED, and competent stakeholders, including aircrew, engineers and the organizations' management. The Bowtie barriers to minimize the threat to the top event (*Engineering diagnostics resulted in NFF being recorded (Release of aircraft with FNF))*, were updated to reflect the FRAM analysis as a means to dampen the resonance and highlight the critical areas, i.e., those to be targeted to minimize the occurrences of NFF on airworthiness. Moreover, the FRAM analysis identified internal and external variabilities with potential indicators. The Sugeno fuzzy logic inference established a link between the differing aircrew and engineers' assessment of an aircraft's airworthiness levels based on NFF or intermittent fault occurrences. The outcome of this leads to a means to assess the aircraft's overall airworthiness risk level for different risk matrices. It enables the airworthiness fuzzy logic to be flexible to align with different organizations' views of airworthiness levels and risk appetite. Moreover, it meets Objective 4, to devise an approach to be used by aviation establishments to assess the level of NFF and its impact on airworthiness.

All of this analysis was included in the NFF/airworthiness flow charts, which should be viewed as a key policy document for an aviation organization, (specifically the MOD), to contribute to the organization's NFF policy, as advocated by ARINC (2008). The impact and critical effect of NFF on airworthiness were highlighted from the fuzzy logic analysis and fed directly to the Duty Holder's decision-making process. Any link between NFF and

airworthiness that poses a significant hazard to the operators, engineers third parties etc., is critical and should be elevated for analysis. It relates to a possible risk to life and further investigation is warranted.

To support the analysis and to prevent any researcher bias, the FRAM analysis was reviewed for completeness and accuracy by four SMEs. Moreover, in Task 2, the fuzzy logic was based on 11 SMEs' viewpoints to remove any individual's bias and to show the effect of combining different assessments of NFF. Table 6-11 was reviewed by a SME for accuracy. The following aspects are original work and analysis:

- FRAM NFF/airworthiness model and analysis
- Bowtie NFF/airworthiness model
- FRAM to Bowtie,
- Fuzzy Logic inference for airworthiness
- Engineers' view of the impact of NFF on airworthiness, is an acceptance that it is not binary, yes-no.

The requirement now is to answer the research questions and assess how the Objectives have been met in achieving the Aim.

7 DISCUSSION

"It is an old axiom, and well said, that *Beauty is in the eye of the beholder"*
(Hungerford, 1878)

The link between NFF and airworthiness is in the judgement of the beholder.

7.1 Introduction

All interpretation of information is down to the reader, with experiences, knowledge, qualifications and behaviours all contributing to the final outcome. This research aimed at establishing whether a link exists between NFF and airworthiness. To address this, an assessment of the analysis against the research Objectives, Questions and Aim will follow. It will establish the link of NFF to airworthiness, whilst addressing gaps in the literature and previous research. Moreover, it will highlight the original contribution to knowledge, i.e., that which "advances knowledge in the field of research", namely (a) "filling a significant gap in the research", (b) "using established techniques or approaches in a new context", (c) "developing a new … model" and (d) "challenging … prevailing …theories" (Craswell, 2005. p.174). As such the following 'original contributions' are asserted.

a) The aircrew's view towards NFF and specifically in relation to airworthiness.
b) The joining of the Bowtie and FRAM approaches emphasizes the critical aspects on which to focus to reduce the occurrence of NFF and reduce the impact on airworthiness.
c) A Sugeno fuzzy logic inference model to aid the assessment of an aircraft's airworthiness level based on the views of aircrew and engineers.
d) Assert that there is a link between NFF and airworthiness and as such is a serious concern that duty holders must consider when establishing if a system is ALARP and tolerable.

7.2 Research aim, research questions and objectives

The main aim of this research was to:

Explore the relationship between the NFF phenomena and airworthiness to establish if there is, or is not, a link between the two.

From this, two research questions were developed.

1. Is there a link between the phenomena of no fault found and airworthiness?
2. Do aircrew perceive a link exists between the phenomena of no fault found and airworthiness?

The first question has been partially met from the literature review.

The objectives to achieve this research aim were split into two. Objectives A and B were conducted during the literature review. From the Literature Review, Objectives 1 to 5 were devised.

The Literature Review objectives to support achieving the aim were:

A. To explore current theories for different definitions of airworthiness and NFF and provide ones to be used as the basis for this research.
B. To establish the current understanding of NFF across different industries and the perceived impact of NFF upon operations.

The overarching research objectives to support the aim were:

1. To determine the views of aircrew and accident investigators on the impact of NFF and any links to airworthiness and to assess any differences from the literature view.
2. To analyse the results to establish strengths and weaknesses of current processes that surround NFF and link airworthiness.
3. To explain the links between NFF and airworthiness.
4. To devise an approach to be used by aviation establishments to assess the level of NFF and the impact on airworthiness.
5. To make recommendations for improving the knowledge of NFF and the link to airworthiness.

Objective 1 was the primary one, as it provided the source of primary data on which the other objectives were dependant on. Moreover, it met a key

requirement of providing original contribution to the discipline by “filling a significant gap in the research” (Craswell, 2005. p.174).

7.3 The NFF and airworthiness problem

In the infancy of aircraft design and development, most failures were mechanical with little to no electronic components. As aircraft developments advanced more electrical and electronic components and software were introduced. Furthermore, as the complexity of aircraft increased, including the sociotechnical aspect, so too has the number of NFF reported. This correlation needs to be considered when designing, developing, testing and certifying aircraft.

However, within the literature, the link of NFF to airworthiness was not definitively presented. Copernicus (2017a) sought views from senior airworthiness and support technical managers on whether NFF affected air safety and opinion was divided, with some including airworthiness and providing caveats for when it might. Air accident reports, both military and civilian, both alluded to it and occasionally it was presented as a contributory factor (AAIB, 2012a; MOD, 1984). In addressing Objectives A and B, different disciplines were considered for a definitive definition of both NFF and airworthiness. Neither term had a definitive definition and this contributed to the problem of proving a link between the terms. In 1956, Tye asserted that airworthiness had no satisfactory definition (Tye, 1956) and while there is now consensus to some degree it is not definitive. Airworthiness included a ‘technical attribute’, being designed to an approved standard, being certified and without significant hazard to the occupants and those on the ground. Other definitions included the need for competent individuals (defence.gov.au, 2015). The ‘technical attribute’ provides a link to NFF, as an inherent characteristic that may be live or dormant. Moreover, to understand NFF and airworthiness, competent individuals, including being experienced and qualified, were required. A consequence of having this is communication and agreement between the operator, the OEM and the designer on which airworthiness and NFF definitions to use. Without this common understanding, it is unclear how useful the analysis will be. Therefore, this needs to be identified and remedied to aid the assessment of the NFF on airworthiness

implications between these parties. From the literature review, these individuals were not always evident. Moreover, a competent and 'accountable' individual was required to assess the airworthiness and declare the aircraft ALARP and tolerable. This person is the duty holder (HSE, no date-a; MAA, 2021). The requirement for competent individuals was acknowledged by Kritzinger (2006) and Haddon-Cave (2009). The literature did not provide a means to aid the duty holder to assess whether an aircraft with a NFF or a history of NFF, was ALARP and tolerable. Applying the following definitions this analysis supports an approach to be taken based on the views of key stakeholders, namely the aircrew (first party) and engineers (second party - ground crew).

> Airworthiness 'is the ability of an aircraft or other airborne equipment or system to be operated *in flight and on the ground* without significant hazard to aircrew, ground crew, passengers or to third parties*; it is a technical attribute of materiel throughout its lifecycle;' it is to be undertaken* by competent and authorized individuals, according to approved procedures and instructions. (Adapted from MAA, 2015c; defence.gov.au, 2015)
>
> NFF is "the output of a diagnostic process where the root cause of the reported fault cannot be verified" (Khan et al., 2016).

It is declared that Objectives A and B have been met.

7.4 Objective 1 - aircrew and AAI views of NFF

The gap in the literature was the aircrews' view of NFF. As a group identified in the airworthiness definition and NFF assessed as a technical attribute, their view was essential to fully appreciate the scope of the problem and any linkages between the two terms, perceived or otherwise. From interviews and the questionnaire, key themes emerged with trust between aircrew and engineers being an important aspect. This was presented as a contributory factor to the number of NFF recorded. Further, the engineers' lack of aircraft system knowledge, a reluctance to start complex and time-consuming diagnostic work near shift handover, misbelieving the aircrew, poor communication due to terminology differences and lack of training for how to conduct the PSED were

assessed as other causes of NFF being recorded. The fact that terminology was an ongoing problem is concerning as it was identified in aviation before, regarding crew composition, as impacting the ability to choose the task-specific skill suitable for selecting the best strategy for generic co-ordinating skills (Bowers, Jentsch and Salas, 2000). The aircrew had an understanding of NFF and airworthiness, although these had not been gained from training. This lack of formalized training has an impact on operational success and flight safety (Flewwelling, 2012; Pickthall, 2014). These themes should cause concern for the duty holder where 'competent' individuals are required and these findings do not support that view. Besides, as Tye (1956) implied, airworthiness was assessed as satisfactory by an individual. Additionally, SME(E) highlighted that even between engineering trades non-common terminology exists, which can also impact the diagnostics completed and how faults are recorded as being cleared.

Importantly, intermittent faults and recorded NFF were frequently expected and for some considered the norm for the aircrew, further, they were distractions to the aircrew and thus a safety concern. This aspect had not been included in previous NFF literature. Workload, both physical and mental, was linked to situational awareness and it was acknowledged that the workload affected the effort and attention required (Cooper and Harper, 1969; Salas and Maurino, 2010) but airworthiness was not included in the analysis. However, the complexity of modern aircraft resulted in more NFF being recorded with the most frequent systems susceptible to NFF identified by the aircrew as avionics, communication and flight control. This aligned with the views of the engineers (Hockley, Lacey and Pelham, 2016). Ungar (2015) found that NFF contributed to customer dissatisfaction and reduced confidence in the product. Not a direct link to the aircraft, the number of NFF recorded has affected the aircrews' confidence in, and satisfaction with, the engineers and their diagnostic skills. This was directly identified as a contributory factor for the diminished trust between both parties. Trust has been acknowledged as impacting dependence between parties, a sense of security and safety (Psychology Today, 2023), which establishes a direct link to the airworthiness definition where the term 'no significant hazard' to

personnel is explicitly stated (Section 2.4). If there is a ‘significant’ hazard the aircrew are not safe.

A research limitation of the aircrew interviews is that they were only from current or previous RAF aircrew. Two of these also had civilian aviation flying experience. This impacts the wider external validity of the analysis. However, from an internal validity perspective, the interviews did provide a measure of what was intended to be measured (Wilson, 2014). The interview questions and transcripts (Appendix A, A.3 and A.5) provide a means for reliability as they provide transparency so others can judge the analysis and findings and can “replicate … [the] study if they wished to do so” (Saunders, Lewis, and Thornhill, 2016, p.192).

The AAI understanding of NFF was noted in the Literature review. They had received no explicit training on NFF but did agree it would be beneficial as currently, it was by osmosis. Similarly, they viewed the engineers’ understanding of NFF was by osmosis. The AAI would only include NFF if it appeared to contribute to the accident; only then would it be pursued. They also experienced mistrust between engineers and the aircrew. Importantly, they did acknowledge the impact of NFF on airworthiness and that it was a distraction for aircrew and consequently impacted flight safety.

The interviews and survey addressed Objective 1 and ascertained the aircrew’s views regarding NFF and its impact on airworthiness. Over half the aircrew surveyed declared that NFF and recurring NFF affected the aircraft’s airworthiness and air safety. This is assessed as new knowledge as it fills an important gap in the current research. Further, these findings were key contributors to the subsequent analysis to establish methods and an approach to addressing NFF and airworthiness. Moreover, the aircrew views positively support the view that a link is established between NFF and airworthiness. This is further explored in Section 7.10.2 with regards to Research Question 2. However, as most questionnaire responses were from RAF aircrew this impacts the wider generalizability of the findings.

As per the interviews, the AAI questions and transcripts (Appendix A, A.4 and A.5) provide a means for reliability.

7.5 Objective 2 - strengths and weaknesses of current processes that contribute to the link between NFF and airworthiness

The following details the main strengths and weaknesses within current aviation organizations, mainly the MOD, RAF, as most survey responses were from that organization, that contribute to the link between NFF and airworthiness.

The literature review expounded on the strengths and weaknesses of NFF and airworthiness in different industries. Although none consider the two together. Haddon-Cave (2009) proposed one definition for airworthiness but other organizations proposed others (e.g., IATA, 2008; CAA, 2017; EASA, 2017; See Table 2-1). Whilst the MAA (2015c; 2022c) presents an airworthiness definition, it contains ambiguities. It was for these reasons this research presented a definition to be used within this analysis (Section 5). These still support the notion presented by Tye (1956) that airworthiness does not have one, clear definition. This is a weakness of the current system. Each aviation organization will have to state the airworthiness definition they adopt. It is unclear how informed discussion can take place without consensus on key terms.

A similar weakness exists regarding NFF. There is no explicit definition and there are still numerous ways to record and hide a NFF, e.g. ‘tested satis’, no problem found, as succinctly confirmed in the book No Fault Found; The Search for the Root Cause (Khan et al., 2015). This was also observed from analysing the aviation maintenance data (Table 6-14). Reviewing literature since 2000, numerous authors have presented this as a problem (e.g., Jones and Hayes, 2001; Thomas, Ayers and Pecht, 2002; see Table 2-2). Without understanding what NFF means and how it is manifested, it becomes difficult to demonstrate a clear link to airworthiness. Again, it was for this reason, a specific NFF definition was used within this research (Section 5).

The surveys highlighted the poor resources that the engineers and aircrew have to use, such as no specific facility in which to conduct the PSED, an AMM that contains insufficient detail to allow the depth or variety of diagnostics required to find the fault or test equipment that does not test the systems to the depth

required. The latter is affected by the reliability of the test process and the test set used (Rehman and Rigby, 2021). Additionally, there are reports of a lack of time to conduct the PSED or for the engineers to view the aircraft's history for the indicated fault, the fault history of the aircraft or the history of a specific component. These are all weaknesses of the current processes.

Objective 1 was the primary one, as it provided the source of primary data on which the other objectives were dependant on. Moreover, it met a key requirement of providing original contribution to the discipline by "filling a significant gap in the research" (Craswell, 2005. p.174).

7.6 The NFF and airworthiness problem

From the survey, it is apparent that for both terms, airworthiness and NFF, no formal training is provided or ever has been. Jones and Hayes, (2001) and Flewwelling (2012) stressed the importance of training and refresher training for understanding how systems worked. From the survey, it is established that the aircrew has experienced and can provide an explanation for the NFF phenomena. However, a weakness is that they do not understand the engineers' terminology for how a fault has been diagnosed and declared a NFF. Terminology adds to poor communication, as evidenced in the Ford car problem (Thomas, Ayers and Pecht, 2002). Moreover, the aircrew expressed a view that the engineers did not know how the aircraft systems were linked and worked together and this has been identified as an area where training would improve NFF recording (Jones and Hayes, 2001; Flewwelling 2012).

The aircrew and engineers are not co-located. Moreover, once the PSED is completed that is frequently the last time the engineers will see the aircrew, until the next flight. These two factors are weaknesses as the engineers doing the diagnostics may not be the same as those who attended the PSED due to shift patterns. Having the ability to contact the aircrew for further information about the fault and the conditions at the time would aid the diagnostic process. These weaknesses are compounded by having inexperienced engineers and aircrew running the PSED. It is not proposed that in these cases SQEP aircrew and

engineers should attend the PSED to state what the fault was but to support the PSED to ensure the depth and breadth of relevant questions are asked to ensure a full situational awareness surrounding the fault is recorded. This would also act as on-the-job training and aid the aircrew and engineers with the relevant questions to be asked to obtain a fuller picture of the fault. This also links with using a dedicated PSED proforma to help assess the airworthiness level and to identify those systems that were believed to cause the fault.

A strength of the current system is a set form within aviation organizations for recording the aircrew fault and for the engineering work completed. The form will differ across organizations. A weakness is that the form does not focus the aircrew or engineers on the aspect of airworthiness—how would you assess the airworthiness of the aircraft?—or whether the fault has previously been recorded as NFF or intermittent. Having this information would allow the aircrew to express their views regarding the aircraft's airworthiness, especially for reappearing faults previously cleared as NFF. For airworthiness, this is an important consideration as they, the aircrew, are named within the airworthiness definition. Also, it would focus the engineers on previous diagnostics and maintenance that may in hindsight have been unsuccessful.

The organizations and engineers continue to permit poor practices that have been identified as impacting the number of NFF recorded. These poor practices were previously identified, e.g., by ARINC (2008) and Khan et al. (2015). To address NFF, organizations should do trending analysis to monitor problematic faults or changes across a period. Figure 6-23 clearly shows the spike in the number of autoflight NFF recorded. The associated OEM’s data did not indicate any incorrectly recorded NFF for the autoflight system. The trending analysis would have identified this abnormal increase sooner. Comparing the trend with Figure 6-26 would have indicated how the average for 12 months (20%) had become condensed for 2021 (year 13) where the average NFF recorded jumped to approximately 65%, an increase of 300%. In 2015 the MAA (2015) stipulated the need to analyse for maintenance and fault trends. Yet in 2022, the MAA use the word can, “Data gathered from the Fault reporting process can then be used

for identifying fault trends and providing information on equipment performance and reliability." The emphasis on trending appears diminished. It is difficult for engineers to assess any trends when they do not have access to an aircraft's fault and maintenance history, especially not in an electronic searchable format. This resource needs to be introduced.

A caveat is made that the author is not qualified to make statements regarding the psychology of the aircrew's assessment of trust or mistrust. So, based on the explanation of trust provided in Section 4.3.5 a general interpretation following the analysis of the survey is presented based on the need to be able to depend on, rely on, have confidence in another person and to have a "sense of security" (Psychology Today, 2023). An advantage of the current system is that trust exists between the aircrew and engineers. Aircrew opined that they were not concerned about the recurrence of the fault as it was 'an engineering decision' (Q23 - Figure 5-12). Further, it exists between aircrew and the management, both aircrew and engineering. For the latter relationship, NFF can be discussed to raise observations and concerns. However, this is linked directly to the mistrust of some aircrew towards some engineers. Some aircrew chose to address NFF issues with management as they did not feel they were believed by the engineers and that engineers were not completing the necessary diagnostics to find a fault. They assessed that they could not depend on the engineers. The following two examples from the survey exemplify that view:

- 1)The ground crew don't believe me, 2) they didn't take this seriously, 3) the system isn't reliable
- NFF due to failure of engineers to believe it likely and check properly.

In contrast with those aircrews who trusted the engineers when a fault recurred, some aircrew expressed the top reason for being concerned was due to insufficient engineering diagnostics. The pilot and AAI interviews raised similar concerns. The mistrust that is allowed to continue between aircrew and engineers, even though it impacts the number of NFF recorded and the aircrew's perception of the aircraft's airworthiness level, will contribute to the positive, unstable loop A. The influence diagram (Figure 6-2 and Section 6.2.2) considered

self-induced pressure on the engineers. However, mistrust between both parties, if known and not addressed will impact communication, the outcome of the PSED, fault diagnostics and ultimately the number of NFF recorded and the aircrew's perception of the aircraft's airworthiness. Whilst a simple explanation of trust has been presented (Section 4.3.5), its impact on NFF and airworthiness has become evident from the analysis. Trust is required for collaboration, good working relationships and it moves from self-protection to promoting a safe environment. A lack of trust is judged as a trait of poor integrity in a person (Psychology Today, 2023). Linking this to the fuzzy logic inference analysis and the requirements of the NFF/Airworthiness working group will influence the advice given to the duty holder regarding the overall airworthiness. Thus, it is recommended that the relationship and trust between the aircrew and engineers be researched further.

Whilst most of the analysis has been based on the military response to the questionnaire, there are consequences for civil aviation companies. The close working relationship between military aircrew and engineers is reduced within their civil counterparts. Whilst there were some civil aircrew responses to the questionnaire there are insufficient responses to make any statement regarding trust between the parties. However, for military aviation, specifically the RAF, these weaknesses should be acknowledged and addressed. These findings suggest the system is recoverable but suitable resources, including training, are required. Harmony within an organization leads to smoother more efficient operations. Whether military or civilian, there will be an impact in terms of cost, budget, time and operations. So, the link between NFF and airworthiness needs to be seriously acted upon.

It is asserted that Objective 2 was met.

7.7 Objective 3 - links between NFF and airworthiness

The first demonstration of a link between NFF and airworthiness is evident in the airworthiness definition, which includes the term 'technical attribute'. As previously stated, an attribute is a characteristic that is inherent in a piece of equipment, i.e., it has been incorporated into the design. This may be done

consciously or subconsciously. The fact that faults can remain dormant (Avižienis, Laprie, and Randell, 2001) does not remove or nullify the link. In fact, accepting that faults can remain dormant should intensify the diagnostics required before declaring a NFF. The fault may be dormant and reveal itself at a safety critical time, divert the aircrew's attention, increase the workload and increase the hazard—the view from a Task 2 SME. This was stated as a reason for the engineer's airworthiness assessment level increasing (Section 6.5.2). Moreover, Harris et al. (2000) identified the requirement for the aircrew workload to be tolerable for a given scenario. Accepting dormant faults, which are acknowledged to result in NFFs being recorded, impacts the aircrew workload and the faults may occur or recur at safety-critical times, it is suggested that this should be a concern for the aircrew and also the Duty Holder in assessing that the aircraft is airworthy.

The sources of primary data collection methods were assessed for reliability and validity (Sections 3.8.1, 3.8.2 and 3.9.1), which was important as they add credibility to the research and this is important as they endorsed this link between NFF and airworthiness. The interviews with aircrew and AAI confirmed the link between NFF and airworthiness existed. The increased workload, distraction, and frustration were presented as factors that the NFF contributed to causing 'a significant hazard'—words that form a major component of the airworthiness definition. One interviewee declared "It's the only time I have refused to take an aircraft" following a fault repeatedly being recorded as NFF. Furthermore, an AAI, with a pilot's licence, avowed "It's more about the continuing airworthiness …, to the people who are not understanding the failure modes effectively and how they may present." The pilots, with an average of 24 years of flying experience, and AAI interviewed were experienced in their fields and adjudged to be competent to claim a link between NFF and airworthiness.

Likewise, the questionnaire presented a similar view with over half the respondents stating airworthiness was affected by the reappearance of a fault. A definition of NFF and its relationship to an intermittent fault were provided for the questionnaire. As was the airworthiness definition, to ensure a common

understanding of the term was considered for the responses. It should be noted that most questionnaire responses were from male RAF aircrew, so whilst external validity is acceptable for the RAF aircrew population, it is not acceptable for British military aircrew or the civil aircrew population.

The influence diagram (Figure 6-2) presented the NFF and airworthiness problem. Four positive, unstable loops (reinforcing) were analysed as well as the impact the instability could have on the system. If the level of airworthiness increased (i.e., improved) the number of NFF reduced. Alternatively, if the number of NFF recorded increases the airworthiness level will decrease. Accepting this, the threats to airworthiness were recognized and barriers to reducing the possibility of a Top Event '*Engineering diagnostics resulted in NFF being recorded (Release of aircraft with FNF)*' resulting in a Hazard '*Operating an aircraft in the air or on the ground*' were devised. Relating this to the fuzzy logic airworthiness levels an increase in airworthiness level would see the aircraft airworthiness level move along the scale from 10 towards zero.

It should be recognized that the engineer SMEs who completed Task 2 did not refuse to complete the task or question the idea that airworthiness would not be maintained. There were differing views expressed, for example, one SME would query why an aircraft would continue to fly with a NFF, whereas another SME would follow the process of permitting NFF until there were six occurrences before a different action was taken. However, each of these SME views supports the link between NFF and airworthiness. As per the questionnaire, all Task 2 responses were from male RAF engineering officers, so whilst external validity is acceptable for the RAF engineering population, it is not acceptable for British military aircrew or the civil aircrew population. Although, it is accepted that there are strong similarities between the British Army and Royal Navy engineering training and that provided to the RAF engineering officers who acted as SMEs.

7.8 Objective 4 - approach to assess the link between NFF and airworthiness

The following explains how different approaches have been used to reinforce the view that NFF is linked to airworthiness and to provide a means to assess this link. The influence diagram was discussed above so will not be repeated here but it is an approach to show the link between NFF and airworthiness. This section will focus on the original contribution.

7.8.1 FRAM and Bowtie

The following approaches were implemented to demonstrate the link between NFF and airworthiness: Bowtie, FRAM and Sugeno fuzzy logic inference. These all provided input to the flow charts (Figure 6-32 to Figure 6-36) that provided an approach to better manage NFF and airworthiness. These approaches were developed from the findings of the primary and secondary data and specifically the views of predominantly RAF aircrew regarding NFF and airworthiness. Combining these approaches demonstrated that NFF contributed to airworthiness and further that airworthiness is not binary. The following key requirements were identified:

- for aircrew and engineers to be assessed as SQEP (or to be supported by SQEP personnel),
- for training on NFF, airworthiness and how to complete the PSED,
- for a dedicated space to hold the PSED,
- for a PSED proforma that includes the assessment of the aircraft's airworthiness level and identification of the system with the fault,
- for the aircrew to provide an assessment of the aircraft's airworthiness level following the flight,
- for the engineers to have access to and to analyse the aircraft's fault history for NFF and intermittent faults before conducting any diagnostics,
- for a process for engineers to recall the aircrew to provide further information regarding the fault reported,

- for the engineers need to be trained in how to complete the engineering paperwork,
- for aircrew to be trained on engineering terminology to better understand how faults, specifically NFF, have been cleared, and
- for a dedicated NFF/airworthiness working group and to create an organization's NFF/airworthiness strategy.

Many of the above have been recognized in the literature. However, by combining these approaches the key factors that could potentially cause instability and resonance in the system and between NFF and airworthiness have been identified. By incorporating the FRAM analysis into the Bowtie and indicating the critical factors, a simple representation (Bowtie with criticality identified via red and amber colours) of the key factors is available to management. These factors are those that need to be addressed or targeted to maintain the system's safety and airworthiness levels or to prevent any potential resonance. Bowtie diagrams aim to communicate risk (De Ruijter and Guldenmund, 2016) and this includes communication within and between the aircrew, engineers, managers and the duty holder. FRAM complements the Bowtie analysis as it focuses on normal, daily activities without needing an obvious cause or events being activated linearly (Hollnagel, 2012). Moreover, it can be used to assess *work-as-done*, e.g., the Herald of Free Enterprise disaster (Hollnagel, 2012, p.108), or the G-SPAO aircraft crash in Glasgow based on the AAIB report (AAIB, 2015), or the work-as-imagined. The FRAM model (Figure 6-10) enabled the current 'as is situation' to be developed to incorporate the original Bowtie barriers and findings from the literature review and primary data to analyse the potential '*work-as-imagined'* solution. It was this NFF/Airworthiness '*work-as-imagined'* FRAM solution that the SMEs critiqued for accuracy and relevancy (Task 1, Appendix D, D.3).

Having the FRAM analysis reviewed by SMEs provided reliability in the output and reduced any researcher's bias influencing the output. However, as per Section 6.4.3, the external validity of the FRAM model and analysis is limited to RAF engineers, aircrew and operation, as the FRAM model and analysis were only reviewed by RAF engineering officers. The cross-analysis and presentation

of key ‘critical’ factors between Bowtie and FRAM is an original contribution; as it is “using established techniques or approaches in a new context” (Craswell, 2005, p.174).

However, using this analysis with commercial or military aviation organizations enables the ‘possible’ impact to be assessed. It would enable a review of resources, such as no dedicated PSED location, to be conducted. The impact is to be assessed with a focus on reducing the impact on airworthiness. Moreover, it allows an incident, e.g., a ‘near-miss’ to be analysed. For example, if the number of NFF for an aircraft autoflight system increased but was not observed, and the aircrew reported a higher airworthiness level number (e.g., 4-Major or 3-Severe), the FRAM might be used to work through the event to establish whether the resonance was expected. From this, the Bowtie barriers and FRAM mitigation could be reassessed/ reinforced. If this was not previously identified, the FRAM model can be updated. This enhances an organization’s understanding of the impact of NFF on airworthiness.

7.8.2 Fuzzy logic inference analysis

“The fuzzy principle states that everything is a matter of degree”, it blurs boundaries (Kosko, 1994, p.18). One person’s view of what is airworthy or a NFF is different from another—this is a fuzzy concept. The lack of aircrew training on what is airworthiness was identified as an issue. Being able to assess the airworthiness against an unestablished and non-agreed definition will lead to further ambiguity. This analysis provided definitions for both airworthiness and NFF. Further, four levels of airworthiness from an aircrew perspective were presented (Figure 6-33 and Figure 6-34). Engineers assessed, from a personal perspective, how the aircrew’s assessment of the airworthiness level would be adjudged from an engineering assessment of the aircraft’s airworthiness level when NFF were occurring, i.e., what the impact on the aircraft’s airworthiness would be, from negligible to severe. For 10 of the 11 SMEs who completed Task 2 (Appendix E, E.1) their average experience in aviation engineering was almost 32 years. This experience and depth of knowledge provided reliability to the submissions. One SME did not provide his experience. However, it is

recommended that Task 2 is repeated with a sample of at least 100 engineers from the population providing their views as this will strengthen the fuzzy logic inference and surface plots from which the overall aircraft airworthiness level is established. This limitation is discussed further at the end of this Section.

A limitation of this analysis was that the aircrew was not surveyed for their views on the demarcation between one level and another. It is recommended that this is completed for at least 100 aircrews. This will reinforce the outcome and overall assessment of the aircraft's airworthiness level when combining both aircrew and engineers' assessments.

Both the aircrew's and engineers' views of airworthiness are vague and dependent on the individual making the assessment, thereby meeting the fuzzy principle concept. By combining aircrew (assumed a Gaussian distribution) and engineers' (real) vague and fuzzy viewpoint of the airworthiness of an aircraft an overall airworthiness level of the aircraft was created (Figure 6-19). The output of overall airworthiness value from the fuzzy logic inference was cross-referenced with the description and potential outcome (consequences if flown) (Table 6-11). This information contributes to the approach to aid the duty holder in assessing the airworthiness of the aircraft and whether it is ALARP and tolerable. The fuzzy logic inference is not an answer but an advisory tool to aid the decision-making process. What is ALARP and tolerable to one person is another fuzzy concept that would warrant further investigation against identified scenarios.

The key finding was that if more aircrew recorded the Level 4 assessments (severely impact the airworthiness of the aircraft) due to a NFF over a reduced period, from 12 down to one month, the more the engineers viewed the aircraft to be unairworthy. This appears logical. This is even when the engineering is conducted as per the AMM and the aircraft document set. The engineers did not view airworthiness as binary when presented with the number of recorded NFF. Their assessment further supports the view that NFF and airworthiness are linked.

This analysis is an original contribution. It used an established technique (Fuzzy logic inference via MATLAB fuzzy logic toolbox) in an original manner to provide

a reusable approach to support the assessment of whether an aircraft is airworthy or unairworthy. Moreover, it can be easily updated to incorporate an organization's risk matrix as the rules to be applied to the IF (x) AND (Y) THEN output. So, it is adaptable to an organization's risk appetite and assessment of airworthiness levels.

Each aviation organization's airworthiness level may differ. However, this fuzzy logic provides an adaptable advisory tool to aid the assessment of the organization's airworthiness level due to NFF. It can be easily adapted to incorporate the appropriate risk assessment. While the AAI interviewee (Number 5) indicated smaller organizations may practice unsafe procedures, larger, credible organizations might welcome the insight this advisory tool provides as another means to understand the NFF and airworthiness link and impact before taking action, with an aim to keep the aircraft ALARP and tolerable.

Whilst other research has considered multi-decision criteria analysis for the "Evaluation and prioritization of technical and operational airworthiness factors for flight safety" it was conducted from the stance that the "technical airworthiness status" was based on the premise that the "aircraft should initially be designed for safety" and this was founded on the initial airworthiness and type certificate (Şenol, 2020). The definition of technical airworthiness status was not given. What the fuzzy logic inference has established is that the operational and technical airworthiness if based just on the initial airworthiness and type certificate may be insufficient from the aircrew and engineer's perspectives.

To enable wider external validity of the findings, Task 2 should be undertaken by a sample of 100 engineers and aircrew (See Section 6.5.4). This could be conducted to meet the requirement of different companies or to provide wider generalizability of the research findings. Firstly, Task 2 could be repeated to gather responses from solely the RAF as this would strengthen or reframe the current findings. Moreover, aircrew views would be more accurate than the Gaussian distribution applied within the analysis. Alternatively, responses from a sample of 100 aircrew and engineers from another 'single' organization would test the research's wider applicability, external validity and establish similarities

and differences. A third option would be to canvas the views of 100 or more aircrew and engineers across a combination of organizations. From these, specific results for individual companies would be established and or generalized airworthiness levels, 3D surface plots and risk appetite findings could be established. These would support the duty holder's decision-making process by acting as advisory tools. Furthermore, to be of specific applicability to an organization, the risk matrix or matrices of those organization would have to be used to establish the fuzzy logic rules.

7.9 Objective 5 - recommendations for improving the knowledge of NFF and the link to airworthiness

When ARINC (2008) produced their guidelines, it was surmised that it was with the aim that their introduction and adoption would reduce the number of NFF reported. However, this does not appear to have been validated. The literature evidences the continuing number of NFFs across a variety of disciplines. NFF is still very much apparent as evidenced by the views of aircrew and engineers (Hockley, Lacey and Pelham, 2016).

To publicize the link between NFF and airworthiness, aspects of this research were presented to the ADS Military Aviation Safety Group (Lacey, 2021). This covered the following aspects:

- The training requirements to explain both NFF and airworthiness.
- Bowtie and the implementation of specific barriers to reduce the number of NFF being recorded that would negatively impact airworthiness. Note, this is to prevent and not hide NFF occurrences.
- FRAM and the resonances. How they can be used to develop and improve systems to reduce the potential impact on airworthiness from NFF.
- The proposed fuzzy logic analysis links both aircrew and engineering assessment of the impact of NFF on airworthiness.
- The development of flow charts to better understand and manage the relationship.

Industry members from across the different aviation companies expressed their interest in the content and analysis.

The fuzzy logic NFF and airworthiness analysis were also presented to the Military Aerospace and Airworthiness master's level students and MOD engineers and aircrew (Economou and Lacey, 2022). This presented the concept that airworthiness is not binary. It has variations and this is dependent on an individual's viewpoint. For many students, this was the first time they had been presented with the fuzzy principle and the concept that something they accept as being binary, airworthy or unairworthy, was not so clear. It was blurred. The boundaries between the two were not fixed.

These two events have only skimmed the number of aviation engineers who will face the decision about whether to record a fault as NFF. For many, the aspect of whether the aircraft is airworthy will be for the management to make and not the engineers.

To stress the impact of a fault that has not been identified or rectified by the engineers, the term no fault found, NFF, is usually stated. However, this suggests the seriousness of recording a no fault found is not appreciated. It is proposed that the term *fault not found* (FNF) should be used instead. Without this, the impact of NFF will never be truly accepted and reduced. There is no expectation that it will be eliminated as it is an inherent characteristic of a design. As expressed by an AAI interviewee, engineers are not trained to not find a fault.

To promote this original contribution and ensure the link between NFF and airworthiness is recognized the following are recommended:

a) The training for aircrew and engineers on NFF and airworthiness is essential. They contribute to the resonance within the system. The link between NFF and airworthiness must be covered along with the number of NFF recorded for an aircraft. This should include trending.
b) Aircrew and engineers need to be trained on engineering terminology used to explain faults and how they have been cleared so an agreed lexicon can be used.

c) A revised PSED proforma is required to ensure the aircrew's assessment of the aircraft's airworthiness level is recorded. Aircrew and engineers need to be trained on how to conduct a PSED and complete the proforma. Further, a dedicated location needs to be allocated for the PSED.
d) The belief that airworthiness is binary just because diagnostics and engineering have been conducted must be challenged. The aircrew and engineers are named within the airworthiness definition and may be the recipients of a 'significant hazard' because a fault is recorded, and recorded repeatedly, as NFF is no longer acceptable. The aircrew has expressed their concern.
e) The NFF/airworthiness Bowtie needs to be implemented with the barriers to reduce the occurrence of a NFF being recorded put in place. The system then needs to be reviewed periodically to assess any improvement in the number of NFF recorded.
f) The FRAM model and criticality scoring should be implemented. No system is perfect but from the aircrew survey, the current system does not ensure they are free from significant hazards.
g) Trust needs to be re-established and supported between aircrew and engineers. Poor communication, misunderstanding of terminology and rushing the PSED do not contribute to trust. This trust is essential if the NFF-airworthiness relationship is to be improved as it promotes a greater sense of safety and security.
h) Airworthiness and NFF definitions used between the different organizations that work together need to be agreed upon to enable constructive decisions and analysis to be conducted.
i) The recording of NFF needs to be formalized with agreed terminology. Even though proposed by ARINC this is still not being adopted.
j) Psychologist conduct research to establish the trust levels between aircrew and engineers and the impact this has upon operations, including NFF and airworthiness. This should be conducted across different aviation organization to establish any difference based upon people, process and procedures.

7.10 Research Questions

To support the aim of this research two research questions were devised. The following explains how these have been addressed. The questions will be addressed in turn and a statement will be made to state whether the questions have been answered.

7.10.1 Research Question 1

Research question 1 was as follows:

- Is there a link between the phenomena of no fault found and airworthiness?

A link is classified as “a connection between two people, things, or ideas” (Cambridge Dictionary, 2023c). The terms NFF and airworthiness were defined in Chapter 2. Airworthiness was concerned with an aircraft operating without a significant hazard to the aircrew etc. Whilst the airworthiness definition used within this research was based on the MAA (2015c) definition others included similar key terms. Most of the definitions included the need for the aircraft to be *designed* and *maintained* in accordance with a standard or ‘approved design’ (See Table 2-1). So, from this, the design of the aircraft, which includes the technical parts, is deemed of extreme importance. The design includes the technical attribute, where the attribute was defined as:

> “A quality or feature regarded as a characteristic or inherent part of someone or something.” (Oxford Dictionary, 2017)

With ‘inherent’ indicating the technical aspect had been consciously or unconsciously designed into the aircraft. This provides a link to NFF, which was assessed as a technical aspect of a component, system or aircraft, for example. The NFF definitions included the ‘technical standpoint’ or the equipment failure that the engineers cannot demonstrate exists (See Table 2-2). Moreover, literature has identified that technical equipment can have dormant faults designed in (Avižienis, Laprie, and Randell, 2001). Dormant faults are of importance as they link to intermittent faults and NFF being recorded as the

environmental conditions when the fault occurred cannot be reproduced. These faults can be ‘designed in’ and as Reason (1991) identified dormant errors are created by those remote from the operating environment, i.e., the designers and manufacturers.

Additionally, Harris et al. (2000) identified the requirement for the aircrew workload to be tolerable for a given scenario but as identified in Flybe aircraft DHC-8-402 Dash 8, G-JECF the intermittent fault resulted in a “significant distraction to the crew at a late stage in the approach” (AAIB, 2012b, p.26). The aircrew workload is important to acknowledge especially during the design stage of an aircraft. The workload should not result in mental resources being drained and result in diminished performance (Salas and Maurino, 2010). If this happens then it can result in a ‘significant hazard’ to the aircrew, ground crew, passengers or third parties. This links back to the airworthiness definition.

So NFF is linked to airworthiness by virtue of the aircraft technical design, how it is operated such that dormant faults can become activated or undetectable based on the operating environment, they can present a distraction to the aircrew that can result in a significant hazard to aircrew through to third parties. Furthermore, the approved procedures, e.g., AMM, may be insufficient to detect the NFF and continue to represent a significant hazard to the aircrew.

Therefore, from the dictionary definition of a ‘link’, a *connection* has been established between two things, namely NFF and airworthiness. Thus, it can be stated that there *is* a link between the phenomena of no fault found and airworthiness.

7.10.2 Research Question 2

Research question 2 was as follows:

- Do aircrew perceive a link exists between the phenomena of no fault found and airworthiness?

Much of the following has been expressed in addressing Objective 2 but it represented to assert the answer to this research question as it was fundamental to the research and the originality of the research.

The literature review did not provide a firm view on whether the aircrew perceived a link existed between NFF and airworthiness. This was why this research question was judged to be important as the aircrew are the significant 'first party' who should not be subjected to a significant hazard, as stated within the airworthiness definition. Furthermore, reviewing the definitions of airworthiness (Table 2-1) the aircrew are identified three times including the MOD/MAA definition. These are as 'aircrew' and 'competent and authorized individuals'. Thus, Objective 2, was established to ascertain the views of aircrew regarding NFF and airworthiness. This was achieved via the interviews (Chapter 4) and the questionnaire (Chapter 5), which was based on the interview questions and the literature.

Interviewees 1 to 4 and 6 were either operational aircrew or pilots. They asserted that a NFF did impact the airworthiness of the aircraft and could result in a breakdown of the airworthiness being assured (Section 4.3.6) and whilst the airworthiness definition focuses on the type design an interviewee expressed that "It's more about the continuing airworthiness …, to the people who are not understanding the failure modes effectively and how they may present". From the explanations provided the aircrew interviewed and those who responded to the questionnaire understood the terms NFF and airworthiness and were therefore adjudged as credible in stating whether a link existed between the NFF phenomena and airworthiness. This provides some validity to the answer to this question.

From the analysis of the questionnaire, it was established that many respondents had experienced a NFF, so their views are credible. Over half of the respondents expressed the view that NFF *had* affected the airworthiness. Furthermore, within the qualitative response, clear statements expressed this viewpoint.

> "some incidents have had minimal impact on airworthiness or safety whilst others have had a major impact."

This quote is of relevance as it provides a categorization of the impact of NFF on airworthiness, from minimal to major. This upholds the fuzzy logic analysis that airworthiness is not binary.

Like the engineers, the aircrew could confidently identify the systems most likely to result in a NFF or intermittent fault being recorded, namely avionics, communication and AFCS. A concern when considering how to reduce the aircrews' perceived link from NFF to airworthiness was that "the ground crew don't believe me; they didn't take this seriously; and the system isn't reliable." This links with the 'competent' aspect of the airworthiness definition.

Also evident from both the interviews and the questionnaire, is that the aircrew requires training on the terms and how NFF are manifested to raise the profile of the impact between the two terms.

Therefore, from the dictionary definition of a 'link', a *connection* has been established between NFF and airworthiness. Thus, it can be stated that the aircrew *does* perceive a link exists between the phenomena of no fault found and airworthiness.

This is of importance and should be of concern when conducting operations or maintenance. It should raise the profile of NFF occurrences and ensure they are monitored from the maintenance records and also the logistics chain, with items classified as NFF when returned from the repair organization. The aircrew's perceived link between NFF and airworthiness affects the trust between the parties involved and can result in a 'significant hazard' being presented. This further endorses the need to monitor and review NFF occurrences. The risk associated with a NFF needs to be ALARP and tolerable. The aircrew's voice and concern need to be heard.

7.11 Impact, importance and criticality

It was stated in Section 1.2 that this research will aim to establish what links there are between NFF and airworthiness and how these might be categorized according to impact, importance and criticality.

7.11.1 Impact

Impactful means to have “a powerful effect on a situation or person” (Cambridge Dictionary, 2023a). The situation is airworthiness. The person may be the aircrew, engineer or duty holder. The impact of NFF on airworthiness was addressed under the Literature review Objective B and throughout the analysis. It impacts four areas. economics, training, maintenance and safety.

It was evident from the air accident reports that a NFF impacted the airworthiness and consequently the flight. This impact can result in economic costs that may be intangible, especially in a military context where profit margins are not considered. The cost may be due to additional time for diagnostics and maintenance. The additional number of spares within the supply chain due to frequently changing components that after the test are assessed as NFF. The number of curtailed or cancelled flights, especially if these must be reprogrammed or impact the training and operational programme. Moreover, there may be a capability cost. In military operations with other national forces, the curtailed flight may have been for the only aircraft that had a specific capability that was being depended on. As previously stated, establishing the number of flights curtailed indicates the seriousness of the fault and the impact on capability (Copernicus, 2012). These can also damage an organization’s reputation.

The lack of training on the NFF phenomena and airworthiness results in more NFF or ‘tested satis’ being recorded. These in turn can result in a significant hazard to the aircrew. From the airworthiness definition, a lack of training impacts the competence of the personnel involved in flying and maintaining the aircraft. Moreover, the lack of training and understanding of NFF directly impacts the maintenance conducted to diagnose the fault.

Maintenance, and the design for testing and diagnostics, should be considered early in the aircraft’s lifecycle. During the design and testing phases, the notion of dormant faults should be accepted. Testing across the design envelope is required to minimize the occurrence of dormant faults. Additionally, any NFF should be monitored to determine if a trend exists, and if a specific event initiated a dormant fault. If so, this needs to be considered when creating or updating the

AMM. In doing so the engineers are better prepared for resolving faults quicker. The diagnostics and maintenance completed before a shift handover should be monitored to establish if ‘quick fixes’ to resolve the fault are conducted. This ‘quick fix’ approach results in more NFF being recorded and impacts the trust between the engineers and aircrew. The maintenance is closely linked to the time available for the PSED and the maintenance. Adequate time is required for the PSED to be conducted. Individuals should be trained in how to conduct a PSED. Rushed PSEDs impact the diagnostics and maintenance as insufficient or imprecise technical information about the fault and the circumstances when it occurred are imparted. This is more of an issue for older aircraft. The lack of training to diagnose faults and NFFs directly impacts the trust between the aircrew and engineers, leading to a sense of insecurity and being non-believed. This increases the management workload as the issue is elevated within the hierarchical chain and further impacts the economic cost.

Safety is impacted and a NFF can diminish the airworthiness of an aircraft and result in a significant hazard to the aircrew and engineers, as evidenced by the air accident investigations. A NFF was known to cause a distraction for the aircrew. Moreover, when a fault will reappear cannot be planned. If recurring during a high-workload period, when the crew are fatigued after a long or arduous flight, it may increase the impact of the NFF on airworthiness. The significant hazard under these conditions may be more difficult to manage. Further, the ‘significant hazard’ may impact the air safety of other aircraft and aircrew (See airworthiness definition Section 2.4).

7.11.2 Importance

‘Importance’ is linked to criticality, as evidenced by the definition of critical (Cambridge Dictionary, 2023b). Here is it used to establish why a fact or act is important, in that it has an influence or a great effect, when considering the link between NFF and airworthiness. There are crossovers with impact.

ICAO (2006, Article 37) acknowledged the importance of qualified operators and this applies equally to engineers and designers. Qualified entails these individuals being trained and probably assessed but they also need to be

experienced. This is linked to being competent—the reason for the Aircrew and engineer experience and knowledge assessment tool being developed (Appendix F). Task-specific knowledge and skills were assessed as important as they include an obligation to know “recent and anticipated equipment problems”, evaluate the consequences of various behaviours and choose the best strategy that results in the chosen generic coordinating skills (Bowers, Jentsch and Salas, 2000). However, the aircrew also needs to possess and apply the correct attitude and behaviours, as one does not necessarily imply the other (Bowers, Jentsch and Salas, 2000). These qualities are important not only when operating the aircraft but also when engaging with the engineers during the PSED.

An important aspect of training is the need to ensure a common understanding of NFF and airworthiness is adopted. This should heighten the requirement to report faults, especially dormant faults that may only be active for a short period during a flight, as the impact on airworthiness should be better appreciated. However, questionnaire responses indicated that not all faults were reported (Section 4.3.5). Further, common terminology is important to record how a fault was investigated and cleared. The importance of collating the correct fault symptoms and fault reporting information at the start of the fault diagnosis process was identified (Khan, 2015). This has been established as contributing to reducing the number of NFF recorded. This engenders a level of trust that is essential for “collaboration, the open exchange of ideas, and a strong workplace culture” (Psychology Today, 2023) and provides a sense of security. Moreover, the common terminology is linked with clear communication.

Whilst training and competence are important, so too is the aircrew input to the NFF environment. This was endorsed by ARINC (2208). However, the aircrew are usually included in diagrams as one input (Figure 2-1: The stakeholders and their interaction at the component level (Khan et al., 2015, p.104)Figure 2-1). This was evident from research conducted by Thomas, Ayers and Pecht (2002), who observed that not including the operator in the reporting process resulted in more ‘trouble not identified’ being recorded. Communication, both written and oral, is important in reducing the effect of NFF on airworthiness. Accurate and

searchable records are required from the aircrew, engineers and logisticians. This requirement was established from the literature review and also the questionnaire and interviews. Historical knowledge of an aircraft or component can reduce the diagnostics work completed and reduce the number of components in the supply chain or reduce the number of rogue components. The need for logging data so that it can be used for a search of trends and component history is known (MAA, 2015a; EASA, 2017), This communication was incorporated within the FRAM analysis and flow charts (Figure 6-10, Figure 6-32, Figure 6-30, Figure 6-31 and Figure 6-36)

Additionally, the increased workload on the aircrew because of the NFF is important to acknowledge when trying to improve the airworthiness level of the aircraft. The number of activities the aircrew can be expected to perform before mental resources are drained to the point where the performance diminishes (Salas and Maurino, 2010, p.229) is an important factor to acknowledge because if overloaded or fatigued the aircrew may assess the aircraft's airworthiness as level 4 (Appendix G) and be focused on surviving the fault or ejecting.

The Bowtie analysis included as preventative controls the need for the aircraft to be designed per relevant standards and for trend analysis against NFF occurrences (Figure 6-5 and Figure 6-11). This was established (Section 2.10) as an important point as it contributes to identifying a hazard, recognizing a risk, providing mitigation for the risk and implementing effective measures for monitoring the risk.

Recognizing the impact of NFF on airworthiness, as acknowledged by the AAIB and EASA, is important. The NFF affected the aircrew's ability to fly the aircraft and caused a distraction, and air accident investigations identified it resulted in a significant hazard to the aircrew.

Finally, it is important to recognize that the aircrew did perceive a link between NFF and airworthiness.

7.11.3 Criticality

The link between NFF and airworthiness was assessed as critical—"of the greatest importance to the way things might happen" (Cambridge Dictionary, 2023b)– if it resulted in a significant hazard that could impact the risk to life. It should be elevated for analysis and warrants further investigation.

As covered in Section 2.2 a critical decision for the Duty Holders is how they quantify a "significant risk" because this is down to judgement of the evidence or lack of evidence. Furthermore, those interviewed stressed the *criticality* of the NFF on airworthiness and as the NFF was perceived as significant hazards. The safety of the aircrew could have been at risk.

This aircrew and engineers' relationship is deemed critical if NFF occurrences are the be minimized. The NFF could result in a significant hazard to the aircrew and culminate in a risk to life. Moreover, appreciating how critical the link is, may cause the engineers to change how the diagnostics or investigation could be conducted. Additionally, it may lead the OEM to instigate a change in procedures to diagnose the fault. Also, critically, the SMEs who completed Task 2, identified the link between NFF and airworthiness and instigated a different approach to resolve the NFF.

Any link between NFF and airworthiness that poses a significant hazard to the operators, engineers third parties etc., is critical and should be elevated for analysis. It relates to a possible risk to life and further investigation is warranted.

Milburn et al. (2012, cited in Farnell, 2016) identified training and competencies as key elements of safety defences used as indicators to monitor the state between a hazard and an incident. Another key area indicator to be monitored was 'critical communication'. Communication has been linked to *impact* and *importance* and is a contributor to trust.

7.12 Direction for future work

This section will detail how the analysis can be expanded to incorporate considerations of variance in context (e.g., national military context) and the opportunity for comparative work (e.g., same aircraft in different settings).

As identified, there were limitations identified as the majority of primary data was from RAF aircrew and engineers (Sections 3.12, 5.6.1 and 6.4.3) and this effects the wider generalizability of the findings. Sections 6.4.3 and 6.5.4 proposed approaches to widen the source of primary data, including repeating Task 1 and 2. Moreover, it was proposed that the FRAM model could be assessed against an aviation maintenance company to assess similarities and differences in approach to identify where the FRAM model and then the flow charts would need to be modified to represent that company. In doing so a 'live' model could be applied within that company to reduce the level of NFF recorded and enhance or maintain the airworthiness level.

No two countries' military organizations are the same. Cultures, histories and environment along with attitudes and behaviours impact the outcome, even if implementing similar training tactics and adopting the same regulations, such as EASA or FAA. Moreover, one national military force operating in different environments, e.g., UK peacetime or overseas conflict, may implement the same regulations, procedures and processes slightly differently or without the same rigidity. The MAA, from experience, stipulate what is required but not how it is to be obtained.

The flow charts (Section 6.7) were created with a fixed-base location in mind. However, the UK military forces also operate at deployed locations, including ships (Royal Navy, no date; RAF, 2023). Therefore, this research could be extended to conduct a review of the flow charts (Section 6.7) to identify any differences caused from one military force, such as the RAF, operating from a fixed-base and an operational deployed based. Furthermore, this could be extended to identify the differences between a country's forces, such as the RAF and Royal Navy. The outcome would enable an enhanced worldview and rich

picture to be created to provide increased fidelity to the flow charts. In doing so, the impact of a NFF on airworthiness can be managed and hopefully reduced.

Whilst the above considers the organizations the following will consider the same aircraft but in a different setting. For example, the RAF operate the Typhoon aircraft from RAF Lossiemouth and RAF Coningsby, the A380 is operated globally and the BAE Systems Hawk advanced jet trainer is operated in 18 countries and by 16 military forces (BAE Systems, 2023). The effect of NFF on airworthiness may be considerable different due a variety of factors including the environmental and political climate, the capability required and the age of the aircraft. The research could be extended to examine in a number of aspects. The following are some suggestions. The starting primary data from the aircrew would need gathering and examining to determine any key difference between the RAF and the specific organization. The flow charts would need reviewing to ensure they can be implemented in the chosen organizations. Historical and current NFF occurrences to provide comparative aviation company data analysis for NFF would be required for trending analysis (as per Section 6.6). The views of the aircrew and engineers would be required to update the fuzzy logic membership functions (see Section 6.5.1), along with the applied risk matrix. From this analysis could establish if one country was better at minimizing the NFF impact on airworthiness. In doing so it would enable to operator (e.g., the RAF) or the OEM (e.g., BAE Systems) much improved visibility for why NFF were being recorded and the impact on airworthiness for these different environments. From this knowledge remedial action can be implemented to overcome poor practices. Moreover, this knowledge can be used to improve the design of aircraft and the maintenance practices and procedures.

By replicating the study in other contexts, the generalisability of the research findings can be established (Saunders, Lewis, and Thornhill, 2016, p.194).

7.13 Applicability to other sociotechnical environments

The analysis and models produced have been for the link between NFF and airworthiness. However, these can be adapted for other sociotechnical

environments, such as nuclear, naval, automotive, rail and health. Reason (1991) affirmed that dormant faults are created by those designers etc. removed from the operating environment. This means that addressing NFF and any impact on the worthiness of that specific environment (e.g., drive-worthiness for a vehicle) locally is inadequate and requires the input of a wider group of stakeholders, as identified in Section 6.7.

However, with the link between NFF and airworthiness proven, it has been established that designers now have a greater responsibility to acknowledge this and to develop equipment to reduce dormant faults and to ensure they can be tested for both at the system and component levels. This applies to complex equipment that includes electronic components and software where NFF is most likely to occur. These will be found in environments, such as nuclear and health, where there is a risk to life that needs to be considered and where the operation of equipment needs to be ALARP and tolerable.

Trust is a fragile thing. It can quickly be eroded by poor experiences, especially when the operator's life may be at risk. Within different environments, such as the health or naval, it is suggested that trust between the operators, maintainers and visitors can be equally as fragile. Reputations may be at stake. Understanding NFF in the context of the 'worthiness' of the environment is important to maintain any trust. The operators misunderstood how to use medical equipment (Flewwelling, 2012) and it is suggested that this will have impacted the trust between the operator, maintainer and patient. This stance is supported by psychologists (Psychology Today, 2023). It is proposed that a debrief or post-use proforma for equipment to establish the 'worthiness' of the equipment and the perceived system at fault in other environments would better aid the understanding of any NFF recorded but from trending of the completed proforma, it will allow directed training to be provided or SQEP to assist until operator proficiency has been established.

Joining FRAM and Bowtie analysis together will enable all the key causes of resonance within a system to be reflected in the criticality aspect of the Bowtie and appropriate prevention control barriers to be put in place. FRAM has already

been conducted for the transfer of patients but without the consideration of variability, or timing and control aspects (O'Hare, Baxter and Hardicre, 2020). Additionally, FRAM has been used to analyse a mid-air collision where it was reported that “the system performance and behaviors did not facilitate the buffers creation through potential couplings of actions among functions” (de Carvalho, 2011). Using the findings of where the resonance would have the greatest effect could again be linked to the criticality of a Bowtie.

The fuzzy logic inference model can be adapted to these sociotechnical environments. A suitable risk matrix needs to be converted into the rules, once the inputs have been determined. It is suggested that these should be related to the NFF recorded and the trust or frustration the operator experiences and how this translates into a view of the ‘worthiness’ of the system/equipment. Similarly, the engineers’ views of the ‘worthiness’ related to the number of NFF recorded could be used. The overall ‘worthiness’ of the system or equipment could be inferred and used by the Duty Holder, as additional information to determine whether the system is ALARP and tolerable.

7.14 Reflection on the research methodology

The research was conducted with a Pragmatist philosophy and ontological stance. The latter included objectivism and subjectivism. The research approach was both inductive (via the interviews) and deductive (via the questionnaire). A multi-strategy approach to obtain quantitative and qualitative data was applied. The research design used surveys, with the data collected from interviews and questionnaires. Descriptive statistics and inferential statistics were used as the data analysis techniques.

The pragmatistic approach supports multi-method to collect primary. A pragmatist accepts that there are different worldviews (Saunders, Lewis, and Thornhill, 2016, p.130), a position accepted with the term *Weltanschauung* (Waring, 1996. p.7). This was required to understand the aircrews, AAI and engineers' viewpoints. Objectivism accepts that for example, the management within an organization is similar, the structure may differ but the functions are similar

(Saunders, Lewis, and Thornhill, 2016, p.131). This is acceptable when considering aviation, airworthiness and the role of the Duty Holder. However, the subjective aspect is how the aircrew, engineers or Duty Holder interpret their roles and responsibilities. How they interpret NFF and airworthiness. This was necessary for the collection of primary data. Having this objective and subjective philosophy permitted the FRAM model, fuzzy logic inference and flow charts to be established.

The deductive approach informed by the literature allowed the interview to support the view that has link had been established between NFF and airworthiness. From the aircrew and AAI interviews conducted it was deduced that there was a link between NFF and airworthiness. Aspects of the interviews were also deductive as they enable key themes to be developed that were not readily apparent before the interviews. These key themes contributed to the inductive approach, the questionnaire. This enabled primary data to be gathered to explore the NFF phenomenon and the link to airworthiness and to contribute to the building of a conceptual framework (Figure 6-32 to Figure 6-36) to understand and manage the link.

The survey research design contributed to the research approach and used interviews and questionnaires to obtain primary data. Secondary data was provided by the aviation company. As well as descriptive and inference statistics, descriptive analysis, using template analysis (King and Brook, 2017) were applied.

With any research, there are different ways of achieving the aim, research questions and objectives. As indicated, there are different philosophies and methods to follow but a multi-dimensional set of continua to follow is now acceptable (Saunders, Lewis, and Thornhill, 2016, p.131). Applying just an inductive approach would have missed the aircrew's viewpoint of NFF, airworthiness, communication and trust etc. Going forward a longitudinal research design could be used to assess the difference in the NFF and airworthiness link.

7.15 The research aim

This research aimed to:

> Explore the relationship between the NFF phenomena and airworthiness to establish if there is, or is not, a link between the two.

This analysis concludes that there is a link between NFF and airworthiness. This has been established from the definitions, the interviews, the questionnaire and the different analyses conducted with SME reviews and critiques. This link has been presented.

Whilst with any information and interpretation the reader needs to be convinced, it is asserted that the analysis presented supports this link. Redoing Task 2 (Appendix E, E.1) and surveying a sample of the aircrew population to establish their view of the aircraft's airworthiness level in five years would indicate any changes or not to the fuzzy logic airworthiness advisory tool. This could form the basis of a longitudinal study to establish if the approach presented has resulted in any developments and improvements with NFF and airworthiness.

7.16 Summary

The aims, research questions and objectives of this research have been met. The belief that airworthiness is binary has been dismantled. The notion that NFF does not contribute to airworthiness has been disestablished. The aircrew has voiced their concern and provided examples of where NFF has contributed to an unairworthy aircraft. This research aimed to establish whether there is or is not a link between NFF and airworthiness. It is adjudged that this has been achieved. There is a link between NFF and airworthiness. Furthermore, the importance of and the impact and criticality of the NFF link to airworthiness has been presented. Also, the limitations of the research regarding wider validity have been explained along with suggestions for how this research could be extended.

It is recommended that training is an important pillar to aid the dissemination of this material. Further, the Bowtie, FRAM and fuzzy logic models should be considered for implementation by aviation organizations, specifically the MOD. In

doing so they would enable their staff to better understand the link and how it can be managed to reduce any negative impact between NFF and airworthiness. The upstream-downstream resonance and internal and external resonance are manageable facets. However, they need to be acknowledged and acted upon. It was for these reasons that SMEs with a wealth of knowledge and experience were employed with critiquing the FRAM and providing an assessment of an aircraft's airworthiness but upon criteria provided by aircrew. This has reinforced the view that NFF is linked to airworthiness.

It is not anticipated that NFF can be completely eradicated. However, with an understanding of the causes (e.g., the inherent design), the aviation organizational structures that allow the issue to be preserved can implement a positive change. A dedicated team of aircrew and engineers working with the Duty Holder and organization can improve the '*as is*' situation to turn the positive, unstable loop, into a stable loop and system.

So, whilst "Beauty may be in the eye of the beholder" (Hungerford, 1878) *the link between NFF and airworthiness is in the judgement of the beholder*. This analysis has provided aircrew, AAI and engineer SME views to demonstrate and support the link established between NFF and airworthiness.

The requirement now is to draw together the recommendations and express how this research fits within the wider context of NFF and airworthiness.

8 CONCLUSION

8.1 Introduction

The NFF phenomenon has been evident for many years and is more apparent in electronic and electrical systems. Aviation is a complex socio-technical system where the lives of the aircrew are constantly at risk. It is for this reason, the Duty Holder must ensure the air systems are safe to operate and operated safely. That includes ensuring the aircraft is airworthy. The link between NFF and airworthiness has a direct input on the aircrew's risk to life. The following will succinctly state whether the aims and objectives were met, namely to establish that there is a link between NFF and airworthiness. It will highlight the key findings from the research and indicate any limitations of the research. It will state how these findings can be useful to other industries, such as health and automotive. It will consider the findings from the research in terms of the wider aviation environment and airworthiness activity where NFF will be apparent. It will finally present recommendations for further work either to develop and support the findings from this research or to analyse any differences at a different period.

8.2 Aims, research questions and objectives

The main aim of this research is to:

> Explore the relationship between the NFF phenomena and airworthiness to establish if there is, or is not, a link between the two.

From this, two research questions were developed.

1. Is there a link between the phenomena of no fault found and airworthiness?
2. Do aircrew perceive a link exists between the phenomena of no fault found and airworthiness?

The aim and research questions were undertaken by completing the following objectives:

A. To explore current theories for different definitions of airworthiness and NFF and provide ones to be used as the basis for this research.
B. To establish the current understanding of NFF across different industries and the perceived impact of NFF upon operations.

1. To determine the views of aircrew and accident investigators on the impact of NFF and any links to airworthiness and to assess any differences from the literature view.
2. To analyse the results to establish strengths and weaknesses of current processes that surround NFF and link airworthiness.
3. To explain the links between NFF and airworthiness.
4. To devise an approach to be used by aviation establishments to assess the level of NFF and its impact on airworthiness.
5. To make recommendations for improving the knowledge of NFF and the link to airworthiness

The findings support the assertion that the research questions and the aim has been achieved. There is a link established between the NFF phenomena and airworthiness. This was borne out from the literature review, the aircrew and AAI interviews, the aircrew questionnaire, the FRAM analysis, which was reviewed by aviation SME engineers, and the engineers' input to the fuzzy logic inference task. These combined answered in the affirmative that research question 1 had been answered a link had been established. The interviewees agreed NFF affected airworthiness. Refusing to take an aircraft with an ongoing NFF was cited as an example. The aircrew who completed the questionnaire agreed with the interviews. Further, they provided examples of the systems most prone to NFF, negative interaction with the engineers, reported NFF being insufficiently investigated and which contributed to reduced airworthiness. Again, an example was provided that culminated in the aircrew refusing to take an aircraft as the NFF was deemed to endanger the aircrew's life and the aircraft was assessed as unairworthy. The findings from the interviews and questionnaire answered research question 2. The aircrew do perceive a link exists between the phenomena of no fault found and airworthiness.

Each of the Objectives contributed to establishing this link. Objectives A and B were met in the Literature Review. Airworthiness is a technical attribute, i.e., something that is inherent in the design. Some faults remain dormant until activated under specific conditions (Avižienis, Laprie, and Randell, 2001). Sufficient testing must be completed to ensure these dormant faults do not become active, endanger the aircrew and passenger, and then become dormant when the aircraft closes down power. Only then for it to be recorded as a NFF. Designers will have a greater responsibility to consider how to design complex equipment to avoid the possibility of NFF occurrences and how to improve diagnosis and test procedures for current and future designs.

Objective 1 was met from the survey, both the aircrew and AAI interviews and the aircrew questionnaire. Objective 2 was met from the survey, the influence diagram and the FRAM analysis. The airworthiness environment is unstable and contains resonance that needs to be managed to ensure it does not become unstable. The performance indicators need to be frequently reviewed. The FRAM model enabled the identification of those aspects where the resonance had a greater impact on a NFF being recorded. Objective 3 addressed the links between NFF and airworthiness. As airworthiness is a technical attribute and for flights to be conducted without a significant hazard to the aircrew, and be undertaken by competent, authorized individuals, the air accident reports highlighted the link and the serious implications for when NFF is not addressed. The lives of aircrew and passengers are at risk. Objective 4 was met by the FRAM, Bowtie and Fuzzy Logic inference NFF and airworthiness models that each fed into the flow charts and culminated in the NFF/Airworthiness working group taking action to monitor and reduce the number of NFF recorded. This overall model included the new aircrew PSED airworthiness assessment. The combination of these models provides an approach to assess the link between NFF and airworthiness for different viewpoints and to reduce the number of NFF reported that can impact the airworthiness of the aircraft and the risk to life for the aircrew and passengers.

Establishing the link between NFF and airworthiness matters because lives are at risk, along with the risk of complex and excessively costly equipment. Moreover, there is a cost attribute to NFF that may be in the millions or billions (Table 2-3). Yet the cost is also in terms of resources and time. It has been evident that trust is an essential part of the aviation sociotechnical environment. This must be preserved if the impact of NFF on airworthiness is to be contained and reduced.

8.3 The original contribution to knowledge

The following are assessed as original contributions to knowledge.

- The aircrew's view towards NFF and specifically in relation to airworthiness.
- The joining of the Bowtie and FRAM approaches emphasizes the key aspects on which to focus to reduce the occurrence of NFF and reduce the impact on airworthiness.
- A Sugeno fuzzy logic inference model to aid the assessment of an aircraft’s airworthiness level based on the views of aircrew and engineers.
- Assert that there is a link between NFF and airworthiness and as such is a serious concern that duty holders must consider when establishing if a system is ALARP and tolerable.

8.4 Wider implications

Whilst most responses to the questionnaire were received from RAF aircrew, there are wider implications for the aviation environment from the findings and the models.

The literature review included air accident reports where NFF had contributed to an event. Luckily no lives were lost. To reduce the impact of NFF on airworthiness those developing, designing and testing aircraft and air systems need to acknowledge that NFF and intermittent faults are designed in from the outset. Dormant faults require certain conditions to be activated. This needs to be understood and test methods introduced to identify, eliminate or mitigate the

effect if the dormant fault is activated. This better appreciation of NFF at the design stage can then be fed into the development of the aircraft document set, AMM, aircrew flight reference cards and test equipment etc. With or without this, training is a key contributor to reducing the effect of NFF on airworthiness. Aircrew, engineers and AAI are not trained on the phenomenon of NFF. Training and refresher training is a necessity to reduce the link. This is all relevant to other industries, such as nuclear, naval, automotive, rail and health as they all involve complex equipment in a sociotechnical environment. They all have equipment whose design will inadvertently include dormant faults.

Aircrew needs to be trained on the definition of airworthiness. As those identified within the airworthiness definition, it is important they understand the term. The PSED proforma requires aircrew to assess the aircraft's airworthiness level. This can only be completed if the aircrew fully understands the term. Producing similar debrief forms for other industries would enable the 'worthiness' of the equipment or environment to be established from the operator's perspective. Furthermore, it would enable the suggested system at fault to be stated and from that, a trend for the number of NFF occurrences can be established to discover whether it was changing.

The NFF/airworthiness model identified key stakeholders. Aviation organizations, both military and civilian, must acknowledge the contribution of each of these stakeholders and associated companies to the recording and reduction of NFF. It must be stressed that recording a NFF under alternative terminologies, such as 'tested satis', only hides the problem. Frank, open and honest conversations on the cause of NFF being recorded are the key to reducing the impact of the link between NFF and airworthiness.

The NFF/airworthiness model (flow charts), Bowtie and FRAM models identify ways to reduce the impact of NFF on airworthiness. These models and diagrams can be adapted for specific aviation companies. Large or small, the companies should review their operations and assess where resonance is felt most. Also, whether the organization's barriers are sufficient to mitigate a NFF being recorded.

The link established between NFF and airworthiness must be acknowledged by an organization's Duty Holder and acknowledged as a risk to life that needs to be managed. For an air system to be ALARP *and* tolerable this link cannot be ignored. Aviation organizations need to review their processes and procedures for identifying, managing and reducing NFF. A NFF/airworthiness working group needs to be established to continually assess the impact. Similarly, other industries could introduce a NFF/'worthiness' working group to monitor and manage any NFF occurrences and the impact on the 'worthiness' being considered.

The fuzzy logic inference advisory tool considered the views of engineers and aircrew assessment of airworthiness. The resultant advisory tool can be adapted for other industries. For example, in the nuclear, automotive or health service, views from the users/maintainers, operators/patients can be considered to aid the assess the overall performance of the organizations. Airworthiness, like 'drive-worthiness' and patient survivability, all consider risks and have the lives of individuals as the focus.

8.5 Limitations

There were four main limitations to the research.

1. The aircrew sample size was small in comparison with the population. The RAF aircrew population was approximately 1800 trained RAF pilots when the questionnaire was completed (Defence Statistics (Tri-service), 2015). 45 respondees were military but only 28 RAF were identifiable from the rank information provided, even though this could be as high as 41. This equates to a 1.5% minimum or 2.3% maximum sample of the population. Furthermore, this effects the wider validity and generalizability of the findings.
2. It was not possible to canvas aircrew for their views on when they perceived the PSED airworthiness level moved from one level to another on a scale of zero to 10. This would have increased the fidelity of the fuzzy logic airworthiness inference.

3. Only 11 RAF aviation engineers completed Task 2 to assess how many engineering-recorded NFF were deemed to move the aircraft's airworthiness from one level to another. This additional insight may have reinforced or clarified the fuzzy logic airworthiness level inference. This also effected the wider validity of the output
4. The MATLAB Fuzzy Logic toolbox does not permit graphical coordinates to be directly inputted for the membership functions. This limitation meant that best-fit lines from the in-built types available had to be used.

These are considered within the recommended further work (Section 8.7).

This research was conducted during the Covid pandemic.

8.6 Recommendations

The following are recommendations to reduce any negative outcomes from the link between NFF and airworthiness:

1. Aircrew and engineers are trained on the terms NFF and airworthiness. They contribute to the resonance within the system. The link between NFF and airworthiness must be covered along with the number of NFF recorded for an aircraft. This should include trending.
2. Aircrew and engineers are trained on engineering terminology used to explain faults and how they have been cleared so an agreed lexicon can be used.
3. Aircrew and engineers are trained on how to conduct a PSED and complete the proforma.
4. The PSED is held in a dedicated, suitable location.
5. A revised PSED proforma is adopted to ensure the aircrew’s assessment of the airworthiness of the aircraft is recorded.
6. The belief that airworthiness is binary just because diagnostics and engineering have been conducted must be challenged. The aircrew and engineers are named within the airworthiness definition and may be the recipients of ‘significant hazard’ because a fault is recorded, and recorded

repeatedly, as NFF is no longer acceptable. The aircrew has expressed their alarm.

7. The NFF/airworthiness Bowtie needs to be implemented with barriers to reduce the occurrence of a NFF being recorded. The system then needs to be reviewed periodically to assess any improvement in the number of NFF recorded.
8. The FRAM model and criticality scoring should be implemented. No system is perfect but from the aircrew survey, the current system does not ensure they are free from significant hazards.
9. Trust needs to be re-established and supported between aircrew and engineers. Poor communication, misunderstanding of terminology and rushing the PSED do not contribute to trust. This trust is essential if the NFF-airworthiness relationship is to be improved.
10. Airworthiness and NFF definitions used between the different organizations that work together need to be agreed upon to enable constructive decisions and analysis to be conducted.
11. The recording of NFF needs to be formalized with agreed terminology. Even though proposed by ARINC this is still not being adopted.
12. The organizations within the aviation environment read the findings and recommendations and review their organizations for strengths and weaknesses and implement those recommendations where the greatest benefit in reducing the impact of NFF on airworthiness can be made.
13. The term NFF is abolished and FNF is used instead.

8.7 Recommendations for further work

The following recommendations for further work are proposed.

- The questionnaire is repeated for British Army, Royal Navy to establish any commonality of views with those expressed by the RAF. This will enable external validity to be completed and contribute to generalized statements regarding the view of British military aircrew regarding NFF and airworthiness and links between the two terms.

- The questionnaire is repeated for civil aircrew to establish their views regarding NFF and airworthiness. This will contribute to external validity of the questionnaire analysis and confirm or refute any generalized statements regarding NFF and airworthiness and links between the two terms.
- Task 2 is repeated for a sample of at least 100 engineers and aircrew from the population to poll their views on the aircraft's airworthiness level. This will reinforce the fuzzy logic inference outcome and overall assessment of the aircraft's airworthiness.
- The Fuzzy Logic, FRAM model and analysis and Flow Charts are applied between and within organization or military forces (national and/or international) to compare and contrast the outcomes to establish how to further reduce the impact of NFF on airworthiness.
- The Fuzzy Logic, FRAM model and analysis and Flow Charts are applied to the same aircraft type but operated in different locations or by different operators to compare and contrast the outcomes to establish how to further reduce the impact of NFF on airworthiness and to provide the OEM with an enhanced appreciation for NFF occurrence so that designs and or the AMM can be modified as required.
- The terms ALARP and tolerable are fuzzy concepts that vary from one person to another and warrant further investigation against identified scenarios to further the airworthiness and air safety assessment.
- The AAI should receive training on the phenomena of NFF and how to identify and assess its contribution to air incidents and accidents**.**
- Psychologist conduct research to establish the trust levels between aircrew and engineers and the impact this has upon operations, including NFF and airworthiness. The mistrust is compounded by poor communication.

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APPENDICES

Appendix A - Interviews information and data

A.1 - Aircrew Interview questions

Background

1. How many years have you been in the military or latest civilian company?
2. How many years have you been a pilot?
3. What type of aircraft have you flown?
4. How long have you been flying the latest aircraft?

NFF

5. How would you describe an intermittent fault? (Introduced after interviewee 1)
6. What is your knowledge, ignoring everything I have said, of no fault found (NFF)?
7. How did you become aware of NFF?
8. So, what experience have you had of an aircraft NFF? Follow-on question
9. What did you do?
10. Did you check the aircraft log to see how the fault had been cleared?
11. Did you remember the aircraft number and look for it in the aircraft log if it happened a second time or more than twice?

Training

12. Moving onto the next bit which is training. During your aircrew training (flying training) can you explain what you were taught about the post-sortie debrief to the engineers?
13. During the debrief, what were the key points to get across?
14. If you think there is a problem, with whom would you talk?
15. How do you think you need to provide information?
16. How do you check the engineers' understanding of what you have said?
17. Do you try to provide the solution?

18. Still on the debrief, on average what percentage of your time are you in a rush to get away?
19. Does this depend on the duration of the flight? Like a long day? Explain
20. The debrief, does this depend on the time of day?

Regulations

21. Are there any regulations / procedures / process that you have read regarding the aircrew debrief? (Keep NFF in mind)

Airworthiness

22. Do you think your intermittent fault impacted airworthiness?
23. Do you think your intermittent fault impacted air safety?
24. Could you categorize the intermittent fault by severity or consequence? E.g. by system?

Closure

Can I quote you by name / post?

A.2 - Informed Consent Form

Title of the Project:	Is there a definitive link between No Fault Found and airworthiness?
Name of the Researcher:	Laura Lacey
Researcher's Contact Details:	l.lacey@cranfield.ac.uk 01793 785287
Participant No:	**Interviewee**
Date:	

1. I confirm that I have been informed about the aim and objectives of this research project and agree to give my inputs.

2. I understand that all personal information that I provide will be treated with the strictest confidence and my name will not be used in any report, publication or presentation. I have been provided with a participant number to ensure that all raw data remains anonymous.

3. I understand that the information I provide will be used by Cranfield University for the purpose of research only. The data will be stored on a secure network accessed only by authorised users in accordance with the Data Protection Act (1998) and GDPR.

4. I understand that the results of the research may be published in scientific journals, and an anonymised version of the data may be published in support of these results.

5. I understand that I am free to withdraw from this project at any stage during the session simply by informing a member of the research team, for whom contact details have been provided. I also understand that I can also withdraw my data for a period of up to 60 days from today, as after this time it will not be possible to identify my individual data from the aggregated results.

If applicable:

6. I understand that the discussions will be audio recorded and transcribed for analysis. The analysis will be only used for the PhD and associated research papers and for no other purposes without your permission. Any results submitted within the final report to the researcher will not be available to me for commercial reasons.

I confirm I have read and fully understand the information provided on this form and therefore give my consent to taking part in this research.

Participant's signature:		**Date:**	
Participant's name:			
Researcher's signature:		**Date:**	

One copy of this form must be given to the participant and one copy held by the researcher.

Debriefing

Thank you very much for your time today to assist with this research. As mentioned earlier the data provided by you will be treated confidentially and you are free to withdraw or change your responses for a period of up to seven days after receiving a copy of the transcript. If you need to change anything you can let me know by contacting me through email or phone (details are on page 1 of this form).

If you are happy for me to contact you by email or phone at a later date if I have missed out important points or need to clarify any of your responses, please complete your contact details below.

Thank you

Participant's contact details: **Tel:** **Email:**	

A.3 - Pilot Interview Questions

The bold text indicates the additional questions posed to pilots number two to four following a review of pilot one's interview responses.

Categorization

1. How many years have you been in the military or latest civilian company?
2. How many years have you been a pilot?
3. What type of aircraft have you flown?
4. How long have you been flying the latest aircraft?

Faults

5. **How would you describe an intermittent fault?**
6. What is your knowledge, ignoring everything I have said, of no fault found (NFF)?
7. How did you become aware of NFF?
8. So, what experience have you had of an aircraft NFF?
9. Follow-on question - What did you do?
10. Did you check the aircraft log to see how the fault had been cleared?
11. Did you remember the aircraft number and look for it in the aircraft log if it happened a second time or more than twice?

Training

12. Moving onto the next bit which is training. During your aircrew training (flying training) can you explain what you were taught about the post-sortie debrief to the engineers?
13. During the debrief, what were the key points to get across?
14. If you think there is a problem, with whom would you talk?
15. How do you think you need to provide information?
16. How do you check the engineers' understanding of what you have said?
17. Do you try to provide the solution?
18. Still on the debrief, on average what percentage of your time are you in a rush to get away?

19. Does this depend on the duration of the flight? Like a long day? Explain
20. **The debrief, does this depend on the time of day?**
21. Are there any regulations / procedures / process that you have read regarding the aircrew debrief? (Keep NFF in mind)

Airworthiness and Air safety

22. **Do you think your intermittent fault impacted airworthiness?**
23. **Do you think your intermittent fault impacted air safety?**
24. **Could you categorize the intermittent fault by severity or consequence? E.g. by system?**

Permission

25. **Can I quote you by name / post?**

A.4 - Air Accidents Investigators' Interview Questions

Categorization

1. How many years have you been involved with aviation?
2. How many years have you been involved with aircraft accident investigations?
3. What is your specialist field? Your specialisation?
4. Engineer or aircrew?
5. What type of aircraft accidents do you normally investigate? E.g. jet, passenger, helicopter.
6. How long have you been working for the AAIB / DAIB?

Faults

7. How would you describe an intermittent fault?
8. What is your knowledge, ignoring everything I have said, of no fault found?
9. How did you become aware of NFF?
10. So, what experience have you had of an aircraft or aircraft investigation with NFF?
11. When conducting investigations at what point do you scrutinize the aircraft maintenance records?
12. Do you look for trends within the documentation? Repeated technical faults?
13. If so, how do you analyse them? Is there a process?

Training

14. During your training (AAIB or similar) can you explain what you were taught about intermittent faults and NFF? How to spot them?
15. If you think there is a problem, who to talk with?
16. Do you discuss intermittent faults with the aircrew who have flown the aircraft?
17. Do you check with the aircraft engineers for intermittent faults or the OEM?
18. Is your investigation impinged by time or technology?
19. Does this type of accident affect the search of the maintenance records?

20. How often do you investigate incidents where NFF or intermittent faults are apparent, even if this is not recorded in the final report?
21. Are there any regulations / procedures / process that you have read regarding NFF?
22. Are there any other points you wish to raise regarding intermittent faults or NFF that have not been mentioned so far, they may be relevant to my research?
23. Are there any other points you wish to raise regarding intermittent faults or NFF that have not been mentioned so far, they may be relevant to my research?

Permission

24. Can I quote you by name / post?

Airworthiness and Air safety

The following questions were added during the interviews.

A. Are there any particular systems that you think are more prone to intermittent faults, no fault found?
B. And then if there are, do you think any are more like to impact airworthiness or air safety? So, any particular systems that are more prone and which are more likely to impact airworthiness and air safety?
C. Would you say that an intermittent fault or a no fault found would impact the airworthiness or air safety of the aircraft?
D. Could or do you think there are certain systems that you could categorize as more problematic for, you know, intermittent fault, NFF and, therefore, airworthiness?

A.5 - Interview transcripts

A.5.1 Interview 1

Question	Answer
Categorizations	
1. How many years have you been in the RAF?	I was a regular of 19 years and I have been a reservist for seven.
2. How many years have you been a pilot?	26 years
3. What type of aircraft?	Puma, Chinook, TriStar, Airbus A330 and then various other things during my test career. LL - For how many years? Puma – Including training that would be three. Chinook - 3 years Tristar – about 8 A330 – 7. LL - How long were you a test pilot? Four years including the training.
4. How long at Brize on latest aircraft?	Seven years. That would be the A330.
Faults	
5. What is your knowledge, ignoring everything I have said, of no fault found?	No fault found would be engineering shorthand where either a fault could not be replicated on the ground or that the reported fault was not considered to be an aircraft unserviceability. LL - That is interesting.
6. How did you become aware of NFF?	Primarily as a flight commander. That would be interaction as acting squadron boss, or Duty Exec, with engineering work and operational delivery. LL – So was it just the reports back from the pilots or was is just the tying of things together? Yes, and frequently because of the nature of the engineering shift system, as the Duty Exec I would have had continuity of a problem for seven days. Whereas the engineering teams would have conducted, say, 14 handovers between four different teams. But the number of times I heard, “yeah we are just going to flush through the right-hand hydraulic system again to see if it fixes it”. “But didn’t you do that on Tuesday and Sunday?”, “Oh, did they?” Also, the time boundary that it gives. “We need to do something to fix the problem. Our shift finishes at five, what can we do that might fix it by 5?” Because the way that the air force engineering system works that makes it very difficult for a job to be handed over half way through. I can feel that on the back of my neck rising.
7. So, what experience have you had of an aircraft NFF?	As a line pilot, very limited because the information is hard to gain, is often coded in engineering terminology. And because we do not fly the same aircraft on a regular basis it is difficult to know how a fault you reported is categorized. However, as an aircrew exec, it was readily apparent where repeated faults had significant impact on the programme.

8. What did you do? Probably as an exec.	Largely looked to take control of the strategic management of fault investigation and diagnosis from the junior engineering officer level. LL – Have you looked at the technical manuals the engineers have to follow? No, not on a, I think once or twice I was invited to look at them, but that statement is not about the technical rectification of faults it was more where we were repeatedly getting to, "we could just try rebalancing the blades one more time or we could do an engine change." Rebalancing the blades will take six hours, an engine change will take two days and driving "hang on you have taken the easy option three times and it has not fixed it", "Ah we don't want to start an engine change on night shift". So, whilst we were not trying to make engineering, airworthiness decisions, the risk benefit balances yeah, the risk versus reward balance as perceived by the engineering shift frequently worked against in-depth fault diagnosis or major component change. LL – as slightly separate question I am going to ask. The F700 for the A330 is that all electronic? No.
9. Did you check the F700 to see how the fault had been cleared?	I would always check the 700 but it is very difficult for me to understand how a fault has been cleared. The information is not readily apparent and often would be coded and it would be extremely short of detail. I mean an F700 box is what two inches by half an inch. AMM procedure 27453 carried out satis. Aircraft serviceable. Does that mean that everything was taken off, lubricated, put back in and now it works properly? Or does it mean the built-in-test set said it was okay and now it has gone back on the line?
10. Did you remember the aircraft number and look for it if it happened a second time or more than twice?	No, however, it would be known that certain aircraft "always did that" or had long running intermittent faults. The rise of social media, in particular WhatsApp, means that pilot groups are far better informed of aircraft snags in disparate locations.
Training	
11. Moving onto the next bit which is training. During your aircrew training (flying training) can you explain what you were taught about the debrief to the engineers?	Nothing at all. LL – So let me just clarify, when you finish a flight, I know for training flight you give a debrief about what happened in the flight and you might talk about it to a co-pilot or someone else but you have had zero training on what information the engineers actual require from you? I think there are two different sociological methods for the debrief. On a helicopter squadron the F700 generally lives with the engineers. Therefore, when the aeroplane is signed in the pilot would be in the presence of the engineering shift, and training would be delivered on the job by the line and the rects controller. On big aeroplanes the tech log is on the flight deck. More commonly than not there is no place to place a verbal debrief with an engineer. LL- Do you fly with a ground eng? Varies. We normally on a military flight takes two engineers away with us because there is an additional procedure on the A330 that needs certifying by engineer's signature. When I do my civvy flying there is normally engineering support at an out station but it is not uncommon for us to do our turnround servicing. That, there is a whole other dynamic there, in that our turnround engineering in Orlando there are two engineers. If Dean is on shift then the other guy is in. LL – Are those civilian?

	Yes, but they just want to get the aircraft turned and back to a main operating base. So, they are really not keen for faults to be reported.
12. I do not think this is going to be applicable, so I have said, what were the key points to get across? But for you, you have not had a particular no fault found so there were no	Ah, it is very difficult to know if it was a no fault found or not. LL – because you cannot check the history? From my perspective, I have reported the fault. I would assume that the engineering authority has rectified the problem. It is really more so again as an Exec, where you saw yesterday's fault and tomorrow's flight you saw the same problem coming up again. Or as a TP [test pilot] where you are flying one aircraft repeatedly and you are getting to know that aircraft quite intimately. Thinking of that pitot static fault, I put in an air safety report. LL – an ASIMS or a DASOR? It would have been DASOR or its previous incarnation because of having the same incident twice. If it had been two different pilots it is not clear that the two would have been linked unless the engineers decided they wished to say "it did that yesterday as well".
13. If you think there is a problem, who to talk with?	If there was a problem with a fault? LL – if you thought there was a problem with an intermittent fault that was not being cleared? In my current employment I would probably raise it through the duty pilot, who would be one of the pilot managers, and previously the first port of call would probably have been the Duty Exec. And the reason for that is that it could frequently become difficult if a captain was seen to be directly challenging the engineering judgement of the maintenance organization. LL – That is actually a really good point. I had not really thought about that. I see it from the other side from an engineer and not from the pilot side. If you get a young JP [junior pilot] coming in and your perspective as a JEngO [Junior Engineering Officer] and the warrant officer says "I have just had that stroppy Roberts [e.g.] coming in and he is telling me he is not flying that aeroplane. We have done all the checks on it and there is nothing wrong with it, it is good to go", whereas the Duty Exec would be able to take it to the SEngO [Senior Engineering Officer] and culturally the profile of experience and authority in the RAF engineering organization is part of the problem with this. Responsibility for strategic direction and decision making of complex fault diagnosis lies with the junior engineering officer who must be guided by the experienced SNCO [senior non-commissioed officers] cadre, who feel duty bound, understandable, to protect the interest of their team and shift. LL – Is that at the cost of airworthiness? Yes. The civil model the person in that role is an experienced technician in their own right. I would think that there are huge parallels with new doctors who are starting their early rotations. A good nurse would provide guidance and keep the junior doctor safe. But the doctor is in a very vulnerable position whilst they are gaining that experience. I can remember one conversation with one JEngO, "Why have you changed the APU again?", "Because the chf tech said it was a good idea." LL – I will come back to that to give you my background so it will a bit more make sense. That is not a dig at JEngOs. It is just you have put people in charge of the strategy of the organization who are least well equipped to deal with it and you have put people in charge of the day-to-day maintenance and oversight of tasks, who frankly would be better replaced running that strategy of where we are going with it. When it worked well, where you have a strong confident JEngO who understood, or even hallelujah a JEngO who got techy experience. Simon who was one of our JEngOs before two Simons, he just got it and he ended up being the Support JEngO, the one upstairs, and there were four shift JEngOs, and he just knew when the wool was being pulled over his eyes. It was the other four. We had one shift that was

	just bouncing tasks, “oh we have done some more prep for the curing of that panel”, “So you have not done the panel?”, “No but we have done some more prep on it”. That had already been done. But because of the strategy for, okay we can do this, we can do this, we can do this, there is a 20% chance that this will fix it but it is only a one-hour job but if it does it solves it if not we have got to go and do that. It is just missing. It is missing from the call. Were you an ex techy? LL- yes. All right. LL – I will give you my whole background.
14. This is probably irrelevant but how do you think you need to provide information?	Again, the difference between legacy and current types. On the current types I need to provide information for things the computer cannot see. So, if it was a banging noise or I could smell smoke I need to provide quite a detailed debrief on that. If the fault was associated with some form of warning on the aeroplane, then if I tried to debrief an engineer, if he is on the aeroplane, I would be told don’t worry, I will get it off the post-flight. LL – I have heard that from Chris. And largely the only debrief for them is so that they know to look at the post-flight early as they need an extra bag of spanners, they don’t need a spanner on the Airbus, or they might need to reset a circuit breaker. The Tristar, a completely different debrief. And helicopters as well really. I would generally try to speak to the rects controller and the trade manager if possible, if it was complex, as they would generally question me to fill in the gaps and I would be more certain that the verbal information for the debrief would be retained by the maintenance organization.
15. How do you check the engineers’ understanding of what you have said?	LL – You have provided the debrief, how do you check they’ve understood what you have said? Just by the questions they are asking you? Or don’t you? You could normally get a pretty good impression of the engineer’s understanding by the questions that they asked at the time and there attempt to fault diagnose, temporaneously. And you have heard that type of thing when someone is going through the wiring diagrams and says “that system switches from a-to-b after every reset. Okay did it do it on the first and the third? That means it is probably one side of the box and not the other. Was it only on take-off or was it on landing as well?” One thing that might be of interest to you, the debrief on Tristar, largely done by flight engineers. Culturally they see themselves as boundary spanners, with one foot in the engineering camp and one foot in the aircrew camp. I think you would probably see a different debrief between aircraft with an air eng and an aircraft that did not have an air eng. Likewise AGEs, aircraft ground engineers, travelling engineers, they would tend to take ownership of a single aircraft for a task and that providing a debrief on what they had done and what snags the aircraft had fell into their remit.
16. Do you try to provide the solution?	A solution to what? LL – What you think the problem is on the aircraft? Um, LL – fault diagnosis? I think you need to go away and do this? I am not supposed to provide the solution. LL- you have not answered the question. However, especially those pilots who are of more technical bent when faced with fault diagnosis decisions that appear illogical or perverse, I would try and structure the debrief to point out the faulty system.
17. Still on the debrief, on average what	100%. It would be rare for you not to have completed a long day.

percentage of your time are you in a rush to get away?	
18. Does this depend on the duration of the flight? Like a long day ?? Explain	Yes, this again depends on question 17; it depends on the sociological set up more than the technical. On a A330 I will have 12 cabin crew sitting on the bus waiting to finish their day's work whilst I close down the flight deck and that includes the debrief. On a helicopter squadron I would walk into flight control. It would be a more social and interactive experience, and would be led by the engineers. I don't debrief on A330 unless it was something like, in fact it is not a NFF but I had smoke and fumes in the cockpit, lots of smoke, could not work out what was happening, turned back for an immediate landing at Akrotiri, once we had started to taxy back off the runway, the aircraft informed us of a CB having popped, which was the mechanic call button, like the car horn. Not sure if they had it on the Tristar but the horn to get the engineer's attention, the plan was too cleaver to think we need to know about it in the air, because why would you need to call an engineer when you are flying, and that horn had caught fire in the nose bay and was putting smoke up into the air conditioning packs, that pump into the cockpit, but the post-flight report of the aeroplane would have explained all of that without me having to say anything. It told them there had been an over current, told them there had been a CB popped, told them mechanic's horn was not working and told then where to go and look for the problem. Even for a smoke and fumes event I don't need to tell the engineers anything, they would have been able to fix that problem by themselves.
19. The debrief, does this depend on the time of day?	LL - For example whether it is 4 o'clock in the morning or 4 o'clock in the afternoon? Yes. Using a Tristar example, more people would be awake in the shift on a daytime. Engineering management people are more likely to be available and critically the trade managers, who would have the best technical system understanding. LL - And on A330? It does not really make a difference.
20. Are there any regulations / procedures / process that you have read regarding the aircrew debrief? (Keep NFF in mind)	LL- i.e. what is should contain, why you are doing the debrief. I cannot recall them. LL – let me do a follow-on question. If I wanted to ask somebody, who would be the person to go to who could give me a contact for training. As to who is responsible for teaching aircrew how to do a technical debrief? It would be somewhere with whatever training group it belonged to (????), someone at 22 Group. Because with the advent of DSAT I am sure it is an objective somewhere. But I could not point you to it. I know that when I teach on A330, we talk about the correct filling in of the technical log, but there is very little, in fact there is no guidance on exactly what should into an aircraft defect. LL – I have been trying to find something in the civilian stuff, the military stuff and I cannot find anything. It is not there. I have gone to a civilian pilot and he said you might want to look at this. I have looked at it and there is nothing there. It does say something in one bit but that is in the training for the engineers. But it does not really state anything. We all know what NFF is seen to be by aircrew. What we would frequently get is 'cannot replicate the fault on the ground' and there are somethings that would be niggly little electronic, electrical things that were happening and you go well yeah, I can see why that light came on for 30 seconds, then went off and then came on for 30 seconds

	and then went off. Something like a dodgy lead somewhere is, if it was my car you would be looking for a dodgy lead. Somewhere is causing it. But when you had a problem that was really significant, like the pilot static one and that came back as NFF. LL - I will send you the AAIB report. The impression that comes over is not one of a … And I have seen it handled in two ways. One was, explain why we cannot reproduce or replicate it. We have done everything we possibly can, we cannot reproduce the fault, we have changed all the components we think will fix it. LL – and the second example? Two, it is where it would just say NFF, no fault found. Which is effectively on a personal level is saying that never happened. What you put in the book didn't happened cause there is no fault. So, therefore, either what you have written is not important or it is wrong. It does not take many for people start thinking "what is the point in putting anything in the book". Or worse that had been snagged three or four times already so there is no point me snagging it again.
Permission	
21. Can I quote you by name / post?	I will tell you what I am going to say before I publish it. I will not mention any companies. Do you mention aircraft types? Yes, but I can change those to helicopter. Use A330 instead of the alternative. Can I have chance to see what you have written before it goes out? It might not be for some time but absolutely. If you are happy or not happy, I could just tweak it to say for example transport aircraft modern, transport aircraft legacy. You get a copy and I get a copy.

A.5.2 Interview 2

Question	Answer
Categorization	
1. How many years have you been in the military or latest civilian company?	Laura: We start the interview now. I've broken the questions down into a little bit about you, the aircraft you've flown, then about No Fault Found and then we go onto the debrief process and then any training issues or any training, because I'm quite interested in that, if that's OK? So, how many years have you been in the military or latest civilian company, So military? Pilot: 15 possibly.
2. How many years have you been a pilot?	Pilot: I'd say 15. Laura: So, you didn't do any flying before you joined? Pilot: Actually, I did do 4 years in the University Air Squadron before I joined in 2000 and then I started Officer training in November 2004.
3. What type of aircraft have you flown?	Pilot: Grob Tutor, Tucano, Hawk. Laura: That is quite a mixture. Pilot: Squirrell, Griffen, and then a Chinook Mark 2 to 6.

4. How long have you been flying the latest aircraft?	Laura: How long have you been flying the latest aircraft, so all your previous aircraft since you came here since you're not flying at the moment? Pilot: I flew the Chinook from 2010 to the summer of 2018. The last time I flew would be May 2018, so about a year ago.
Faults	
5. How would you describe an intermittent fault?	Pilot: I would say a fault that is substantial enough for you to notice it, but either not continuously present throughout the sortie that you're flying or that occurs on some, but not other sorties with the same aircraft. So you might notice the issue on a Monday for example, but not fly the same aircraft again on the Tuesday but then it comes back again later that week or in that single sortie it occurs 5 minutes in, 60 minutes in, an hour and a half in, for small durations. Chris: So how are aware are you that you are flying the same aircraft such as lima or foxtrot? So, the last one was the operational conversion unit for the Chinook OCU [operational conversion unit] at Benson. So, we had quite a small pool of aircraft, the numbers fluctuated a bit. For the majority of the time we had 4 aircraft, of which if you have one in depth, not depth but one in primary maintenance at one time you are probably looking at the same 2 aircraft on the line throughout the week, so you kind of get to know them. I'd say probably when I talk about intermittent fault, my mind would first go to a fault that reoccurs during that sortie. So, you notice it, you start to do something about it and it goes away. It's like a flickering caption, disappears and then it comes back later.
6. What is your knowledge, ignoring everything I have said, of no fault found (NFF)?	Laura: So, what is your knowledge, ignoring everything I may have said, of no fault found? Pilot: So my understanding is it's an engineering decision, output, a statement in response to a fault that aircrew raise on an aircraft post sortie, and my understanding of it would be that the engineers have completed some, any diagnosis process in accordance with their instructions and are unable to replicate or identify the fault that was reported.
7. How did you become aware of NFF?	Laura: How did you become aware of NFF? Or not as the case may be? Pilot: So I think when I was flying the Tutor, Tucano, Hawk Squirrel or Griffin whilst I was in training, you're looking at a larger pool of aircraft and as a student you don't tend to be the captain that much as possibly the amount of time you do on the course, so I wasn't really exposed to it then, but in my experience when I moved onto a front-line aircraft and you are then working with a pool of aircraft that you are flying with repeatedly and you are the captain of the aircraft and you are signing for the aircraft more often and reporting faults more often because you are signing the aircraft in more, you tend to follow the outcome from previous faults more closely, particularly once you've flown that aircraft previously and reported something. I suppose, to me, my interpretation of the definition of No Fault Found, I think if you had asked me before I started flying, I probably would have guessed at something quite similar to what I have said. I don't think it has particularly changed. But, when you do raise a fault and the engineers come back and put a No Fault Found against it, it is probably then there is some discussion you would have with them where they have explained in particular circumstances how they have arrived at that decision. So that may be quite a long way of saying it is an ad hoc thing.

8. So, what experience have you had of an aircraft NFF? Follow-on question	Laura: can you think of any examples? (feel free to email me afterwards if you think of anything) Pilot: I have seen it for faults on a radio. Laura: So, what happened with the radio? So, I think an aircraft with a poor receive capability so there's an excessive amount of static or other distortion. Laura: Was that on one aircraft or across other aircraft? Pilot: It was on one particular aircraft. In that particular example I think it was logged as a fault after the sortie and a no fault found but then I remember not seeing a repetition of that particular fault. Chris: It was it recorded as a no fault found, initially? Pilot: Yes. Chris: So, it was logged by the aircrew as a fault, by you, but the engineers came back saying no fault found. Pilot: Yes. Pilot: There didn't appear to be a recurrence of the problem. Chris: but then? It was solved by the engineers, no? A transient fault? Pilot: So that was an example of where they were unable to replicate the fault, subsequently the fault didn't occur again, so there wasn't any intervention by them. And I would assume a colleague would have turned the radio on, tested it, gone through their series of tests and said the fault was tested satisfactorily, released it back to the aircraft and it's gone through our test procedure and we can find no fault with this item, released back to line. On that particular one we would take it again the next time an aircrew flies a sortie. Laura: Can you give me examples where it was recorded no fault found and then the fault did reoccur? This was a couple of years ago but I think it was a wandering HSI [horizontal situation indicator (compass)] and it was slowly wandering throughout the sortie to the point where it was noticeably different to the magnetic standby. It was slowly giving a different heading, could be resynchronized and then re-slaved back to the correct heading, and then over a period it would slowly wander again. Chris: And you could do that in the air? Yes, so it would be slowly resynchronized and then the sortie would continue because it was a good day, visual and meteorological conditions and what we were doing was on the airfield and it was appropriate to manage that particular fault, but was something that we obviously had to report at the end of the sortie. I remember we reported it, there was no fault found, and then the engineers released it back to the line. It was flown again and I remember a subsequent captain then snagging it for the same

	thing the next time it was flown, which is probably a classic no fault found cycle.
9. What did you do?	Laura: I want to ask what you did, but in that instance, you reported it? Pilot: Yes. Laura: When you then went to the 700 did you go back to look through the paperwork to see what they had written, what work they'd done? Pilot: Yes. As a matter of course when you check the 700 before a sortie you would look back to see, at the previous faults that we raised and if relevant, over a reasonable time period you'd look back and see what faults had been raised, and what work had or had not been done on them. You would do that as a matter of course anyway, but if you knew in particular that you were going to fly an aircraft that had previously been returned unserviceable you would obviously want to pay particular attention, and you would know to look for, if you knew the aircraft had been unserviceable, with the small number of aircraft, you would look to see what the outcome of the previous investigation was. Laura: When you said it was if you knew, did you know sometimes because another pilot had told you, as in discussed it with other aircrew? Pilot: Yes. Chris: Would that be sort of normal chat in the crew room, they would be concerned at handover and that sort of thing? Yes. I think if, particularly somebody had curtailed a sortie because of a fault then that would be probably catch most people's interest and the duty authorizer on the desk. So on 28 Sqn on the chinook OCU, where you would generally programme the same duty authorizer for a week, so that person, as well as doing it unofficially through, you know you might bump into somebody who flew the aircraft previously, you might ask them when they flew it how was it, but also the duty authorizer if they're on for that week by the end of that week period might well have been aware of something that was raised as a fault on Monday put back on Tuesday, raised as a fault again and they probably get a quite a good feel for it by the end of that week period. From that they would look at the previous week's log Chris: Interesting point about the same continuity of engineers' shift. Shift handover and that sort of thing? Pilot: Yes, and so the duty authorizer would obviously be working quite closely with engineering shifts and so would certainly know, generally turn up a day and a night and the engineering shift would kind of overlap those, so the day authorizer would probably see both shifts. They'd see one of them mostly in the morning and the other at the end of the day. Because if was a helicopter and the tight set up they would be discussing stuff like that with them.

	Chris: If you were getting day flying and night flying would the duty authorizers do one day and one night? Pilot: Yes, usually so. Chris: it wouldn't be the same person? Pilot: No, unless you were doing, unless it was a very, very short programme with one short wave at the end of the day and one short wave at the beginning of the night, but ordinarily there would be somebody at the beginning of the day who would do a day and somebody else would take over at the late afternoon, early evening to carry out until the end of the night flying.
10. Did you check the aircraft log to see how the fault had been cleared?	See below.
11. Did you remember the aircraft number and look for it in the aircraft log if it happened a second time or more than twice?	Pilot: No Laura: But you did look in the logbook to see if it happened again? Pilot: Yes. Laura: I think that ties in with the previous answer that you gave.
Training	
12. Moving onto the next bit which is training. During your aircrew training (flying training) can you explain what you were taught about the post-sortie debrief to the engineers?	Laura: Have you provided training for others as well? Pilot: Yes. Laura: We might get 2 different answers here then. During your aircrew training, i.e. flying training or when you've been given training, can you explain what you were taught about the post-sortie debrief to the engineers? Were you given any training at all? Pilot: Yes, and in the very, very initial basic training I can't remember what was said, but I would be surprised if there wasn't. In the very first ground school that you do before you start flying I know there was an element about technical ops, a short element, but I can't remember what was said about that but the training I remember receiving when I was a student would be when you flew the aircraft solo. Certainly for the first time you did that, or just before the first time you did that you would shadow the instructors who would take you through the process of looking through the 700, and they would show you what they were doing pre sortie. That would include looking at previous faults, and then they would show you the process post sortie including recording faults. Then when certainly the first time you go solo there would be an instructor watching you doing that for the first time to make sure that you understood what you were doing. Laura: When you say watching you and instructing you, in what way were they instructing you? Did they just tell you; you need to fill this out with the information or did they give you guidance on the wording to be used?

	Pilot: So, the first time, in my reflection, the instruction took the form of them just verbalising what they were doing, say right I am looking at this section and on the pre-flight this is what I am looking for, this is where I put my details, this is how I fill it in. Then on the post flight they would say okay this is how you sign the aircraft in now. I think, again from my recollection, if there were no faults on those particular sorties, they would mention it, and they would say if you were to record a fault this is where you would do it. But at that stage I don't think, because there were so many permutations of faults, that you could record that the guidance was pretty much if you are going to report a fault certainly as a flying training student the first thing you do is you speak to the duty instructor. So, I can't remember specific examples, but I do remember as a student I would have filled in some kind of faults, not necessarily serious but post-flight faults and invariably as a student, because you don't want to mess it up, pretty much the first thing you do is you speak to the duty instructor to explain what you're going to do before you put it in there and they would discuss with you and discuss what a suitable form of words would be to convey the message, and you would probably get more guidance in that way. Chris: You wouldn't necessarily discuss it with the engineers; you would go to the duty instructor first? Pilot: As a student, I would go to the duty instructor first. The duty instructor would on a couple of occasions; they would then take you to the engineers as well, so they would do that with you certainly for your first few sorties. Chris: So, it would be quite managed? Pilot: Yes, to make sure that you filled it out correctly. As a student you don't cause a lot of unnecessary work by using the wrong phrases or perhaps not reporting things fully, although invariably you are still learning and then I think as you go further down the line I remember being confident, you're confident enough to do stuff on your own which you've already seen or which feels analogous to stuff that you've already seen. Then I think as you go through your flying career if you then come to things as you are still learning throughout the training system, but once you are on the front line as a junior pilot you still make use of the duty authorizer who would be a more experienced aircraft captain who would help you if there were things you hadn't seen before so perhaps uncommanded flying control movements, that sort of thing. Laura: So, when you were providing training what instruction did you give to anybody about the post-sortie debrief? I'm thinking about the engineering fault aspects. Pilot: So, I think the way I did it was the way I'd seen it largely as I was taught. So, what I would try and do is, my instruction was on the front line, so the students that arrived with me had already completed, been doing ??? (unclear) standard, so had an assumed level of knowledge from that point of view but I would walk them through the process fairly early on in their flying anyway, in the flying syllabus for any standard post-sortie debrief, sorry standard completion of the forms, and then I tended to find that if there was a fault, particularly one that had curtailed the sortie, the students often tended to be quite interested anyway and would want to shadow me any as I reported it through the engineers, but if not I would, if it made a good learning point, I would try and get them along anyway, because they're quite good training opportunities sometimes if you had a

	fault or a problem. So, coming in from the sortie I would get them to stand on my shoulder and I would show them the way I'd talk to the engineers, how I would describe it to the engineers and then how I'd completed the paperwork.
13. During the debrief, what were the key points to get across?	Laura: During the debrief process, the engineering debrief process, what are the key points to get across? Pilot: So, I think the key points were, are a factual and chronological if possible account of what occurred, and in the first instance I would try and give the observed symptoms, which could be cockpit indications, flying control feel, you know almost in a legalistic sort of way of this is what happened at this point. Then I think the next thing is what action, if appropriate did you take to remedy that within the bounds of the flight reference cards. Then common sense, that sort of stuff. What was the outcome of your attempt to rectify that? Was that successful, and then did the fault recur in the same way did it manifest, or did another seemingly related fault occur? What further indications were there? Then very, very broadly what was the impact on the sortie? Then having done that I would try and separate in my mind to then to give further background that might be helpful. So, for example, if I had flown that aircraft and observed the same symptoms previously I would describe that and I would perhaps relate whether it was similar to a previous occurrence I had seen or whether it was different, certainly if I was flying an aircraft where I had had that exact fault before I'd do that or I might say if I had seen the same indications but at another time or on another aircraft, I'd perhaps discuss that. Then as much for my own training as for a bit about the fault I would probably then have a bit of a discussion with the engineers about certain hypotheses, about causes. Chris: Would that be from your basic knowledge of what you go through when you first join an aeroplane? Ground school? Pilot: Yes, that would be, so on the Chinook for example, that would be everything you know about the aircraft from the ground school where you do the lessons, read the tech manuals, all the way through to your experience of it. So, for example, an attitude indicator that was slowly starting to topple, some marks of chinook previously, we would have seen it would be an indication of a vertical gyro that was on its way out so that sort of thing. So, I might go through all of it and then say it seems a bit like something that happened 3 years ago. But I would always try to make a differentiation between the factual stuff of what I saw and the experienced and then kind of interpretation so as not to upset the engineers. Laura: I've got a question on that. So, if you think there is a problem, who would you talk with? The engineers and the duty authorizer? Pilot: Yes, so what we might do, what we did do commonly was if it was safe to keep the aircraft running and we came back, and it was something like an avionics fault, or something that was there then, we would quite often land and we would radio in and ask for an electrical / mechanical / avionics engineer to come out and observe the fault in place. Obviously, if it was at the start of the sortie, we would probably do that to try to have a chance of rescuing the sortie if we thought it was something that they might be able to fix. But even at the end of the sortie if it was something where we thought they would really benefit from seeing, or if it was something that we hadn't observed before, or was unusual, we'd get the engineers out so that they could then have a first-hand experience of it. So that would be kind of,

	I guess the first time you would be perhaps report stuff over the radio and that would be through the duty authorizer and possibly you could get the engineers involved in that, then on landing you would get the engineers into the aircraft and then on shut down, you would generally, if it was a significant fault, the engineers would already be aware of it. You would have told them as you were coming back in. Usually cause it would have an impact on the flying programme, if for no other reason, so they would be aware of it, so they would often have perhaps some of their trades specialists ready, and you would usually then have a, so long as the duty authorizer was a briefing. You would probably have a quick chat involving the engineers so they're both there. Their guy sort of in change of managing the programme from an engineering side and perhaps one of their specialists and the duty authorizer. Laura: If in the event that, say for example, where you have the possible no fault found before and that reoccurs, who would you talk to then? If it was one that had reoccurred would you go through the same process again? Pilot: So, you would go through the same formal process of recording a fault in the 700, so that would be the same. You would ideally speak to the duty authorizer and you would speak to the engineers again. Ideally if it was an engineer who you had previously spoken to who had been working on that fault and they were there, you would try to speak to them. Laura: A side question just for my knowledge. What's your normal rotation of flying /non flying within a week? I'm trying to see how much you would as I am trying to see how much you would align on the same shift that you reported for problems if it was within the week. Pilot: It was quite ad hoc, certainly from the aircrew side. So, from the engineering side, this was from 28 Squadron when I left, they would have a day shift and a night shift and they would generally keep that pattern for the week. I don't know if individuals would sometimes swap, but my impression is that they would usually, for the vast majority of time, keep to that. From the aircrew side of it, it was very much more ad hoc. I think if you were going to night fly you would ideally try and do that for an extended period. So, if you were particularly instructing on a course you would do that for a week maybe, so you get into that sort of routine. In terms of the amount of flying that you did in a week depended on the number of aircraft available. So I have had weeks where I'd flown every day and maybe twice on some days and at least 7 times a week and I have had other weeks where I have flown only once in a week, because I was only programmed 3 times but it broke because the weather was bad. So, there was no deliberate intent to synchronize you with an engineering shift, but you would probably find that if you were night flying you would probably see the same shift that week. Laura: I think you've answered that one because I said how do you think you need to provide information, I think you gave a full answer to question 13, which was during the debrief what were the key points to get across, so I think that's been addressed. Unless you've got anything you wish to add? Pilot: The only other thing that is, or can be important, certainly for the Chinook is we have a health and usage monitoring system HUMS, there's an event key on that so particularly for stuff like abnormal aircraft handling responses and there is a definite benefit in marking an event on that tape

	so that the engineers can link the time that you are reporting something to their analysis of the aircraft parameters that they can monitor through that. Laura: I've got a later question, but I don't think it quite covers it. When you finish the sortie how hyper or tired are you? I've got a particular question about the debrief later on but it's more how do you feel at the time of giving the debrief? Pilot: Obviously that really depends on what you've done because the sorties we fly could be anywhere from 20 minutes for a simple air test through to 7 or 8 hours for a longer operational sortie for a combat-ready check or something like that so I think that probably determines that answer largely. And it depends on the arousal level of the sortie that you are doing as well so I think if you are going up to do an air test in particular obviously you go with the mindset that you're looking at the aircraft from a more technical point of view more specifically and so, therefore, perhaps you come back in more in the mind set to, when you're flying you're predisposed to observe and record things but formally and perhaps less formally as well, and then when you come back in you are slightly more formal framework and you are prepared to report stuff. Sorry to be a bit vague. Does that answer that? Laura: Yes.
14. If you think there is a problem, with whom would you talk?	Not asked here.
15. How do you think you need to provide information?	Not asked here.
16. How do you check the engineers' understanding of what you have said?	Laura: How do you check the engineers' understanding of what you've said during the debrief, or don't you? Pilot: I think there's a lot of assumed knowledge, so there is a large extent to which assume that you have reported the fault clearly and you expect that they've understood it clearly. I think, in my experience things, if they are very clear here, in terms of seeing a caption on a caution panel then that's kind of how it's reported, that that occurred. That would be the sort of thing you would put in the log. Or that an engine performed in that way, you're giving the numerical parameters. I hope that's unambiguous. I think in a lot of cases the engineers inevitably have questions as well. Some things that you can answer and other things that you can't answer or that you wish you'd observed at the time, and then I think that final bit probably comes back to the engineers a little bit, is that you give the engineers a debrief which they record then you go and log something in the 700 and quite often, in fact this might go back to one of the earlier questions, quite often before I record a fault in the 700 I will actually verbalize to the engineer on the desk what I am going to put in it. Not for them to approve or veto whether you are reporting a fault, but so that if what I am putting in is ambiguous or doesn't provide them with the information or does not provide them with the direction, I guess in a way to go and investigate something. They will sometimes come back and say 'actually do you mean Y instead of X?'

17. Do you try to provide the solution?	Pilot: Yes. Inevitably, of course you do. Laura: You made a point earlier; I can't remember the exact wording, about 'without trying to step on the toes of the engineer'. So, can you talk a bit about how you provide a solution without doing that? Pilot: I think that's very personality dependent. I think it is personality and experience levels a little bit. As I say the way I do it is to try and give the factual stuff and try and be objective first, and then if I try to provide the solution, I am usually trying to provide it as a hypothesis, and that's as much to test my understanding as it is to actually to provide a solution to the engineer, because I know that they're going to go away and they're going to follow their procedures anyway, so if I tell them to go and change a component and I know that is not the way it works. They will have their mandated maintenance procedures that they're going to have to complete.
18. Still on the debrief, on average what percentage of your time are you in a rush to get away?	Pilot: That's a really difficult one to answer because. Laura: I need the answer that's the honest answer because I don't want you thinking what looks better against you. Pilot: No, I think I find it really difficult to put a number against it because inevitably sometimes you're more rushed than others, because you've got something else to do. You've got another sortie or you need to just get away back. Laura: Let me re-ask the question. Does it depend on the duration of the flight or like a long day? So, you said some of your flights are 7 to 8 hours, and if you're doing that, and the next follow on one from that one is does this depend on the time of day? So, whether it's day flight, night flight or something. Pilot: Yes, I think it depends and I can give you the factors that I think would make you more rushed from the aircrew point of view, which would be the end of a long day, the necessity to go and do something else as well. So, you might have another event, for example another sim [simulator] trip, another aircraft you need to brief, another meeting or a family commitment or something that makes you want to wrap it up and leave, I guess. I think it's kind of related to it, but I do think I'm more inclined to rush if I feel that what I am reporting is a simple and uncontentious and that I can report it quickly. Does that make sense? But I think, if I think if I have ever come back with a more serious fault or with something where I know there's going to have to be a bit of an investigation, like a UFCM type incident. I think on the whole you accept that you have to give the time that's necessary to complete the debrief. Even if for no other reason than people won't let you get away without doing that, I think.
19. Does this depend on the duration of the flight? Like a long day? Explain	Not asked here – asked in previous question.
20. The debrief, does this depend on the time of day?	Laura: So, does it depend on the time of day. You said yes, but is it more likely to be rushed night-time or daytime or is it still down to the time of the flight and with the duration of the flight, just for clarification if you've got a 7 or 8 hour flight what is your prep time before that, before you can actually get in the aircraft, so I can work out your length of time?

	Pilot: So first of all, I think night-time, there's definitely a feeling at the end of the night so for example landing from a sortie to 0200 to 0300 in the morning, something like that. I wouldn't have described it necessarily as a desire to rush to be somewhere else, but I think probably more a fatigue element at that stage in that you are naturally tired. You want to sleep and it's a question of how much mental effort you feel like you are able to devote to it. Does that make sense? Laura: Yes. Pilot: I never land at 2 o'clock and think I must get back to this now. Although there is a slight thing of if you are doing a debrief know you've then got to go and debrief the rest of the crew, so you are aware that there's the crew duty of everybody, of people diving home, flying or whatever the next day is kind of dependent on you wrapping things up, sometimes in a reasonably orderly manner. But I would say yes, I think it's also human nature when you're tired to want to do things in a more expeditious manner I think than when you're not. In terms of the timing for it, the 7/8 hours I think that's more an operational sortie or some rare check ride. Normally on the OCU I think we would tend to fly 3-hour sorties. The way that the crew day would be structured would be 14 hours of crew duty. So normally you should plan for 12 but you could go for 14 hours of crew duty and that would be from arriving at work, reporting for duty effectively, to completing the last check and shutting the aircraft down. So, it wouldn't include the post-sortie debrief time or anything like that. Where that would come into play would be if the programming of the crews and the sorties that would be such that you were doing something and that the rule is that you need to get away for 8 hours of uninterrupted rest, so that's treated basically 8 hours in bed with the light out, until your alarm goes off again. So, there can sometimes be, if a sortie's gone late or whatever, that has an impact on what you are going to do the next day. In terms of preparation for the sortie we brief, probably on average on the OCU, we probably brief for about an hour and a half before the aircraft lifted. So that's an hour and a half from sitting down in the room to start the brief to the aircraft starting to taxi or from the aircraft lifting, going wheels up. Longer for a more complicated sortie, up to maybe 2 hours possibly slightly more beforehand for a complex formation sortie. And then an amount of sortie planning which is entirely dependent on the complexity of the sortie and I think on a chinook you could probably, as a crew for a simple sortie get everything together within half an hour. But a more complex sortie, the planning would start days beforehand if it was something that involved other elements.
21. Are there any regulations / procedures / process that you have read regarding the aircrew debrief? (Keep NFF in mind)	Laura: Are there any regulations / procedures / process that you have read regarding the aircrew debrief, the engineering debrief? Are there any regulations / processes / debrief manuals that you were asked to read to explain what you are supposed to do? Not for a verbal debrief, that I have read. I am not aware of anything which mandates or dictates the way that you have to report the fault to an engineer. I know that completing the 700 post sortie is obviously a mandated requirement, and there is guidance within the 700 for completing that, in quite a bare-bones, that sort of mechanical way. Laura: It's fill this box in, fill this box in?

	Pilot: Yes. If you are going to report a fault it needs to be in this box and you need to put your name here and you need to describe the fault here. Laura: But not about how you describe the fault? Pilot: No. Chris: And nothing to alert you to look for things like repeating faults, from previous sorties etc.? Pilot: No, I think it would probably come under two areas. To my mind, in the military regulations, there's a mandated requirement on the captain of the aircraft to ensure the sortie is planned and briefed properly, and I would always understand that as an understanding of the capabilities of the aircraft you're flying would be part of that. So, for the Chinook when we're going to do the sortie brief, we go through the weather, we go through what we're actually going to do on the sortie. And in fact, we started, we would say something like Initiate Stoppers and you would hope that nobody would turn up to the briefing with that. At that stage the crewmen for the Chinook, the first people to engage with it are pretty usually the crewmen. They go away and look at the book first for the purposes of doing the weight balance. They will look at acceptable deferred defects and lots of stuff like that as well. On the OCU we are lucky because the crewmen are very experienced as well, but a lot of them will tend to look at faults as well. So, they will come and look at that stuff because they've flown the same aircraft during the week. So that sort of stuff will generally get raised in the book. I mean, you'll probably know on the OCU as a captain because you've flown that aircraft and you've had a good run at continuity and you've been flying that week, when you see your name against that aircraft. You can usually remember flying it and you might have been the last person to fly it anyway. So that's probably the first bit and then the crewman will look at the book, they'll come to the brief and they'll talk about the physical entries that are in the book and that kind of primes you, and then the final stage is you, as the captain, sort of checking that stuff to make sure that nothing's been missed before you go. I would say that to my mind that process, although I have never seen it explicitly laid out, that's partly covered, I think in the military regulations that take you to brief the sortie properly, and plan it so I think understanding previous faults to the aircraft is part of that. I think part of that is good airmanship. Laura: Which military regulation? Pilot: I can't remember off the top of my head, I've got a photocopy of it. Laura: Did you look it up? Pilot: Yes. Laura: Is it possible to get a copy of it? Pilot: It should be freely available on line. If I can find the reference for it but it is Responsibilities of an Aircraft Captain, and it's something I remember being briefed in basic ground school. It will say something like the basic responsibilities of an aircraft commander and they will reference it.

	Chris: At that stage it particularly points out it's quite important to look out for the fault history of an aeroplane you're about to fly? Pilot: So, I think that comes from the particular training school, so I think I've never seen a mandated military regulation that says an aircraft captain must view that, but there might be one. In all the training courses I have been through and I would teach on the OCU, I think it's the responsibility of the instructors there to teach it to the students to say part of preparing for that sortie is to read the tech log properly, part of the reading the tech log properly is to engage with this bit of it and the previous faults. Chris: It's a debatable point, but is it something that should be mandated or is it just part of good practice that should be taught as good practice to look for fault history? Pilot: So, I think in my personal opinion, I think that should come down to, it's good practice and good airmanship and I think that's the responsibility for an OCU, for example, to teach that good practice to students now. You couldn't write absolutely everything down, so how directive you are then on an OCU when you write your training syllabus and you go into the documentation there. I guess perhaps only an educational specialist within the RAF could look at something like that and tell you how far you have to go down with that sort of stuff. I don't recall on the OCU having been told when I became an instructor you must formally teach this, but because I saw it when I went through it at every stage, I have therefore done that same thing. Laura: So, who would, because you said about the training schools, who would direct the training schools? If I wanted to go and talk to somebody who would I talk to about how they direct the training schools to do the training? Pilot: So, it depends what level you want the answer I suppose. So, for example on the OCU there is, on the Chinooks OCU there is Training Officer who is responsible for coordinating the training documentation we have. Then I am going to guess the syllabus that we teach at the OCU level, we don't make it up, it's always ratified by Command, so for example, on the Chinook OCU what we want to teach is what JHC, it is agreed through the Chinook force and then it's a JHC and other commands to tell us to do that. So, for the rest of the training system, I suppose that's 22 Group there would be probably somebody in this building who would have a better answer for that. Laura: I might come back to you. It's something I am interested in quite a bit.
Airworthiness and Air Safety	
22. Do you think your intermittent fault impacted airworthiness?	Laura: OK, change of tack now. Do you think the intermittent fault you had affected airworthiness? So, you might want to think about what airworthiness means to you, so if you want to give me definition that's fine, but do you think it impacted air worthiness? Pilot: I think, to use the example of the wandering compass on the HSI, I would say yes it does. The fault itself does impact the airworthiness and that's not necessarily to say that what happened was a flight-safety risk because of the severity of the fault, or the circumstances in which it occurred, but I would say for most systems where you're going to be

	bothered to report a fault, I think if you are reporting the fault I think it's an element of that aircraft system, that air system that isn't working as it should do, so that is the airworthiness again, I guess that does affect the airworthiness but, I'll just get myself off the hook by saying, to a very variable degree because it depends on the fault. Laura: Yes, I am going to come back to that. You made an interesting statement there where you said 'it depends on the severity of the fault or the criticality of the fault as to whether you report it'. So, does that mean there might be some faults you don't report? Pilot: I am trying to just think. I would say the only faults that I wouldn't report, as in formally record, would be something which was maybe transient, and then disappeared. So it would be perhaps possible on the flight that you might get a flicker of a, I don't know a flicker of caption, but let's say in the case of a compass something had wandered a little bit you resynched it, and you have then flown for 3 hours more and observed no reoccurrence of the fault. Maybe you even shut the aircraft down and start again. I think I would probably, informally I would, I wouldn't debrief. I would mention it to the engineers and the duty authorizer as I came in. But for some things I would otherwise for something serviceable, I wouldn't raise the fault because I wouldn't have any expectation that the engineers would find anything. Chris: No, it's safely worked for 3 hours. Pilot: Yes. So, when I said fault criticality, severity you wouldn't report I think pretty much everything that should work, you know down to a broken seat belt or whatever, you would report. You would log it. You would snag it because somebody would need to address it. Clearly some of them, because we do for example, do rotors running handover on the aircraft. So some of them, you know something like that might happen and I might even be content to sort of verbally pass it to the oncoming captain and some of them will accept it as a fault and say as they go flying so it's not that we would, I wouldn't report something that was still there at the end of the sortie or had occurred significantly throughout the sortie but if it happened once at the beginning and it wasn't in my view significant and didn't occur again, I might not report it. Laura: OK, you use the word significant which is quite good, so with a fault or an intermittent fault which is what I am particularly interested in are there different categories that you think affect the airworthiness more, so a particular system that you're more concerned about than other systems? Pilot: Yes. Laura: So, for example, what would be the most critical? Pilot: So, possibly flying controls, problems with flying controls, for the chinook in particular the transmission, obviously engine and fuel and then I would probably say other stuff I'd be most interested would be avionics depending on the amount of redundancy and perhaps the sortie profile or the conditions of the day as well I think. So for example, if I was going to go instrument flying, and I knew it was a day when the weather was really poor and it was legal to go instrument flying but I knew that I was going to be in cloud and my only option to recover the aircraft were going to be via an instrument approach, I wasn't to become visual and then the importance

	of attitude heading, all that sort of stuff, would be greater than it would otherwise be on a day like today for example, where I could fly around at 1000 feet on a clear day.
23. Do you think your intermittent fault impacted air safety?	Laura: Do you think your intermittent fault impacted air safety? Pilot: No, I don't think it did impact air safety, I think where it becomes a bit more grey maybe, is it's got the potential to. So, something like a heading system, a heading reference system that doesn't function. There are redundancies to it so for one set of circumstances it can be absolutely no problem because you might be doing hover work on the airfield, but I guess, but again if you sort of change the weather, change what you're doing, it can be potentially.
24. Could you categorize the intermittent fault by severity or consequence? E.g. by system?	Laura: Could you categorize the intermittent fault by severity or by consequence by system? I think you've just done that. Any questions for me? Pilot: No. Laura: OK
Permission	
25. Can I quote you by name / post?	Pilot: I'd rather you didn't if that's OK Laura: that's absolutely fine. You may go ahead Mr. Hockley.
Additional Questions	
26.	Chris: Can we go back to what experience you have of aircraft no fault found, we did some research particularly with the chinook which on ASCS, which was about 4 years ago was quite a problem and we made some interesting discoveries about the engineering refurbishment of ASCS and there's quite a tie up between ASCS and UFCM of course. Pilot: Yes. Chris: So, could you expand on your experience with the chinook of ASCS and UFCMs? Pilot: Yes. Chris: in terms of intermittent fault and anything you saw. Pilot: When you were asking me for an example of an intermittent fault, I know I have experienced intermittent faults that have been with the ASCS and UFCM, but the reason I didn't go with that was I can't remember clearly enough which the system was and what channel that came on. So I didn't think I would be able to provide it but I can give you an example from a detachment where the aircraft would make an undemanded input so I can pass that to UFCM, the engineers will go through it and complete the BIT tests and were unable to replicate the fault and after going through it with you. With the UFCM it's more formalized so the difference is obviously you could have, you know you can have perhaps ASCS issue but not necessarily a UFCM but it is in this case a UFCM so then after all the investigations it then completed an air test satisfactorily and then went flying and then on the next sortie it had the same UFCM about half way through a long sortie again, so obviously it came back and the difficulty then is, I say again there's a personal opinion that there's a little bit of tension between how do you attack that, do start replacing components? There is a little bit

	of a hypothesis about what way do you start to look at something like that. I think they, in this example, and this is why I didn't quote it, I can't remember the exact proposal otherwise it would have been quite a good one but they then, I think, did change a component out for another component to see if that would fix and that was it. Then the obvious component would have been that one to fix. I sent it up for an air test which it then failed I think exhibiting the same fault again during that and then I think it was then quite a way down the line. Bear in mind this was on operation, so I think that aircraft was then used for other parts to generate serviceable aircraft so the whole process became very protracted and drawn out and it kind of got to the point where I think after a couple of months, I can't remember what it was, but I think it was a brainwave from one of the engineers who'd just been to deployed out there who took their investigation down a different path to what they'd been doing before. I know it is quite prescriptive in some ways in the ways they have to respond to a UFCM, it has to cover all the bases: Chris: From Laura's research point of view the issue is, is it a UFCM by your definition from the fault that you've experienced or is it just a transient intermittent problem, which is likely to be ASCS and so on. So how, going back to the discussion in the aircraft with the engineers or the duty auth whatever it is how do you lead in that particular flight safety airworthiness type of issue? Do you declare a UFCM or do you say I have this transient intermittent you know? Pilot: So, I think we have to be deliberate and careful when we use that because as soon as we put the UFCM down that is black and white and is categorical and engineers are mandated to go down a certain path in the enquiry. And so people, I think on the chinook aircrew are aware that when they report that they are putting an aircraft unserviceable for a protracted period and they generating a lot of work, and that being said I think an example of a UFCM that I experienced was rectified, so it wasn't a no fault found, the engineers went through it and found it but it was obvious we were flying and there was a sudden, in conditions where there was no turbulence so it was obvious that it wasn't an environmental effect that you have to watch as you're flying over mountains there are sudden gusts of wind or whatever are going to do things to the aircraft and manoeuvre it. But you know when we say as we look at it that it is an undemanded departure from the flight path or it's an undemanded movement of the controls, it's either of those. So, in our case it was like a kick in yaw which was pronounced by about 5 to 10 degrees. It was like a sharp kick which then corrected itself that came from nowhere and we were on an air test at the time. It was not an air test, I think, the air test we were doing was not for any component that would have caused that. Chris: Yes. Pilot: So, I think it was just a, at that stage it was an ASCS air test actually, but at that stage we hadn't disengaged anything. Sorry to confirm that it was an ASCS air test, but it wasn't in response to the fault that we experienced so I think some component had been replaced that mandated an ASCS air test be carried out. We were flying in a kind of transit regime of the flight so we weren't actively doing anything to it. So, the aircraft was trimmed down when it exhibited that same, in that example we made the decision to discontinue the air test, we thought well it's exhibited a UFCM. We were happy that it had done that, we are not going go and continue with

	an air test, disengaging systems to see when it had just done something unexpected, so we took it back and declared it as a UFCM. Chris: We did this research where we declared something that was obviously rogue and just kept churning round the system, and the end result was just done for interest really, and what it was it was the procedures in the bay where they were servicing them there was some shoddy practice, but it was how they were built how they were being told to test them that was revised and the whole thing almost went away after that so just a second-line bay procedures that were done that virtually solved the ASCS air problem. So hopefully it's gone away. Pilot: So, the bit where my knowledge is deficient now is my experiences of chinook mark 3 and 4 you know the new DAFEC (?) aircraft. So, I have converted to that and I did about six hours flying on that and in a flight simulator in order to convert to the new aircraft type. I have stopped flying and moved into a new role so a lot of my experience is on a mark that is now out of service effectively, notwithstanding the fact that a lot of components are the same. So I guess perhaps the interesting thing for the chinook now is you've got the new dedicated new build of DAFEC chinook, which are designed to be that way and then you've got the older marks of chinook which are a mix of the old aircraft with the new, with the new system of load. I guess there are people now who have been flying those at Odiham, people there will probably have better data. Chris: Were you ever familiar with the engineer's No Fault Found Log? Pilot: No. No, I never saw that I mean. Chris: Because I think we found that Odiham that we used on one. (interruption from interviewee 3) Laura: Can we just wrap because there's 3- or 4-minutes left. Pilot: I know that more and more they're not supposed to keep an unofficial record of faults. So that it is official. Laura: You said twice but you've not clarified tension between. You were cautious of tension between? Pilot: I'm sorry, in what context? Laura: Where you were reporting a fault, so you mean between the engineers and the aircrew? Pilot: I suppose so, not necessarily in a bad way but I think in terms of, I think it's inevitable it is life or processing an aircraft is a tension between, a dynamic between, reporting faults fully to maintain the airworthiness of the systems, and to make sure safety is not compromised and not over reporting faults which are going to create new nugatory work. That's a really difficult one because nobody kind of, you know the official guidance says if there's a fault you report it but, in the example, a small transient fault that the aircraft captain doesn't deem significant that occurs at the beginning of the sortie and doesn't reoccur. When I say tension, I think that is probably what I mean it is. You could record every single time the aircraft didn't perform to parameters in a sortie and you would fill up pages and pages of

	the tech log with utterly irrelevant stuff and you would further serve to swamp the one crucial bit of information you're trying to get across I guess. Chris: You mentioned HUMS and the availability of the event and is that pretty standard so that people understand the benefit of the HUMS? Pilot: So really. Chris: It's not every aeroplane has it? Pilot: No. Chris: That's the trouble. Pilot: On the chinook, I don't know what they teach in ground school. I would like to think that perhaps when they talk about the event the key, if kind of comes up as part of, that we mention it. I know, you know what they probably are still odd people that, you know I've had it before where it slips your mind because, if something big has just happened potentially and you're concentrating on diagnosing it, and there's all the other stuff about the particular aircraft. I would say it's widely known. I wouldn't put my hand on my heart and say it is formally taught. I think it's probably airmanship. Chris: And putting intermittent faults into a simulator, is it done? Pilot: Yes. That's common practice. Although in my experience I think it tends to be used, I think they put in intermittent faults for the purpose of showing something which might build to a more serious problem. So, for example, a classic example would be a generator tripping offline because it's not being called properly. A transmission isn't called for that so they might show you that and show reoccurring frequency. Chris: So, the emphasis is on the airworthiness management as opposed to the engineering implication? Pilot: Yes, I think so. I don't think they tend to put in stuff that then goes away, and they think it's fine. I think that leads to simulator's paranoia. The thing is out to get you. I think they try to be objective first. Laura: I've made a mistake I'll come onto that I'll say what. Could you just sign the bottom of there please and I'll explain? What I should have done is bring some consent forms with me for you to sign that clearly explains how I use your data or don't use your data. I will email that through to Interviewee 3 and you can sign it and scan it and send it back to me. Pilot: Yes. Laura: So, you've got a copy and I've got a copy. It gives you the right to say I don't want to use anything I've said if that's the case. You will get full copy of the transcript at the end of it, probably in about a month's time when I get back from America. I have it very clear it read that it is anonymous. So, when it's typed up the name won't be in the transcript file it will be down as Interview 2. Pilot: OK Laura: Brilliant. Thanks very much. Have you got anything to add?

	Chris: It's been hugely valuable. Pilot: Was it useful? The UFCM, I'm sorry I can't remember the specifics of the incident I couldn't give you the systems. I could only talk about it generically. Laura: Yes, some of your answers are the same as the other pilot I interviewed in that not sure if there's any training given on the post-flight debrief. The fact it's got crew there waiting to go as well and you're conscious of their time and trying to get away for those as well. Again, there's the sortie day and night plan as well. And it's not looking to be judgemental; it's just to find out what the situation is. I'm interested in the training. Chris and I did the previous research when we spoke to the engineers and they were saying actually having a debrief performer might actually help the process. Because you appear to be quite lucky to have experienced engineers. There are other occasions where they sent out the SAC technician who'd got no experience whatsoever so trying to ask the right questions with everything else. Pilot: So certainly, we have a formalized debrief performer from the aircrew-to-aircrew side to the duty authorizer but all it would include is serviceability of aircraft, and a couple of bullet points below that but nothing to guide your discussion with the engineers formally throughout. Chris: Tornado brought in a computerized version of it designed by the engineers to help them solve no fault found on Tornado and it brought down the no fault found rate by 25% - 30%. But then it's slowly, well the aircraft is out of use now. Pilot: I think if you were going to design one, it may be useful, if you get aircrew and engineering input because otherwise the two will just speak different languages. Get when someone uses the proforma and the other asks 'what the hell are you asking me for?' Laura: Thank you both for saying that as it was one of the key observations of the previous pilot who says it's written in engineering terminology and he's reading what you've done which says carried out satis and he's wondering like what does that actually mean, what have you done, he's got no idea, maybe it's useful to have an idea. Pilot: Thanks, no problem. Laura and Chris: No. Thank you.

A.5.3 Interview 3

Question	Answer
Categorization	
1. How many years have you been in the military or latest civilian company?	Laura: OK, I'll just put Jack at the top. How many years have you been in the military? Pilot: 13.5.

2. How many years have you been a pilot?	Laura: How many years have you been a pilot, including any time before the military? Pilot: So, with the UAS, I flew with them, including the University Air Squadron time, so add 3 years to that, so it would be 16.5 years, but as a qualified pilot 3 years minus from that.
3. What type of aircraft have you flown?	Pilot: Training Grob Tutor, then the Squirrel, HG1, and then the Griffin, Bell 412 and then the EH101 Merlin. Laura: Do you know why it's called the EH 101? Pilot: Because it was EHI01 in the air. Laura: The MP's mistake.
4. How long have you been flying the latest aircraft?	Pilot: So, I've not been flying for 3 and a bit years, but I flew the Merlin for 7 years. Chris: Up until 3 years ago. Pilot: Yes, I finished in December 2015, the start of.
Faults	
5. How would you describe an intermittent fault?	So, an intermittent fault is something that mid-flight appears and then disappears again, or a fault that is there for 1 sortie and when the aircraft is used again with no change, it's gone.
6. What is your knowledge, ignoring everything I have said, of no fault found (NFF)?	Pilot: I suppose very limited in other than practical in terms of the experience of I've had for faults that have been disappeared and equally where radios have been taken out, checked, nothing found, dropped back in and the fault's gone, only to appear two weeks later
7. How did you become aware of NFF?	Laura: So, how did you become aware of NFF, because of the practical radio? Pilot: Yes, the radio is the key one for the Merlin with channels going to sleep, not a technical term, and when generally they were when you were not transmitting yourself you would find that your wingman would come up and say you are missing, and say why are you not responding to Air Traffic Control? Then when you transmit, they / you would start receiving again. There was no indication of a failure, yet you were definitely missing on certain channels of the radio. There were others, mostly indications of valves or things that essentially had a failure loop for a very short period of time that didn't complete within 2/10ths of a second it came up with a fail, yet they would dig it, out give it a wipe, put it back, and it would be fine, but frankly if you turned it off and turned it back on again it probably didn't come up either, so the Mexican reboot as it was known, yes, power down, power up, problems all gone away. So clearly it wasn't a physical problem, or there was and it didn't repeat. It was pretty standard practice on a Merlin on start up probably 50% of the time you would kill faults by just turning the power off and turning it on again. It was CB [circuit breaker] pulling but using the switches rather than CBs, which again was quite common for electronic sensors within the engine management systems.
8. So, what experience have	Laura: My question was what experience have you had of an aircraft NFF and I think you've answered that. Were those do you think NFFs or intermittent failures?

you had of an aircraft NFF? Follow-on question	Pilot: They were both I would say, because they are intermittent in that the problem which, as in the radio, was inconsistent during the sortie. You could clear the fault for most of the sensor failures or assess some (unclear??) issue by powering down and powering back up. So, they were intermittent in that sense and, when for the radios, virtually never was there an identified answer to why it happened. As far as I am aware, they never resolved that much. They tried air flow changes to heat, to reduce heat and cutting of vents in and all kinds of things, but as far as I am aware the problem never went away. It was more common in Afghanistan, which is why I think they went down the heat line. However, we also used 7 channels in Afghanistan and using them all the time, so the radios were working harder. So that's a potential heat issue and also you were running the radios so you had a much higher chance of noticing the fact that a channel was not working. Laura: I've got a question for you at the end.
9. What did you do?	Laura: If you had an intermittent fault, what did you do, as in recording, why you were talking to anybody? Pilot: Depends. Some of them had specific actions with the flight reference cards but most were minor issues, that BOV valve was one of them. Laura: Bleed off valve? Pilot: Yes, bleed off valve. So that was a, don't know what the timing was, was a certain speed that the valve had to close after, so it was in the incorrect position for a period of time and that set off the BOV caption. Then that was fixed on, so it didn't clear when the problem went away. So, therefore, we pulled the CB of the BOV, put it back in, did a power check and assuming it did not come straight back up again, you went well that's not actually a problem. It was an intermittent fault. It meets the time threshold. Reporting wise, those wouldn't, nor the radio issue, would be reported live back to the engineers. It would be reported on landing. But if we had it, the radio one potentially, you would get, you'd cancel the sortie, because you would go 'the radio's unsafe'. Laura: I've got a particular bit on that one. Pilot: Or you would, but for the BOV or for a minor issue you would hand it on to the next crew, so the engineers would not necessarily see anything of it until the sortie, day sorties, were complete. And frankly for the BOV, I would have thought 10% were actually ever reported to the engineers because it was such a standard fault. The aircraft permanently had BOV captions, and some others. I think the one that was linked to engine failures, not BOV, it was another one, ECU something, something failure, which 90% of the time was absolutely nothing but was associated with engine failures. Again, I had one which the engine had run away up and turned itself off, but I was in the UK and it didn't really matter, but we had several in Afghanistan where if you lost the power you were required to end the flight essentially, which was significant.
10. Did you check the aircraft log to see how the	Laura: When you report a fault, specifically something which has had an intermittent fault and a No Fault Found did you check the aircraft log to see how the flight had been recorded, so the 700? For how it had been cleared by the engineers?

fault had been cleared?	Pilot: How it had been cleared? No. There was very limited feedback for any reporting either flight safety or engineering support in particular of any fault. So, say, a more significant issue of a hydraulics leak I refused to take an aircraft. It's the only time I have refused to take an aircraft, because I'd put it the time before and I'd put it back in because it was the hydraulics level low, and the engineers assured me that they had checked it, in the pre-flight servicing, as they should have done and, therefore, they assured me that it was full at that stage and it then had a low. Therefore, it was I think 6 litres, something that was quite a significant amount of oil had disappeared, they then told me there were no faults. So, I said you're wrong so either they were lying about a) stage 1 or there is a fault and then I got very strange series of odd descriptions of where this oil could have gone which were fundamentally untrue. They clearly didn't understand the system well enough because they were explaining odd places where this oil could have disappeared to and it got no resolution. So, I'm unclear actually if the aircraft ever got any work done to it, or if it was flown again. I refused to fly it. Laura: So, when you sign the aircraft out do you go back and look through the log cards, at the engineering record cards that are still there? Pilot: So, anything that's open and minor issues that are still allowed to be open, yes. Laura: When you say open, do you mean, only because Chris and I would say you can't fly the aircraft with any entries open? Pilot: Yes, so some 700 faults, they [the engineers] would say 'no you can't take it as the book, it hasn't been signed off' and it wouldn't be handed to you but you can have minor deficiencies. Laura: LIMs and ADFs yes? Pilot: Yes, LIMs yes thank you. Three and a half years is wearing my memory. So, you would have things like this might be in those sections that tell you this had repeated faults. Laura: But you wouldn't look at the engineering record cards to see how they had closed down some of faults? Pilot: No, they were removed. So, I think those, we were a part, some of the aircraft were part of an electronic system, so I wouldn't physically have seen them. But anything that was closed down and finalized would have been removed. Yes, so all the faults would go, or certainly they wouldn't stay in there for the long term. So, I am not sure, it might have had the last few faults in there but you wouldn't see the full history of the aircraft. You'd mostly be looking for things that are identified as not working, such as a spotlight 1 broken but 2 functional, or dents, bashes that sort of things, so you'd know that when you do a walk round that there's supposed to be a hole there.
11. Did you remember the aircraft number and look for it in the aircraft log if it happened a second time or	Laura: So, let's go back then to, for example either the hydraulics fault or the radio, assuming that was reported, and then recorded a no fault found. The answers we know from what you've just given me. Did you remember the aircraft number and did you look for an entry in the aircraft log next time you flew it?

more than twice?	Pilot: No and no. I probably wouldn't have a recollection of which aircraft I'd flown, particularly as an air-test captain. So you end up doing lots and lots of air tests, so I could end up flying 10 aircraft in a day because you would bounce from the ground run for one, to an air test of another, to go to the sortie, back to another ground run or do another air test, so little recollection of something working beautifully, which we talked about. Personally, they seemed to go through fits of being good or bad and no I wouldn't dig back to find the standard faults. I think the NFF reporting was driven by the hierarchy, of what was trying to get results to, if you go through ASIMS reporting is wildly skewed by what people have been directed to report. So, for example, slippery floors, another classic Merlin one, where someone would fall over and hurt their back in the back of the aircraft and then the senior persons would say right how have we been reporting these. Well it's always slippery and then everyone reports it so you will find there are 300 reports of slippery floors for a couple of months until everybody gets bored again and then it will disappear, and I have certainly seen it quoted that the problem seemed to be temporary, and it has now resolved. That was a Merlin flight safety meeting. Which was rubbish, it was that people were bored of writing the same words every sortie, back at 3 in the morning writing the flight safety report to report something they'd had for 7 years on the same aircraft and no one had done anything with it. That's a failure to progress issues leading to apathy in flight-safety reporting. Merlin had a rubbish floor from day one to the day I left where people walked all over on it. Chris: A busy aircraft is going to be wet most of the time presumably? Pilot: It is. It is muddy feet that are the real issue, the crewmen, soldiers, the ramp is very steep, couldn't get on the ramp, so you had this farcical situation where people were trying to slither their way up and it was fine when it was dusty but when it would turn wet so you get people falling down the ramp landing on the wet bit in the middle of it, on the ramp.
Training	
12. Moving onto the next bit which is training. During your aircrew training (flying training) can you explain what you were taught about the post-sortie debrief to the engineers?	Laura: Moving onto the next bit which is training. During your aircrew training (flying training) can you explain what you were taught about the post-sortie debrief to the engineers? So, the engineering technical debrief. Were you taught anything? Pilot: Yes, so before you could be an aircraft captain so must have been, therefore, within the ACU. You were taught what to report, how to fill in a 700. I can't necessarily remember the details of how we were taught to feed information back, but certainly the process of filling in a 700 was a lesson on the OCU, before you go for a survey. Laura: So, the lesson was on the process not on the technical detail, or the technical information? Pilot: Yes, so your ground school, start of the OCU, gives you the technical detail of how the systems work and is largely taught in that fashion, so you are looking at how a system flows so it will be Box A through to Box B rather than knowing necessarily where you'd find that on the aircraft. So, the focus is very much understanding the system, which is great, so is key to understanding what is linked to what, for example the hydraulics issue that system A was not linked to system B. For that exact reason, therefore, the idea that oil was going from one to the other was farcical and so if you told me to trace it around the engine, I was much less skilled in that. We did have some practical training on where things were physically recessed on

	that as well but because on the Merlin you can't do pre-flight servicing as aircrew, as pilots sorry on Merlin, where you could have done on other airframes. Our knowledge is probably less good so I couldn't check oil levels myself. Laura: But the actual technical wording of how you would describe a fault in the 700, were you given a training session? Pilot: Yes, that would have been in that pre first-solo sortie. So, the teaching would be how we should word things and imagine beyond that it's done through experience with your captain, so when the aircraft was being signed in it's a continuous learning from people of more experience. Equally the authorizer, during my air force time at least, the authorizer is a pilot who is an SCR and he is at the desk with you so you can draw them across for advice on how you should record it as well as the senior line guy and the engineers who, again would normally be, flight sergeants, often with lots of experience. So, a good sign-in would be, you would have those people available and you would then be able to articulate the issue and make sure they'd got it as what you wrote down, what you wrote down made sense to them. Chris: Is this you saying that the Merlin aircrew weren't able to do it? Pilot: So, pilots did not do pre-flight servicing at all. Chris: Was this because you always had a crew? Pilot: We always had a crew but the entire idea of aircrew carrying out pre-flight servicing largely won't, it was only if the necessity, partly due to humans doing it badly, leaving panels off airframes, but also the practicality of you had to have a set of ladders to be able to carry out the check of the oil level, as it was 30 feet up, so actually the idea of going to do it was challenging so the crewman would do it but it was done very rarely and as such was not a first answer because they didn't do it regularly enough. Chris: So, the problem of training them but for fast jet aircrew to do it if they landed away but I thought the norm for helicopters it they were flying away all the time? Pilot: On all others types of helicopters yes, but for the Merlin less so.
13. During the debrief, what were the key points to get across?	Laura: So, during the interviewing debrief what especially, thinking about intermittent fault and no fault found, what are the key points to get across? Pilot: When the fault occurred, what flight condition you were in at the time, what actions you carried out following it, any diagnostics you did during the sortie that might be useful to understand the fault, any impact it had on the performance of the airframe, number of occurrences I suppose. I think in terms of what was carried out by the aircrew was probably variable and that would depend on the experience of the crew. So you would find that people with more time, who were probably captains, training captains, air-test captains, would tend to do more playing with the airframes to try to understand it, i.e. pulling CBs and whether they landed in a field to see if you could then cleared it, see if it reoccurred, and doing more diagnostics essentially from their training, from doing air tests. Laura: Just to clarify something. You said the aircrew actions: diagnostics to try to clear the fault and impact on the airframe. Is that impact caused

	by the diagnostics that had been undertaken or the impact on the airframe fault? Pilot: On the fault.
14. If you think there is a problem, with whom would you talk?	Pilot: So, for example you've got a BOV valve caution, have you had power loss in that engine compared to the other two engines, are their performance within range but different now to the other engines? If there was a BOV valve stuck open or if it had just failed to close within 0.2 of a second, there was no difference in terms of indication. They both said the BOV valve had failed. Laura: So, if you had a fault which you cleared would you then report that when you landed? Pilot: I would say 50/50 depending on what it was. BOV valve, this one here, probably not because it was standard, it probably wouldn't be written in the book. You might mention it to the line but would they do anything with it? Very unlikely. If there was a radio failure with the flight safety implications that come with, that would definitely go in the book. The BOV in particular became so standard that no one was interested and you would get out of the aircraft and forget the fact that you'd even had it. Laura: I have to ask this question here or later on, so everything about no fault found or intermittent fault and criticality are there any systems which are more critical to you from an airworthiness, flight safety perspective than others? Pilot: So, to be specific no fault found issues with? Laura: Yes, or things that would cause you to have more concern about it if it was a system where it was deemed to be no fault found like a radio or hydraulics system, or something? Pilot: So, I suppose radios were a key one because of the implications of missing radio calls that would come higher up the priority list than some others. The hydro fault that was a specific occurrence which I don't actually believe is an intermittent fault or a no fault found. I think it was just bad engineering to be honest so I think was probably a bit of a red herring. The ECR valve which was again normally no fault found, but then occasionally then led to catastrophic failure of the engine was initially treated like a BOV failure because the cards [FRCs?] just, there were common actions actually for that. In fact, there were common actions but they were 'continue sortie'; however, that's the guidance then changed when it was then associated with engine failures afterwards. I know they did a load of loom changes but as far as I was aware, they never actually nailed the fault. It was believed it was issues with the wiring loom around the engine, but that never really was found to be correct because we had faults immediately after changing to new ones and so in essence it was a manufacturing issue with them. Laura: Yes, a build issue? Pilot: Yes, so that as far as I am aware continued. Laura: I'm conscious of your time. If there was an intermittent problem / no fault found problem who would you talk with?

	Pilot: I would not raise it in any different way to any other fault, and probably would be less likely to raise it if it wasn't there at the end of the sortie because half the time, you're capturing nearly 10 different faults. That's probably the first ones that you'd drop off your list at the end of the sortie if it's come and gone away again. So, it's probably less likely to get reported. Laura: And for the radio where there was an NFF, was that reported to? Pilot: So we would go into the line, potentially you would report it back at the time to the authorizer who would be on the ops desk, because if you felt that you needed guidance whether you, it was suitable to continue the sortie or you'd need to pass it on to future sorties. There would be the potential of going through London or if you were staying in the local area you might say well I'll just not use that channel, but if the next sortie was going through London or had something that was at night or was more demanding, a paired sortie, that sort of thing you pass it back that way, then on return you pass it on to the line so they were aware of the issue. They would essentially do nothing with it if the ops desk were content that it wouldn't affect the remaining sorties. It would then get checked overnight. I understand that radios would then go back to one of the companies that make them, for those guys to checked it over. I understand most of them had a very, very expensive check over and got posted back to us, saying no fault found. But I think it was a bit of a game between those guys who built the BOVs and the AgustaWestlands who put the BOVs in the aircraft saying well actually, they would say it was an issue for the aircraft, and they don't work with those issues, radio issues and that went back and forth. That's anecdotal rather than what I was involved with.
15. How do you think you need to provide information?	Laura: How do you think you need to provide engineering information, technical information to the ground crew? Pilot: It has to be written because they are busy like we are and, therefore, they are going to drop things unless it is physically written down and then they are forced to acknowledge it and act on it. The verbal handover of a few extra bits of information is useful but ultimately, I would imagine 90% of it never went anywhere because they would be dragged off on to the next thing that they had to deal with. And if you back loop, bringing the aircrew in, I think it's always a good idea, certainly when the flight safety boards for the Merlin, they would raise them from the squadron to the Merlin force and go through all the different flight safety reports. I found one of mine was in there and I read the engineering response to it. They'd utterly misunderstood the problem and, therefore, it had been cleared and the problem was all closed down, yet actually it was nothing to do with the problem that had been resolved, that had been raised, but there was no feedback loop to the person who reported it. There was no way of saying well that's rubbish, they've got the wrong end of the stick, or I've written something clearly incoherent and it was sent down the wrong path. It just happened I was in the room and I saw my own one. I don't think ASIMS has a ???? (too much background noise - 30.11 minutes) feedback loop system, certainly versions 2 didn't. You had to specifically ask for access from a flight safety officer to then see the incident report. But again, most of these no fault founds would not appear in a flight safety report. Probably only the radio would have done because that actually has an immediate safety implication, but the others would, unless they were raised by the engineers, not be reported to the system. Unless we were directed to try to force the hand of the PTs to try to get the problem fixed by this reporting, and then you'd find every Tom, Dick and Harry reporting the fault or something.

	Laura: It's interesting, because with ASIMS you're supposed to get a report back to the person who raised the ASIMS. Pilot: But there's no automatic system to do that is there unless, Version 3 might have. Laura: It's the first thing the person who does the investigation is obliged, I think, to give the feedback to the person who raised it. Pilot: Certainly, as the flight safety officer we would link it and send it back to them at some stage but because it's totally man-draulic I would suggest that was totally flawed. It would be a very simple electronic fix to say at each stage it has to be emailed back to the individual and also they are out the country for six months on det or they are not available because they are night flying, you would want them, the aircraft not be cleared until that person has said, yes you understood right. I would imagine it would ground the air force. Laura: OK.
16. How do you check the engineers' understanding of what you have said?	Laura: How do you check, especially after the example you've just given, how do you check the engineers understand what you have said? So, you do a SMEAC brief if you do your officer training. Pilot: It relies on the line engineer being suitably knowledgeable, so you can say I put in 4 reports, light bulb out, radio channel 2 failed are you content and him being available to stand there and listen. Laura: I'm going to pose a slightly different question. Who is present at your post-sortie engineering debrief? My experience is Tristar so I know who is present there. Pilot: The only person who needs to be there is the line sergeant, flight sergeant, warrant officer. You do a separate in brief to the ops, to the authorizer, where one of the in-brief points is engineering issues. So, you would raise it again to them, but it wouldn't necessarily be at the same time because they are obviously doing other in-briefs. Laura: So, you only debrief to 1 person? Pilot: 1 engineer. Laura: 1 engineer? Pilot: One engineer and 1 aircrew person. If there was a complicated issue, they might well draw in someone from that speciality, sooty or fairy, whatever language we are using, to take that debrief. Generally, the experience during the Air Force time of the Merlin force, that meant that actually there was always a very suitable person on the front desk all times. That changed when the navy took them over so they were all new at the same time. So, there was somebody who was very experienced but not necessarily very experienced with the Merlin. And also, then tended to treat the rank much more strongly than experience, so lots of the authorizations for the SACs / corporals were taken away because of their rank rather than for the fact they had 10 years' experience of the Merlin. So that definitely reduced the understanding of the front desk.

17. Do you try to provide the solution?	Laura: Do you try to provide the solution to the engineering problem? Pilot: Probably. For the first 3 years no. As time went on yes, and probably became more of a pain in the arse and as you start to disagree with people with what the fault is or equally some of the diagnostics that had been carried out by the person who commanded the aircraft. An example being the hydraulic, that's where the fuel has a collector tank and if the fuel is captured there it naturally runs back, a tiny bit of fuel into there, but you have an issue where the fuel comes back in much large quantities and then it is overflowing from that, and an individual came out and used his 'liney', fat finger to drain the tank off the pan (a) awful but (b) an opportunity lost on how much fuel has been leaked into there, so you have no idea as, if it was in a 15-minute sortie that had come back, if you find a litre in there well we've got a proper problem here. If you find 50 mls they probably hadn't got a problem here. Things like that you feedback poor practice because you'd understand how it should be done, and the potentials of the diagnostics from it. But that tends to be people who had been air-test captains, which is the majority of experienced captains would become an air-test captain because there were some air tests where you had to break the normal practice of the airframe to prove a system so only air-test captains could do those. So those people tend to think more diagnostically about the fault rather than just going back in, going it didn't work.
18. Still on the debrief, on average (for the technical debrief) what percentage of your time are you in a rush to get away?	Pilot: Virtually always. Because your first action, you get in so as the captain you will be closing the aircraft down, reporting in to the engineers, reporting back to the desk, doing the debrief, then writing the DASORs from it and that may be the middle of the day, might be just before dinner, might be 3 in the morning. I'd say that's probably not the worst bit, I'd say the DASORs at the end is the bit that would fall off because the idea of sitting at 3 in the morning filling a DASOR when you've potentially been out 14 hours, 15 hours is not very doable. So it's... Laura: a safety occurrence, reporting, defence aviation? [Defence air safety occurrence report (DASOR)] Pilot: Yes, DASIMS.
19. Does this depend on the duration of the flight? Like a long day? Explain	Laura: So, does this depend on the duration of the flight? That going to be yes. Duration? I'm talking about a technical debrief. The amount of time when you're in a rush depends upon the duration of the flight. Pilot: No. Laura: And the next bit is like a long day, explain. And the next question is does this depend on the time of day?
20. The debrief, does this depend on the time of day?	Pilot: Time of day yes, but just because if it's shift changeover they'll tend to be in more of a rush or if you're late at night you may be in more of a rush. I would think the sortie – no. It might change your motivation if you've been flying for 7 hours but frankly that's pretty rare but it might well be actually it's the debrief from your 15th air test of the day, where you're rushing to do an extra one. Often you might bounce. You do a ground one, an air test, do a ground one, come back and debrief them. That's the air-test captain bit. This is the air-test captain who is normally qualified as an authorizer who's on that roster. Is an air-test captain so maybe only one or two in the day might be the adjutant or the ops officer or have another

	officer, who tend to be the busy people anyway, are senior people who, therefore, are also doing air tests and all the training sorties. Chris: All the time you were there was a lack of air test captains?
21. Are there any regulations / procedures / process that you have read regarding the aircrew debrief? (Keep NFF in mind)	Laura: Are there any regulations / procedures / processes that you have read regarding the aircrew technical debrief? Keep in mind NFF and such like. And the next question to that is if so, how do I get hold of it? Pilot: Good question. Yes, it will be laid down, so probably the JHC flying order book would dictate how the debrief should occur. Laura: What about the technical content? Pilot: Again, it will be recorded somewhere but I couldn't tell you where, how the 700 should be filled out. I would think the JHC flying order book would lay out how it should be completed, but I'm not convinced because, would it be standard across all different airframes, probably not. Particularly as the Merlin was partially electronic, partially not. Not that that changes a handover because we still did it physically and it was transferred onto whatever the system was called. It probably would have been created as a document at the time but I can't remember. Laura: What about in some training somewhere, would for example 22 Group or whatever dictate for flying training on squadrons, OCUs, this is how the technical debrief needs to be conducted? Pilot: So, there would have been a lesson on the OCU and all lessons on the OCU are standardized and done in accordance with whatever the training direction is. Whether 22 Group would do that I doubt, because they don't own the OCUs. They only own Phase 2, so OCU's Phase 3, so 22 Group don't own that. However, AoC 22 Group is COS training, so in that guise he owns all training that doesn't sit under his 'OC-ship'; so, he wouldn't necessarily regulate that the training to 22 Group but it would be standardized within that OCU training. Laura: So, if I came back to you with an email saying please would you find me a contact to talk to. Could you do that? Pilot: About the teaching on the OCU? Laura: Yes, specifically that question about whether there are any regulations about technical debriefs and what is it. Pilot: If you come back to us, Interviewee 2 has obviously been teaching in the OCU until a few months ago so he would be able to tell you exactly what they currently teach and who would be the link who writes the syllabus, because I'm not sure. The syllabus is definitely assessed and standardized because I was involved in the process of doing that on the new airframes for MFTS (?). So, what exactly is involved elsewhere, who carries out the coursework assessment, I don't know.
Airworthiness and Air Safety	
22. Do you think your intermittent fault impacted airworthiness?	Laura: Do you think your intermittent fault impacted airworthiness, so my question to you, is how would you define airworthiness? Pilot: That should be easy that. So, can you say the question again? Laura: Do you think your intermittent fault impacted airworthiness?

	Pilot: Yes. Laura: OK In what way? Pilot: So I would see airworthiness as a platform, as a whole thing, and if you have a known area of failure that you can't resolve because you can't find the fault that leads to it, then that would be something that I expect to be raised in the airworthiness manual as a persistent issue. Chris: I remember you talking about the radio, one in Afghanistan particularly, where it was not only an airworthiness issue because you know you might be dropping soldiers into a situation where you'd just been told no, no, no but you didn't receive the radio call first that sort of thing. It's a safety thing? Pilot: Yes, with my airworthiness terminology, I would see that as a flight-safety issue, an airworthiness issue is looking at the suitability of the aircraft as a whole but that may just be my poor understanding of the wording. Laura: The word I've got the definition of, the word airworthiness deems to be the likelihood of causing any harm to those involved with the activity and those not involved with the activity, so people on the ground, and it's deemed to be a technical attribute of the aircraft or the air system. As to how they define a technical attribute of the system I have no idea, I have not found out. Whereas, your flight safety, air safety / flight safety would be wider than that and it include the airworthiness. So, for example the air traffic control and everything else that doesn't come into your flight safety. Air traffic control wouldn't come into the technical attributes and the aircraft and air system hurting those operating, or on it or just nearby. Pilot: So, yes in the sense that it definitely an airworthiness issue and through that there's an air safety / flight safety issue, specifically with radios in terms of clearances, phased response clearances, air situational awareness and so on. And the ECR valve failure, which was the one I was struggling with, is a safety issue because it led, a percentage of them, to engine failure, which depending on the location of flying in and your stage of flight could be catastrophic. Laura: So, you'd put that down as an airworthiness issue? Pilot: Yes, so that probably is the key to... Laura: Airworthiness. Pilot: Yes, they're the two key examples of airworthiness I would say. The radio failures and that because it didn't lead to a crash but it easily could have done when the engines failed. So, in the early stages of Afghanistan an engine failure we were 3 engines committed to the ground, so falling to the ground, only with all 3 engines working from a couple of hundred feet so to ??? (Unclear voice), you would have undershot and crashed. As we were often landing in confined areas in dust, so you'd have zero opportunity to go short. That risk appetite dropped as time went on because we were bound to forget ourselves at some stage if we kept on doing that frankly. And potentially that fed in to the reduction of risk appetite part. I'm speculating on that. Certainly, in that flight situation with that failure you would probably be stuffed.

23. Do you think your intermittent fault impacted air safety?	See above answer.
24. Could you categorize the intermittent fault by severity or consequence? E.g. by system?	Laura: I'll send you some definitions from the MAA how they deem it. Could you categorize the intermittent faults by severity or consequence? So, you've given 2 examples - 1 being the radio, 1 being the ECR valve or the BOV as well all being intermittent no fault founds. How would you categorize them in terms of severity? Pilot: So, I think the radio fault would be conditional on the radio requirements of the sortie, i.e. if I'm in the circuit I would just switch radios and crack on. If I was in Afghanistan, and it was imperative, then I would potentially crack on anyway but I would put that sortie through London I probably wouldn't, I would go around or say that it wasn't suitable and not take the aircraft because of the requirements of the radio. So that is probably the condition of the BOV valve, I would categorize it as extremely not important, because it's, i.e. only the one time there was actually any BOV failure that continued and it wasn't a very short duration fault. I drew this through that diagnostic process. Laura: The ECR valve? Pilot: We, particularly in Afghanistan we would take the aircraft back to Bastion and land it there or potentially you would take it somewhere else but you would change your flight profile, you'd then sortie and make a decision on risk balance on whether you were going to fly it back to Bastion and because you obviously don't want to land it in the FOB and end up causing a fire fight because you've got a false reading. So, you would probably change your flight profile to minimize power demand. So that if you had a feeling, you could weather it. Laura: I suppose my question then is which system or particular elements of systems would cause you to curtail a flight? They would be the more critical ones for you? Pilot: I suppose the key to me would be hydraulics. Probably Number 1 because you have zero you can do about it. Number 2 engines because we had 3 of them and depending on your flight profile and attitude, country you're in etc., etc., so UK you would fly around to, next and then I suppose radios, communications after that, cause again we had a very good radio suite so you could mitigate it very effectively particularly if you were working with second airframes which you were always working with in Afghanistan. Chris: In the Merlin do you count transmission failure, broken links say as part of flying controls? Pilot: As in physical? I would other than my 1 notable incident where I severed some flying controls, I have never known of any issue with any flying controls. I suppose actually that's not true; we had some actuator failures in the control runs causing issues but you could always overpower them. So, they were in the autopilot element of the flying controls runs so you could turn the autopilot off and do it yourself. Chris: Because in different aircraft, the chinook the transmission is so critical.

	Pilot: So, transmission and gearboxes, so that's obviously very key but it's just nothing. We never had faults with gearboxes, so occasionally you would have the magnetic sensor would come up with chips and you were allowed, for the accumulators, a certain number of small chips, a certain number of large chips. But actually, it was something you would look at and see what the rate of the accumulation was etc., but the gearbox, I think, was felt to be pretty solid and, therefore, not a real problem, flying control runs not a problem.
Permission	
25. Can I quote you by name / post?	Laura: By Chris' watch I have got about 2 minutes left. So, can I quote you by name or post? Pilot: I'd rather not. Laura: That's fine. Pilot: I'd rather be quoted as... Laura: Interview 3. Pilot: If there's something particular you would like to quote give me a call. Laura: Absolutely. Any other questions from Mr. Hockley? Chris: No. Laura: Could you just sign the bottom and I will send a copy to you, so you've got those. And if you'll just let me quickly upload this before you kick us out your office and I'll turn the recorder off.

A.5.4 Interview 4

Question	Answer
Categorization	
1. How many years have you been in the military or latest civilian company?	Pilot: Well I started my flying career in the Royal Air Force, I was a university cadet from 1970 onwards and finished my training in 1974/75, for the rest of the seventies I was a Harrier pilot in the Royal Air Force Germany and then came back to the UK and was an instructor at the technical weapons unit at Brawdy for 3.5 years before joining the Tornado force when it came to service in the early 1980s. Then flew through the 1980s in 617 Squadron, 14 Squadron out at Bruggen and then back to TWCU at RAF Honnington where I was chief weapons instructor. That was my final tour in the Air Force in 1989 and when I left the service I joined British Airways and I flew for British Airways for 17 years, on European, Middle Eastern and North American routes, on the Boeing 757 and 767 before gaining command on the Airbus 320 series, where I've been stuck ever since. I had to retire from British Airways in 2006 because the retirement age was 55. I then did 10 years for easyJet, before finally retiring. I was a Training Captain for British Airways for about 6 years, and all the time I was with easyJet I was a Training Captain and examiner and I still work on a freelance basis as an A320 type Rating Examiner.

2. How many years have you been a pilot?	Laura: OK there's about 10 questions in one there. So, with the latest civilian company is that still easyJet? Pilot: Yes. Not directly employed, but on a contractor basis. Laura: That's fine. So, cadet from 1970, when did you stop flying, did you say 3 years ago? Pilot: Yes. March 2016.
3. What type of aircraft have you flown?	Laura: Yes, so you've flown Harrier, Tornado, BAE Boeing 757, 767, then Airbus A320 series. Pilot: Yes.
4. How long have you been flying the latest aircraft?	Laura: So how long have you been flying the latest aircraft, so that would the A320, would that be the last one? Pilot: Yes, since early 1999. So, I've been involved with the A320 series for 20 years now, just over.
Faults	
5. How would you describe an intermittent fault?	Laura: They were the background question for you. Think about just aircraft, how would you describe an intermittent fault? Pilot: An intermittent fault, something that occurs briefly on a fairly regular basis. Laura: From that do you mean across flights or within a flight? Pilot: I suppose I meant within a flight but it could be across flights as well if it's not dealt with satisfactorily.
6. What is your knowledge, ignoring everything I have said, of no fault found (NFF)?	Laura: What's your knowledge of a No Fault Found, an engineering no fault found? Pilot: What precisely do you mean by that? Do you mean knowledge of the process of arriving at? Laura: What one is? How one would describe a no fault found. Pilot: Purely from a pilot's practical point of view I would look at it with a slightly cynical view and take the view that it was tested, it went through the built-in tests satisfactorily and no fault was found. Laura: And the un-cynical view? Pilot: I don't think I have an un-cynical view. Laura: Quite telling, your answer, which is interesting.
7. How did you become aware of NFF?	Laura: How did you become aware of No Fault Found, the term no fault found or any experience of no fault found? Pilot: I think, first of all, it started to appear in my consciousness when aircraft became more computerised, especially digitised. The older aircraft that I'd flown, for example I'd flown the Hawker Hunter for 3.5 years, clearly basic analogue stuff and it was just something that really didn't happen in those days. An item of equipment broke, the technicians on the line knew what to do with it and they could fix it fairly smartly.

	Then came the more computerized aircraft with their built-in test equipment where you had to do a press test every flight and make sure you got the green light or whatever before you went flying. Nowadays there's none of that, there's no press test on any equipment at all, or you just switch it on and go and if it doesn't work you recycle the computer; give it another reboot. And that seems to be the way of things, and if it still doesn't work you call an engineer, he comes on board and goes through the multifunction display unit into the engineering part of it, and runs his tests. At the end of which he either comes up with a fault or he doesn't. Or she. Laura: That's quite a change isn't it?
8. So, what experience have you had of an aircraft NFF? Follow-on question	Laura: what experience have you had of an aircraft NFF? Name 1 or 2 aircraft experiences. Pilot: I'm really scratching my memory now. I think it mostly related to avionics equipment. With transponders for example, most commonly, or weather radars, which didn't work. Which is not an uncommon occurrence and if you'd put it in a tech log the engineer would come on board and perform his various tests and find nothing wrong. It didn't relate to the flight control systems or the propulsion so much. None of that. More the avionics side of the house.
9. What did you do?	Laura: So, I think you've answered this but you might have more information. So, the next question is what did you do? So, where you said: You would call the technician and he would come on board is that for the A320 series? Pilot: Yes. Laura: What about the earlier aircraft? Pilot: When I was flying the Boeing fleet at BA it was pretty much the same sort of thing. They didn't seem to be interested in what we had to say terribly much, unlike the old days in the Air Force where if some item of equipment didn't work you actually tried to make some fairly detailed notes so you could to tell the technician exactly what you'd observed, exactly what had happened, which might have helped him to pinpoint the fault. Laura: On those aircraft do you have a HUMS recorder so if you see something in flight you press the marker point? Pilot: On the Airbus series, I think the Boeing as well, there was a button you could press on the cockpit voice recorder panel which would make a mark on the flight recorder if something happened which was of interest, but I never, ever used it and I wasn't aware of anybody else I flew with ever using it. Laura: Specifically looking at civilian aircraft, when you landed did you give a debrief to the engineers or would the Airbus be just downloading what I call a 'brick' from the aircraft? The information. Pilot: Well if you weren't leaving the aircraft, yes, he would. The engineer would be on the flight deck and if you'd already made your tech log entry then there would be a quick verbal face-to-face before one of us got out of our seats so he could have access to MCDU. Laura: And then he would just interrogate that?

	Pilot: He would interrogate that, yes. And if we were going off the aircraft we would wait until the engineer turned up. But it was a fairly rare occurrence. I have to say with over 20 years flying with the Airbus 320 series they were very reliable. Laura: So, if you then went back, did you know you were going back to the same aircraft or would you never know if you'd gone back to...? Pilot: You'd never know. Laura: OK, is that because of the size of the fleet? Pilot: Yes. And the company rotate the aircraft round the bases on the fairly regular basis as well. So, the lots got for example, basically 80 aircraft based at Gatwick at the moment but it's not always the same 80 aircraft. They'll move them all over Europe. Laura: Is that to level out the flying hours? Pilot: Yes, and to get aircraft in the right place for scheduled maintenance. Also, on a seasonal basis as well because the aircraft numbers at various bases go up and down depending on the time of year. In the winter they lay aircraft up. A base may have say 10 aircraft in winter but 15 or 16 in the summer months. Laura: I'm going to jump back a question, just because of what you've said. Would you say your intermittent faults varied seasonally? Pilot: Gut feeling, yes, I would. Simply because in the winter months the digital equipment is more sensitive to cold and moisture. It's a bit of a joke about the Airbus in the winter, on a cold winter morning starting it up it usually takes a boot or two of some of the computers, but in the summer it doesn't.
10. Did you check the aircraft log to see how the fault had been cleared?	See above answer.
11. Did you remember the aircraft number and look for it in the aircraft log if it happened a second time or more than twice?	Laura: So, the next question would be, did you remember the aircraft number and look for it in the aircraft log if it happened a second time or more than once, but you would be not aware of it happening more than once on the same aircraft? Pilot: I am completely unaware because the chances of flying the same aircraft twice in a week or even twice a month or year were pretty small to be honest, operating from a large base like Gatwick. Laura: Yes, that's why I am interested to understand the differences between the civilian and the military. Laura: I'm going to move forward to training.
Training	
12. Moving onto the next bit which is training.	Laura: So, if we think about your Air Force training and then your civilian training, which might be different for a civilian, were you taught about the post-sortie debrief to the engineers and what information is required for you to give them?

During your aircrew training (flying training) can you explain what you were taught about the post-sortie debrief to the engineers?	Pilot: No. Laura: Not at all? Pilot: Not at all. I think we just learned by observing other people doing it. Laura: Did you for new pilots joining you, did you give them advice on how to conduct the post-sortie debrief to the engineers. Pilot: No, in commercial aviation there's no such thing as a post-flight debrief, unless there's a fault that needs immediate attention. Even then there might not be. You might just put it in the tech log and walk off. The engineers might say 'were swamped' they can't get anyone to you for the next 2 hours. OK I'm going home. Laura: The tech log, that's the electronic on the A320 isn't it? Pilot: No. Laura: Is it paper? Pilot: Well it was the last time I flew. Laura: So, what would you put in the tech log typically when you landed? Was it the flying hours? The time you landed? Pilot: The details in the tech log would be the fuel remaining, the flying hours, a few boxes to tick on whether you'd used the double (?? unclear) power on take-off, whether you'd done an automatic landing or not, and then a brief description of any defects that required attention. Laura: Are they all recorded in the same box? So, within the debrief is it all recorded within 1 box or do you put any faults, observations in different boxes? Pilot: The faults go to different boxes. On the sheet that easyJet uses the times go down on strips on the right-hand side of the sheet and on the left-hand side of the sheet there are a series of boxes to be entered on an individual basis. Laura: OK.
13. During the debrief, what were the key points to get across?	Laura: During the debrief, what were the key points to get across? So, if you think about your Air Force days, dim and distant past, what would have been the key points for you to get across, for example a Tornado flight? Pilot: Well the first thing is, can the aeroplane be flown again immediately? Was the fault something that was going to ground the aeroplane, which was not necessarily the decision of the pilot? You would do that in consultation with the duty Authorizing Officer or the duty Flight Commander. So that would involve a quick telephone discussion and then an engineering debrief if it was fairly straightforward, with a chief tech. If not perhaps the JEngO or the SEngO would get involved if it was something deeper.

	Laura: So, your first debrief would be the Duty Auth or Flight Commander not with the engineers? Pilot: No, not necessarily, it was something probably done at the same time. Laura: And for civilians? Pilot: Well you would contact, for example at easyJet, it's all run through the Maintenance Ops Centre at Luton, so you would contact Luton. Inbound to Gatwick you would send an ACARS [Aircraft Communication Addressing and Reporting System] message sending them what time you were landing and what the fault is and hopefully they would have one of the engineers from the Company Swiss (?? unclear) to meet you when you arrived on stand. If it was something that was going to affect the airworthiness of the aircraft they certainly would be there. So, you didn't wait too long on the ground; it was prepositioned. ACARS messages were usually sent to warn them in advance.
14. If you think there is a problem, with whom would you talk?	Laura: If you think there is a problem, with whom would you talk, and that would be the Contact Maintenance Ops Centre? Pilot: Yes. An MOC would make the decision whether the aeroplane was going to be on the ground or not. Laura: I would normally go on to ask about a concurrent fault across an aircraft but you've got no knowledge of that the civilian aircraft purely because of the rotation of the aircraft? t: Purely because of the rotation of the aircraft, yes. You don't get to learn the foibles of different aeroplanes. You just don't fly them regularly enough.
15. How do you think you need to provide information?	Laura: When you're providing your debrief information or you're phoning to your CMOC or you've got the engineer visiting you, how do you think you need to provide the information? What are the factors you consider? Pilot: Clear, concise written information is the first thing; the boxes in the tech log are not all that large so you couldn't go into a tremendous amount of detail. So, you had to condense it as much as possible. Then if you thought you had some useful information to give that might assist, you would definitely wait to do a verbal, if there were going to be able to get somebody there. They would during the flying day, if there were going to be aircraft on the ground otherwise. But last thing at night, when you are putting the aeroplane to bed that's when they would be running round doing the checks on the aircraft, and they probably wouldn't have the people to get to you for 2 hours or whatever.
16. How do you check the engineers' understanding of what you have said?	Laura: If you've given your brief to the engineer, for a particular fault you want to bring to their attention or issue, how do you check the engineers understanding of what you've said? Pilot: I never found I really had to do that, to be honest. They usually knew what you were talking about straightaway because they'd often had experience of the fault, and they would come in and just roll their eyes and say 'ah that's happened again', and they would get on with it and do their thing.

	Laura: If you were, just jumping back to a point you just said, when you're informing on the ACARS how much in advance of the landing do you do that? Pilot: As much as possible. Laura: Up to? Pilot: Well depends on how long the flight is. I can give you an example. On one occasion I was flying back from Madeira to Gatwick and on departure we had an over-speed warning on the slats, and to cut a long story short what it meant was that I had to fly back to Gatwick at a restricted flight level and a restricted speed. So it took 50 minutes longer, fortunately we'd loaded enough fuel to be able to do it but as soon as we'd dealt with the fault on the flight deck the ACARS message was sent to MOC Luton to tell them what the fault was and what time we were landing. And that would have been in that case, at least 3 hours prior to landing. Some of the sectors for easyJet are very short and very rapid and quite compressed so like Gatwick-Amsterdam, which is only 40/45 minutes; they would probably get 15/20 minutes warning.
17. Do you try to provide the solution?	Laura: We'll do the civilian first of all. Do you ever try to provide the solution to intermit? Pilot: Provide the solution. No. My knowledge is not sufficient to do that sort of thing. Laura: So as an Air Force pilot when you'd been on the aircraft for a long time would you then try to provide a solution if you thought it was a particular fault, an intermittent fault you knew about or the system? Pilot: In earlier aircraft yes, I would have done. Harrier and the Hunter, certainly. When I was flying the Hunter, I used to do air tests on the Hunter so you would come down from the air test with quite a lot of information on what we used to call the air-test bog roll, meat-pad roll. So, you could point them in a certain direction certainly. But I've never done anything like that since leaving the Air Force. Laura: Is that because of the aircraft you've flown or because of the mindset? Pilot: It's the industry mindset and the aircraft. The commercial aircraft I've flown, the reliability compared to the military types is astonishing. In 27 years, I am trying to remember any incidents I had; I can only remember 1 once, which was on a 757 when we had flaps jammed. That's it, that's all. Whereas flying military types I had several engine failures and landing gears, abnormal gear positions, which was quite a common occurrence on the Hawker Hunter. You had to shake the main legs down and push and pull to get the nose leg down sometimes.
18. Still on the debrief, on average what percentage of your time are you in a rush to get away?	Laura: Still on the debrief, we'll go civilian, what percentage of your time are you in a rush to get away at end of the flight if you need to call the engineer, what percentage of your time are you in a rush to get away? Pilot: All the time. Simply because the days are so long and you're faced with a lengthy drive home. So, if you chock-on at half past eleven at night

	you know you're not going to get home until half past one in the morning. So, you don't want to hang around. Laura: What about if you're doing a stay over somewhere? Pilot: Similar. You'd want to get away as quickly as possible usually because the rest time down route is cut to the bear minimum. You've got to have 10 hours available for rest in a nice, quiet hotel somewhere. Which worked very well in British Airways but not so much on easyJet. Laura: That 10 hours is that actually physically in a hotel? Not from when you've left the aircraft? Pilot: In a room, yes.
19. Does this depend on the duration of the flight? Like a long day? Explain	Laura: Does this depend on the duration of the flight? Like a long day? So long day yes. Time of flight? Pilot: Yes, that all plays its part. Time of day, time zones, length of sector. It's very complicated I'd have to look out the tables on it. It all used to be contained in what was a Cat. Can't remember the Cat. number. Flight and limitations anyway. And the amount of rest you had to have between flights was dependent on time of day, length of sector, how many time zones you were crossing and so on and so forth. It was very complicated, which meant that if you were flying from the UK to the west coast of North America for example, you'd be on a 10.5/11-hour flight. When you got there, you had to have 48 hours off before you could fly back. Laura: Doing that, there's a very good research paper where they looked into this specifically which direction you were flying, time of day you were flying, and I think it was also seasonal as well, and then what was the other factor, how much automation was involved as well, how bored you were going to get as well. Pilot: Going eastbound was always easier than westbound. The Atlantic cannon hauls are always killers. That's why I never did it.
20. The debrief, does this depend on the time of day?	See above.
21. Are there any regulations / procedures / process that you have read regarding the aircrew debrief? (Keep NFF in mind)	Laura: Slightly different question. Are there any regulations / procedures / processes that you have read regarding the aircrew debrief and how it should be conducted? Pilot: No.
Airworthiness and Air Safety	
22. Do you think your intermittent fault impacted airworthiness?	Laura: Do you think your intermittent fault or faults impacted airworthiness? Pilot: They should do, but I don't think they do. Basically, if the fault is tested and no fault is found it all falls within the provisions of the minimum equipment list. The aeroplane is serviceable to fly and that's it, and that's the end of the story.

	Laura: Is that the same for civilian and military aircraft? Pilot: No, it's not I don't think. Commercial aircraft I don't think would be pulled out of service to do deeper investigation, whereas, from my recollection, in the Air Force they would be. Laura: Is that because it's commercial and money in your view? Pilot: Yes, I think so. They cut corners wherever they can.
23. Do you think your intermittent fault impacted air safety?	Laura: Do you think an intermittent fault will impact air safety? Pilot: Potentially, yes. Laura: Could you give an example? Pilot: Well transponder faults and TCAS faults on commercial airlines certainly have the potential to have a serious effect on air safety. And GPWS faults. Laura: But you've not experienced any of those? Pilot: No, no direct experience. Autoflight system faults as well would be in there because that would put crew work load up, which concerning a long flight and in the wee small hours of the morning it's not the sort of thing you want to end up doing, having to hand fly the aircraft across an ocean. Laura: Just for my understanding when does your working day start? So as in you turn up to do a flight, just say you're flying seven o'clock in the morning to wherever it is, how does your day start for that, as in check in to the aircraft and do whatever it is you need to do? Pilot: The working day starts at check-in time; typically, check-in time would be 1 hour before departure these days. It used to be longer for the long-haul flights in British Airways when I was doing those. If I remember correctly it was an hour and a half before departure, we used to check in. It's becoming less and less. What easyJet now do is they consider check-in time to be, let me think, it's less than an hour now because the crew rooms have been moved to air sites so the crew go through security first, then to the crew room. They're even now talking about doing check- ins actually on board the aircraft. So that will cut it even shorter. Laura: What does your check-in process entail? Pilot: It will entail checking in with your password on a computer, picking up the flight plan, which would be pre-printed for you at the big bases but not on the small bases. At the small bases they would have to print their flight plans out as well so there would be a frustrating few minutes with IT [information technology] problems, quite often. Analysing the weather, deciding on a fuel load, all to be done in 15 minutes. So 1 hour prior you check in, you've got 15 minutes to get your flight plans, look at them, decide on your fuel load, say hello to the cabin crew, pass information between you about the day's work and then get on your way out to the aeroplane; which was not long enough. So, people used to check in 10 or 15 minutes before the official check in time. Laura: But no engineering information passed?

	Pilot: No, apart from airport statement on the crew brief whether or not the aeroplane was carrying any faults, any ADDs. Laura: Just again for my knowledge, do you ever, on a civilian aircraft been informed, right there's been this fault, we can't find it can you look out for this on the flight or do anything particular on the flight to test it at all? Pilot: No. You never do any testing on a commercial flight. If it requires air testing the company has a small group of pilots who do the air testing. It certainly wouldn't be done with passengers on board. Positive testing as a distinct role, just keep an eye open for this and let us know if something else occurs.
24. Could you categorize the intermittent fault by severity or consequence? E.g. by system?	Laura: Could you categorize an intermittent fault or system that might get an intermittent fault by severity or consequence, so which do you think would have most impact on you when you're flying the aircraft if there's an intermittent fault, either distraction, work load? Pilot: Anything involving the autoflight system would put the work load up and anything involving transponder. It would be flight restrictive, because if you've got a transponder fault run or an autoflight system fault that means you can't fly in RVSM [Reduced vertical separation minima or minimum] areas, so you have to get out of the RVSM air space immediately and move away from your planned cruise level down to flight level 290, which puts the fuel flow up which gives you another little headache to think about. Laura: Anything else apart from those? Any communications systems, propulsion systems, flight controls? Pilot: Communication systems were all very reliable; never had a radio failure on a commercial aircraft. Same with engines; never had a commercial engine so much as cough. Fuel system, no. No faults there either. All very reliable. Laura: So auto-flight system or the transponder? Pilot: Yes. Laura: OK. I will send you 2 Air Accident Investigation Board investigations they did. One was to do with, I think, a flight-control system, I need to check that and one was to do with a communications system that wasn't communicating. One of them they distinctly said was caused by no fault found. So, I'll send those purely for information so you're aware of them. Which is sort of why I am interested in an air force, military / civilian view as to the difference in how the aircraft are operated, the engineering log procedures, the debrief procedures, the training and everything else in that. Have you had any, I think the answer's no, any training on no fault found at all? Pilot. No. Laura: In your military time would you discuss any intermittent faults or problems with aircrafts with other air crew members? Pilot: Yes,

	Laura: Would you hold the snags until the Friday or would that depend on what the Duty Auth said? Pilot: That would depend on what the Duty Auth said. Then on the duty Flight Commander. They would make the ultimate decisions on whether to pull the aeroplane off the line or not, in consultation with the SEngO. Laura: What did you see the role of the Duty Auth as? Pilot: Apart from the basics of flight authorization and running the daily flying programme, liaison. Between the flight-crew side and the engineering side, and with ATC and the Met Office and all the other bits and pieces. Laura: Were you ever aware of the Duty Auth bringing certain aircraft to your attention for intermittent faults or ongoing problems with the aircraft? Pilot: Yes, occasionally, if there was you would get a quick word about it at the out brief. Laura: What was the purpose of that? Pilot: Information gathering I think; just to see what the frequency of the intermittent fault was. Laura: Were you ever Duty Auth? Pilot: Yes, and duty Flight Commander. Laura: So, if you explain to somebody, a pilot, that there was an intermittent fault or something wrong with the aircraft, what would happen when the aircraft landed? What would your discussion be? Pilot: Did it happen again, frequency, how did it affect you? Do you consider it worse/better, whatever? And then a quick chat through the hatch with the flight sergeant or the warrant officer or the JEngO and discuss whether or not it should be pulled. Laura: Terminology, which I think will only apply military wise because I think you would have looked at the aircraft 700 more than you would at the civilian one. Did you understand the terminology the engineers were using to describe the work they'd done? Pilot: I think so, yes. Laura: How far back would you have gone through the aircraft 700 to look at the faults? Pilot: 7 days. Laura: Would it be the Lims and the ADF or would it be the 707B, as in which ones had been raised and cleared or? Pilot: No, you'd look back through the sheets as well for however many days were still in the log, just to see if there was a trend.

	Laura: A trend for what? Pilot: A repetition of any particular fault. Laura: Would you then class that, if there was a repetition, as an intermittent fault? Pilot: Yes, I suppose you would. Intermittent is a fairly vague term isn't it? It can mean 5 or 6 times an hour or it can mean 5 or 6 times a week. Laura: There's an aircraft no fault found, which might have been easyJet, where the intermittent fault was over a period of 6 months. Pilot: Really. Laura: But because the aircraft was being maintained at different locations, or it was being reported at different locations and an engineer at Place A would do something and an engineer at Place B may never see what that person's done, that's why it took so long to actually resolve it. Pilot: So, MOC wasn't doing its job? Laura: Sounds like it; I might go back and read it now that you've come up with the term MOC. Good. OK. I don't know if you've got any other questions, any questions for me? Pilot: No, I don't think I do actually. Laura: It's been quite enlightening purely because I do not know the civilian way of doing anything. I understand the Air Force. I understand what happens on a Tristar squadron or did happen. I am quite amazed by how that is sometimes different to what happens on a Chinook aircraft squadron and what they did differently. I know that at Brize Norton for the aircraft they've got there now, because it's a digital aircraft the pilots are doing very little with the engineers unless they flag something and want to bring it to the engineers' attention at the time or the engineers will just come on and do what you said, look at the information, download the information and then work on it, but I know that they have serviceability issues over there but that's probably down to the different flying regimes and everything else. It's quite interesting. Pilot: It might be worth your while approaching easyJet and asking if you can spend day or half a day at MOC in Luton. I'm sure they'd be open to it. Laura: Do you have any links into there? A name or a post? Pilot: I haven't got my mobile phone with me. I could give you a contact email or phone number maybe. Laura: That would be useful, really useful. Alistair might want go across as well for information. That would be brilliant.

Permission	
25. Can I quote you by name / post?	Laura: Can I quote you by name or post? Pilot: Yes. Well not really by post because I don't have an official post as a freelance contractor anymore. Certainly, call me by name if you like. Laura: If I can just get you to sign this as you've seen me scribble everything down and the fact that you said I can quote you, and then I will send you a full copy of the transcript and then you can come back and correct or change or agree or disagree if you can read my scribbles, hopefully you will get it within a month. Pilot: Every page? Laura: Whatever. It's more of a bit just to say you've seen the paperwork and Alistair is my witness Pilot: OK right.

A.5.5 Interview 5

Question	Answer
Categorization	
1. How many years have you been involved with aviation?	Since 1983. So, 36 years.
2. How many years have you been involved with aircraft accident investigations?	Since 2007, full time and a little bit before that cause I was part of the board of inquiry for the Navy.
3. What is your specialist field? Your specialisation?	So, I am aeromechanical, chartered.
4. Engineer or aircrew?	Engineer
5. What type of aircraft accidents do you normally investigate? E.g. jet, passenger, helicopter.	Everything. Whatever was thrown at us. So, it could be a microlight, a tri-axis microlight or flex-wing, right up to a 777 or a 380 whatever; everything in between. So not just jets, not just piston engine, just whatever comes in, and of course helicopters.
6. How long have you been working for the AAIB / DAIB?	How long have you been working for the AAIB / DAIB? So, if we start with working with the Navy Air Accident Investigation. So, I did that from 2007 to 2013. And then with branch from 2013 to date. That is the background information.
Faults	
7. How would you describe an	So, an intermittent fault is in my view, is something which appears on and off, not necessarily consistently maybe something that you start up it is not

intermittent fault?	there, it appears, you do something it disappears. It may be as a result of a certain combination of factors, it may not. Is that across one flight or more than one flight? Oh, it could be more than one. And certainly, we used to have that with the sea harrier, which was one of the beasts I had to look after. Its early avionic systems were a little teasy sometimes and you could have weeks without something and then wallop, pilot comes and reports whatever was playing up again or, people would do things, change things and the known problem would be back again. Interestingly, in civilian experience, one of the things they often do in, and we had this with aircraft, is that they re-rack things. So, they go out to large aircraft, go to the avionics bay, take out the component and then shove it back in again. And that is often because they are part of multi-instant connections systems. So, they have on the back, they will have a large plug or socket with 30 pins or something and it just takes one to be slightly misaligned and it will not be connecting correctly. So, they do that quite a bit. The Navy never tended to do that quite so much. Having said that I have seen people going in to, certainly a colleague of mine used to regularly go in to a thing in weapons aiming computer and take a board out and shove it back in and that would often clear certain faults. It is that and that would boil down to a design issue rather than a fault in itself. I will come back to that.
8. What is your knowledge, ignoring everything I have said, of no fault found?	A specific example or in general? In general. No fault found is where you may have something on the ground or you may have something in the air, you land, you report it, another person goes out to the aircraft or looks at it and can't replicate the fault. Even though they might do all of the things it says to do in the manual. They might use their experience to do other stuff to but they just cannot replicate the fault. It just does not manifest itself. Now that in itself often creates a little bit of a problem, certainly between personalities. So, you know the pilot will be adamant or the operator will be adamant that something is not working and then out goes the mechanic and whatever he does, and so they then doubt each other. And it might also be that you could have a component or a system, and I have had this happen in the past, where you go out and you don't actually find the fault reported but you find another one that manifests itself in what the thought or the opinion of the pilot or operator was. Sometimes I suppose, there are contaminations, if you like as well, with a no fault found where someone has an opinion of what it may be, say a pilot or whatever and, therefore, makes their own assumptions, directs an engineer or a mechanic out to have a look to see what and has lead them up the wrong path. And so, they can't fault that particular system as there is a misunderstanding as to actually what the problem was.
9. How did you become aware of NFF?	Oh, it was something, by osmosis really, in your experience. And certainly if you are in managerial roles, which you will be familiar with from your RAF days, certainly managerial roles, yes so if you are in a managerial role and somebody, you know there is an aircraft which is not available, someone say this has been reported we have it on jacks we are doing this we are doing that and we cannot find any fault. Then you start to make a decision as to whether they have done enough or whether you have done enough

	or whether there actually is no fault. But I think early in your career you certainly start picking up that there are somethings you cannot fix. I do a lot of fixing of my things as well, cars, plumbing, and stuff and yes lots of times I cannot find the fault and put it back together and do something and it has disappeared.
10. So, what experience have you had of an aircraft or aircraft investigation with NFF?	In my recent period not many. Most of the times we track it down because there is a result. There is something gone wrong or something broken, or worse. But what I have got an example of, which is quite interesting, is that if you were to put a particular component - let me give you the background. So, we had a Boeing 737, which happily was going from Portugal to Scotland, and long story short, the way the Boeing works is that it judges it position in the world and thinks I am now over X, Y or Z. This is not navigation. Inertial navigation is slightly different. It judges its position over the world and then drives the artificial horizon, so the thing that tells you which way is up, to where it thinks it is. Now this particular aircraft had a sudden step off set if you like which then said to the aircraft systems, well you are now over northern Finland and so it is alright, if you are over northern Finland, your artificial horizon should be that way and drove itself. The component manufacturer was Honeywell, took this great lump to Honeywell, I didn't take it but it was sent to Honeywell, and the test bench engineer had a look at it as well. I can explain a little bit more about why they did it. And they could not fault it. They put this piece of equipment on the test rig. They did hours and hours and hours of testing and although it had built-in-test system with codes and the code had said that it had had an off set they could not get it to do it. So, they went further down into the system and looked at all the components that were in the system and there were three accelerometers, and one of the accelerometers they suspected. They took that out and put that on its test system, and again hours and hours and hours of testing, they could not fault it. So now ordinarily you could have put that box back together and returned it to service but what they did on this occasion was wire in effectively an accelerometer system, which they then dialled in the fault that they thought had driven it and got exactly the same symptoms. So, by deduction they said right, so for a moment that accelerometer had a hiccup but we cannot fault it with all the tests that we have. So, our conclusion is that it had some sort of momentary issue but there is no hard fault remaining which can be demonstrated or proven. Was it the first accelerometer? I am just trying to work out, just for myself, whether there was a spike in something at all, a change. Well whether it received a duff input, not sure probably not because the BITE [built-in-test equipment] check said no. The built-in test sort of said you now have a 60 degree off set. We produced graphs for this and what have you from one of the data inspectors to see where this jump suddenly happened. We have not published the report yet but, so what are the effects of that accelerometer now, so bin it but if you put it on the test bed and take it off the production line it would be perfectly serviceable to issue. It is just whether it happens on another aircraft but then that is the next bit of the investigation because we've now had more than one occurrence and trying to but what symptoms are you reproducing. Yes, and the other problem is that you daren't, daren't take the risk as it could be catastrophic and it could be catastrophic in so much as this aircraft broke its RVSM [Reduced vertical separation minima] rules. In other words, it started to deviate from the very accurate flying that it is required to do to

	remain in RVSM. So, and that is where you have to have a certain standard of aircraft system, tolerance, to allow you to fly in the air lanes and reduce the separation. So, the principal is that if you are all very accurate, if all your systems are really accurate, then you can have aircraft that are flying sort of with 100 feet separation. It is not in reality 100 feet apart but they could be flying, one could be flying at 3100 feet and the other could be flying at 3200 feet, guaranteed the systems is so accurate that the aircraft will not bang into each other. You always need them apart but that is what RVSM is and the thing about that is that this one lost its parameters, nobody actually noticed and air traffic did not notice and the crew just had flew it and blah. There's a whole series of other events that came to, that could have been serious because if they had not detected that, it could have, because everyone thinks they are flying at plus 50 feet when they are actually flying at plus 500 feet.
11. When conducting investigations at what point do you scrutinize the aircraft maintenance records?	Very early and sometimes, in an investigation, the first thing we do is a sort of grab. So, we deploy to the accident site. I have legal powers so I can impound aircraft, anything from small aircraft to huge aircraft. Huge aircraft are always a problem because they can't be moved and it is difficult to know what to do with them; others will just fit on a trailer. And part of the process is, and I have a mantra which is 'when you start all bets are on'. In other words, you do not know what it is so you grab everything. And maintenance documents are grabbed pretty early in the process if not simultaneous. And that often means going to where they are held and effectively getting them in a box and taking them away or sending someone else to go and get them. We did that the other day when we deployed to Dubai for a G registered aircraft accident before actually getting on the plane to go to Dubai, we went down to Shoreham to collect all the documents and they are not allowed to withhold them. And that is sometimes is three of four boxes and if it is an older aircraft it could be boxes and boxes. One of the aircraft I will show you in the hangar had 16 boxes of documentation, including from when it was first built right up to the accident. How do you manage that with electronic recording? Well if it is electronic stuff then we would expect it to be downloaded onto either a stick or disc or we might just take the whole hard drive. There is difficulty with that because of the systems. So, BA would in a bit of a fix if you started taking lumps of their system out so they tend to download it. There are regulations about how that is done and what they have to do. It is debilitating for a fleet of aircraft if you have to lock the system so no one can access it until we get hold of it. So, they can't be tampered with. It is very difficult thing to do. So, we are very mindful of that and we take great care. But going into the maintenance documents, if it is a technical accident, sometimes it is obvious it is not technical. So, flying into powerlines and all that sort of stuff. Having said that we never stop asking the questions. If they flew into the powerlines was there something that caused them to do that, because they'd lost control. But in general, you get a feeling and I have got one in the hangar at the moment that I will show you that has very few documents but maintenance might have been an issue or an assessment of something might have been an issue. So early in the investigation.
12. Do you look for trends within the documentation? Repeated technical faults?	Yes, yes, yes. An absolute humdinger of an example of no fault founds which are across a fleet that are sporadic and although not causal to an accident but because of other work that we did, but was highly frustrating for the operator. That particular accident (there will be a lot of writing here and I can talk it through with you in the hangar if you like in more detail) but to summarize there was a helicopter that crashed into a pub roof in Glasgow in 2013 and the issue was that we had started the investigation and two

	weeks later – no let me start from the beginning. During the investigation very early the chief engineer of the operator said 'be aware that we have now been wrestling with a really odd issue for years on this aircraft type'. And that was only understood after we completed our investigation, after we did our investigative work. The fact of the matter was the pilots were reporting odd fuel readings. So, they would go flying and they would say I started off with 400 kg of fuel, I flew for an hour so I should have this left but I actually have this left. I actually have more than I should have. The chief engineer was convinced that it was something to do with water getting into the fuel and but could not really put his finger on it. He did a lot of work, a lot of work backwards and forwards with the manufacturer and said, "look it only seems to manifest itself a few hours after we do a compressor washes." Anyway, long story short, the fix, often, was to drain all the fuel out, take the fuel sensors out, replace them with new ones, send them back to the manufacturer and 9 times out of 10 the manufacturer would say "why have you sent us these sensors? There is nothing wrong with them." Because these are now dry, their capacitor sensors, (I will show you the hardware as well actually – it will be a really good illustration). So, these sensors were dry and clean and worked perfectly. It is only when we started doing the investigation for the pub aircraft that it was brought to our attention that an aircraft had done something really odd and a pilot had picked it up because he thought they are doing an investigation on an aircraft and this might be important. So, he rang in and said he had just been flying on an aircraft where the fuel systems showed it had reasonable amount of fuel in it but my fuel low-level warning light came on, two of. Would you be interested? We were very interested. So high-tailed it up to the aircraft. Put it on the ground. Don't touch it. We will be there. So, we went up and effectively took the aircraft bits we needed apart and brought them down to the hangar, and with fuel and all sorts of things. And low and behold, with the sensor that I had from this aircraft I could not find anything wrong. So we got the fuel expert up from Airbus Germany and brought loads of kit with them and I said this is what we are going to have to do because we want, the reason the aircraft crashed into the pub was because it ran out of fuel in the right tanks and the pumps had been switched off so it was not transferring fuel to the tanks it should have been doing. So, we were wondering if perhaps the pilots had been confused by the fuel situation. So long story short, we did a lot of testing and found that if you introduce fuel into the water, into water into the fuel in small quantities it doesn't actually have any effect. But if by any chance that water gets picked up by the fuel pumps, sloshed around and emulsifies in the fuel, when it goes into the sensors within the tanks, if it gets in amongst the sensors, so the plates are the sensors, it sends them off scale. Sometimes it sends them off scale such that it will go 'fuel degrade', and big cross, and say you are telling me crap so I can't tell the pilot this. And other times it was insidious in so much that it would show that you had more fuel than you actually had and it was still, through all sorts of complex software things, show fuel depleting because it was seeing it deplete normally, because it was being used, but the sensors were actually reading it. I think there was probably 10 years' worth of musical sensors before we got to the bottom of it. Now I didn't know about the 10 years until we done all this. Until we started – and all we did in the hangar was actual squirt water between the plates. So, I said to Airbus, "I need a fuel system to test that is the same as the aircraft." And they sucked their tongues a bit and said that would be difficult, and then they rang me up four weeks later and said, "We've got one." We put the bottom of a helicopter onto a hydraulic rig with windows in its tanks, everything and it works normally. I said "How did you do that?" "Ah we had a bit of an incident with a helicopter we were delivering and a bridge." So, they had the

	bottom half of a helicopter, the top half wasn't too good. I can show you all that in the hangar. I'll show you the sensors as well. I was wondering at what point they did water sediment checks. They do water sediment checks every day. And so the water would come out but the point about it was, that it has to be a very, very special set of circumstances where you have a small amount of water which is picked up by a pump, which gets emulsified, and then gets read by the sensor as being odd. And looking with hindsight, why didn't they see this, why didn't they see that because, nothing linked up. They were doing their daily water checks and they would get a tiny bit out. They didn't, it wasn't understood at the time that when you do a compressor wash there are two types, three types actually. A hot wash where the engine is running and you just bung waste down it through a spray nozzle. There is a cold soak which is intermediate where they fill it with a chemical and water, leave it for a few minutes and then run it dry motor, what have you. And then there is the long chemical wash where it is left for a while, 10 minutes or something with the chemical in it and it drains through the engine and there is a little system which collects it and it turns out the little tanks, which collects this ullage if you like, get overwhelmed and if they are overwhelmed they do one of two things. They either let the water be blasted out as you run the engine cause it is sucked out by gas action, or they get overwhelmed and it gets into the vent system of the fuel tank, collects in a sort of anti-rollover vent tank, which is to stop fuel spilling if the aircraft rolls over, and then after you've got about 800 mm there is enough for it to overflow the little pipes at the top / bottom of this tank and get into the main tanks, but it is a whole series of combinations that have to be - and it is sporadic. It wasn't, but every time they took, because the manuals say it's a fault do this, do this, do this, the fault is, it must be the sensor, take it sensor out and send it back and they say nothing wrong. A really good example.
13. If so, how do you analyse them? Is there a process?	The next question was if so, how do you analyse them? Is there a process? I think the process is as you said to actually try to break it down to component parts, or then systems, and manuals and everything else to actual say 'well okay let's look at the bigger picture to see what is actually happening. The big picture is the key here because we have the ability to draw together the experts in the field. And we have actually just done the fatal accident, I gave evidence to it over Easter, and the second person after me in the box was the manufacturer, and all credit, the manufacturer sent their fuels systems expert who was involved all along in this. So, he was responsible for the design of the fuel systems. All of the knowledge in Airbus, he headed up and also the chief engineer of the operator plus all of the people who had been involved down the line as it were. We were able to get them all together in the same place, which is not always that easy when you are in, when you are operating aircraft, normally. So when we got them all together in the same place and then I had the ability to do experiments, all that cerebral wattage if you like that you have drawn together, can now start focusing on all the different bits and pieces and draw all of their little bits of experience together, so you could see it all laid out on a table if you like, and then you can start working towards what it might be. And the other thing of course is our job is to, we can never un-know anything. So, this is an issue that needed dealing with. Now it didn't cause the accident to the aircraft hitting the pub. The reason for that was, we found no evidence in our fuel or our tanks of any water so what we found with the test tanks in

	Germany was that when you introduce water artificially through the system you got globules on the base of the tank, even when you drained the fuel out. So, when we drained the fuel out as it dangled over the pub, if you Google it you will see all this on the BBC and all that, we drained the fuel out so the tanks were empty and it was in the wrong place. The two tanks that should have been full were totally dry. No fuel at all. No usable fuel at all. The main tank which should have been happily pumping fuel to the two little tanks, 90 odd litres, so he had plenty to go where he was going to. So again, I was questioned at the fatal accident inquiry "Why are you sure there was no water?" Well we had a third-party independent fuel chemical laboratory test it. And secondly, not just me but all of the experts I'd gathered had our heads in the tanks and were looking for, specifically focused on an issue but we could find no evidence for it. Which is the whole point I think, if you have a NFF which does not actually contribute to the accident but may well, and I will come onto this in a later question, may well contribute to the airworthiness of the aircraft and the air safety. It does. But actually, you would not report that in the report. We did. You did in this case? We did. The reason for that is that we knew that we had found a situation which some quarters would have said there is your answer then but we needed to be able to publicly and documentarily eliminate it in the public eye; in the public mind if you like. And when I say the public mind, I mean other pilots and operators who would say 'it's obvious, this has happened' but it is not. There was a piece of evidence, a piece of the jigsaw, in this case wasn't there to suggest the pilot had been confused by the fuel. However, and again I said this at the fatal accident inquiry, the never unknown anything, we are duty bound and actually the manufacturer thought 'well okay how do we stop this happening to the sensors'. So, one of the issues is the fuel gets, fuel and water absolutely hate each other electrically, so the water will effectively form little globules, which are surface tension, as it is being rejected by the difference in potential with the rest of fuel. So that is why you get these little globules and if they see each other the little globules will actually clump together. We found that if you introduce water artificially into the sensors, a little globule will go shooting straight to the bottom and jam in a drain hole. And by experimentation the manufacturer found that actually change the drain hole and it does not do it. So, there is the modification, so that was done. And then there was the issue of pumps and how they run and how there is a run-dry system, which goes into much more detail. So, they changed the design of the software. They changed the design of the pumps. They made lots of changes which were not as a result of the cause of the accident but a result of education and learning due to us researching every line of inquiry that had to be eliminated. Do you remember the number of the AAIM inquiry report number?

	Just look Clutha, GSPAO-EC135. Don't worry about the number. If you put it in our website it will pick it up. Go on the net and you will get even more stuff.
Training	
14. Moving onto the next bit which is training. During your training (AAIB or similar) can you explain what you were taught about intermittent faults and NFF? How to spot them?	Moving onto the next bit which is training. So, your type of questions will follow the format of the questions I have asked the pilots. During your training (AAIB or similar), and the answer is probably none, can you explain what you were taught about intermittent faults and NFF? How to spot them? Oh, this goes right back to naval training really and it was always assumed that you would find the fault. There wasn't really a form of, the formal if you find a no fault do this, this and this. Because it was always assumed that your knowledge and experience would pull out where the fault was. Naively perhaps. And bearing in mind there has been a change in over the years, electronics have become much more reliable but also less, there isn't the ability to mechanically diagnose electronic components so much. So if you have a circuit board now, multi-layer circuit board, which we see a lot, the chances are it is sealed in a sort of resin stuff but it might be rows of identical circuits boards and all that's different on them is the software that they are carrying and they choose bits of the route and components to do certain things. So you could have one circuit board actually you call as the power supply or the amplifier or something like that in simple terms and it looks identical to the one that is also the, I don't know, the tone generator because that day it has be told to be a tone generator. Whereas older systems often where you had sort of more analogue electronics you could see where there were dry-solder joints or you could see whether there were broken wires and one of the things, certainly in experience in cars, is that they work round faults. Certainly, in engine control symptoms you don't get, you might have a problem and the thing, the component systems it's telling me I got less, my O_2 mix is wrong. I must change this. So, hide a fault until it gets really very bad. And when it can't cope and it is only in a trace. I have a car that when you put a diagnostic tool on it, and it will show you all these transient faults that it has fixed itself. It will say something like diesel coil overheat. Something like that. And it is just recoded it and nothing has happened cause nothing has gone wrong because it has fixed it itself. Because it has reconfigured itself. So mechanical symptoms are always easier to diagnose. I would suggest it is rarer in pure mechanical systems to have a no fault. So, if you have linkages, gears, bell cranks, levers, hydraulics, hydraulics manifest themselves in all sorts of stupid things, leaks and that sort of stuff so it is pretty obvious. But no faults are usually more complex avionic or electronic control systems. I would be unhappy to find a mechanical fault. So, no specific training though? No. Experience is a lot to it.
15. If you think there is a problem, who to talk with?	In your current role, if you think there is a problem, who do you talk with? And I think you have answered that in the previous example. So, we are talking the manufacturers and the operators. Yes. Manufacturers, operators, we will find the designer, we will go into the old documents, manuals and books and bearing in mind, a little while back, only a couple of years or so, I ended up doing an investigation on a Bristol Centaurus engine. There is nobody around now who really understand those engines. As the manufacture Rolls Royce who own the name Bristol,

	certainly Bristol engines, have nobody who remembers them being in service. But what you might do is go and speak to one of our colleagues who does. So, there is a gentleman in the Branch who, and this is only an example, who worked for the Bristol aeroplane company, and designed bits for Concorde. But his dad was part of Bristol and he did bits of aero-engines. And he has got a corporate knowledge. So, we are not proud of who we go and ask. Sometimes we go to a contractor, a third-party contractor. Certainly, for metallurgy and for some of the chemical stuff we might go to a university, we might go to 1710 Naval Air Squadron, which is the old laboratory down at Portsmouth, QinetiQ. No, we are not proud. And we will go and ask who we think knows. So, it is not on my sheet so I am going to ask it. Just take someone like Justin. How long has he been here? Three years is it? Maybe? Yes. So, would he be shadowed to start with, to have that oversight, that mentor going through the process? Yes, as I was and I have done it for other people. So, you have usually a mentor. You are divided into groups. So, there are two groups of engineers. At the top of each group is a principle inspector. Same with the Ops inspectors. And the principle inspectors usually have been here in excess of 10 years and have huge amounts of experience. But none of us, including principals, ever say 'we know everything about everything' because we don't. But there is always someone who knows a little bit more than I do, or you, or I may know a little bit more than they do. So, Justin is a good example. Hugely experienced on production and airworthiness of a product, manufacture, because he did Tornado, Typhoon, and all that sort of stuff and then did accident investigation as part of BAe. So, he would be the man to go to if we were talking about something on ejection seats or something. Where we don't come across it very often but when we do, he might be the person to look to. Likewise, A**** might be the person to talk to if it's aerodynamics or a wing-design aspect or that sort of thing. So, but we, a mentor is somebody that we just say "how are you getting on? What are you doing with this? Have you thought about that?" But a lot of business is done over the lunch table, actually to tell you the truth. People say I've got a bit of this and a bit of that. And he would say, "I had one of those 30 years ago and this is what I found. Have you thought about this?" "Oh no I haven't thought about that."
16. Do you discuss intermittent faults with the aircrew who have flown the aircraft?	Yeah. Yes, so in the case of the EC135 with its fuel we spent a lot of time speaking to pilots and test pilots actually. Who knew the system inside out. Having said that it's interesting when you get, I was not an expert an expert on the EC135 until after I finished the investigation cause you have to make yourself an expert because at some stage, certainly a fatal accident, you are sitting in a box with a sheriff in a case of Scotland, a coroner in a case of the UK, and there may be smart lawyers, highly paid smart lawyers, who are going to try to discredit what you say. So, you have always got to be the expert in what you are talking about. And I don't know whether it is how we are selected, but rarely have I seen any of us been caught out. But when you get that experience and when you get that sort of knowledge, in the case of the EC135, if somebody says now we have an EC135 issue, they might come and see me about it. But speaking to the pilots, we have people who were qualified on that aircraft here, one of my colleagues who has retired actually was EC135 qualified so he was person to call. The pilots who were having the sort of intermittent fuel warnings, and the sort of odd

	readings, not that they understood they were odd at the time but with hindsight that happened to me. You could speak to them and get the circumstances and each little piece they give you is another piece of the jigsaw. The interesting thing or course is that sometimes there are corporate opinions which aren't right, which are muddying the waters. I have a perfect example. I asked a test pilot; let me start from the beginning. Myself and Peter Coombs, actually who was helping me with this. We found ourselves a perfectly good EC135 and said to the owner a big company, "Can we borrow that aircraft, we don't want to fly it, we just want to play with it." So, we sat in it for an hour or so, fiddle with switches, made a combination of things and I noticed that when we switched the fuel pumps off there was a three-minute delay before the caption on the screen said 'your fuel pump is off'. That is interesting. I wonder if that is the pressure dissipating. I subsequently discovered it is actually an algorithm which says if the fuel pump runs dry wait three minutes or 2 minutes 58 actually, until you light up the caution to say your fuel pump is running dry. Long story as to why it happens but to cut a long story short the same thing happens if you switch the pump off. The same algorithm comes and says right I am turning this off in three minutes. So I said to the test pilot who was sitting with me over another matter, so we were testing these systems in the aircraft to see if they could confuse people and I said 'Why is it that the light for the fuel pump, the warning caption on the instrument stays off for a few minutes after you have switched the pumps off?' And he said, "that's pressure dissipating." I said, "Actually it is not. It is the algorithm." And his jaw dropped. He was astonished and then I explained to him why and he said, "Ah, now I understand why this happens as well." Something else he had always noticed and never really understood. So, we do speak as broadly as we can, to as many people as we can, to try to get as much information as we can before drawing a sensible conclusion. And the phrase you often us for all of that is *due diligence*. Have we covered ever single aspect or is there going to be a fast ball? We publish the report. It is controversial because there's a lot of fatalities, and someone comes and says "And you know the 'gungell snocket [interviewee's fictitious term] is on backward don't you?" And we are very, very careful of not getting our facts wrong. We have to be very careful. I wonder whether the pilot brought previous knowledge of a different system and just assumed it was the same. Yes. It is an assumption. So, we found ourselves having to be one step slightly ahead. There is also the trick of being the dumb questioner helps. I don't really understand this, would you … and they do. See what they think. The so what, how, explain, because. Yeah.
17. Do you check with the aircraft engineers for intermittent faults or the OEM?	And this might be even if you don't think there is one to start with. It is just whether you include it as part of one of your questions. No. There would not be a standard question to that not unless there was a line of inquiry developing. It is interesting also how much information is volunteered. "I shouldn't be telling you this should I but …" And then you think really that is interesting. So, we do, we try and be very open and impartial and we never name names in our report – ever. It is difficult sometimes when it says there is only one pilot.
18. Is your investigation	Not exactly although, yesterday we were holding a big discussion with a chief inspector on another investigation which is going on, as to when the

impinged by time or technology?	point is that we have to call a stop. So right we are going to have to publish what we have got. That always is very lively discussions, very robust discussions. The chief inspector, Crispin Orr, who came from the military actually incidentally, but it isn't like the military in so much that an inspector has a say and if an inspector thinks no, we have to do such and such, we will fight back robustly. It isn't a sort of autocratic - you will do. Now there are relevance, so accidents if you drift on too long, now there is a famous case in the AAIB years and years ago where an investigation for a very simple thing seemed to take years. And it was all to do with an aircraft that got into a phugoid, so it started to do this sort of this, and I think it was an autogyro and opinion was divided as to how it got in to that situation and how it was taking off from a field, which was like that, and that sort of set up this imbalance. Taking years of rubbish. No one actually said, "Right enough is enough. Report what you have and make you recommendations if you can." But with high-profile, complex investigations with fatalities, then we would do our utmost to chase down every aspect. And I have published a report that says 'research by third party is ongoing and we will report to you when complete.' Actually, that was Centaurus; we did that because it was quite straightforward. Nobody killed and 1710 did the analysis and in the end but they had to do it on the back burner as the aircraft was in private hands and not government hands. Although it was being flown by a service pilot. Long story but they said, "We will do it but on the back burner." Which they did and eventually came up with an answer. So, there is a point where we have to say, in the case of Clutha, the Clutha helicopter, we do not know why the pilot appears not to have been running the fuel pumps, because we have no flight data recorder. But we know now enough about the aircraft as to say what it wasn't. The what it wasn't also needed fixing so that was a two-year investigation so that was 2013 – 2015. And we did the fatal accident this year because the Crown Office, the Procurator Fiscal Service, had to produce effectively a whole case to present to the sheriff and then organize a huge court case. So that is why it took so long. So, accidents where you have an immediate cause that is quite obvious then you just make sure nothing else is a left-curve ball sort of thing. And they are quite quick to do. But if you have got an accident where you cannot really put your finger on it or there are several possibilities and you have to weigh the possibilities, they are the ones which usually take the longest. And you soon, you often speak to victims' relatives and we say, "We know what it wasn't but we don't know what it was and we may never know that." Which isn't great for them sometimes, especially when there is a death involved. So that is when the time, because you have to go up cul-de-sacs and come back down to eliminate things, if you can.
19. Does this type of accident affect the search of the maintenance records?	I have said, does this type of accident affect the search of the maintenance records? Well in the case of the Clutha yeah, I went through engine changes, gearbox oil replacement, and little faults here. But in fact, the aircraft is very reliable. The type is very reliable. So, there wasn't much. Mainly routine stuff but I went through and picked out everything I could find to do with fuel systems and when the police came, because they did a parallel investigation because they thought perhaps that there was some sort of, they wanted to make sure there was no crime effectively and to help them out, to the letter of the law I should have said to them right, "Here are the documents off you go." But they don't, they never see an aircraft manual or log. So, I said to the investigator, "Here are the things of interest that I am looking at." and they just recorded that and took copies and what have you. So, yeah, we do, looking for trends and looking for, ah this is the third gungell snocket [interviewee's fictitious term] that has been replaced on this

	aircraft. In fact, Justin has got one where there are reports of an engine misfire on a number of occasions which eventually lead to the pilot having to turn back, which he possibly shouldn't have done and ended up a fatality, which is what Justin is now doing at the moment, an inquest. The engine actually ended up running backwards at one stage, when it started which is not unusual for old piston engines if you (unclear word) them. I know it sounds stupid but they do run backwards if you are not careful. But not very well. But he found in, bearing in mind that private aircraft records are not always brilliant, but he found a whole series of chasing of a misfire which they never really solved. It is worth reading that report actually. So that is a tiger moth, I can't remember the registration number. I'll search on the system. Yes, search on Tiger Moth, Compton Abbas.
20. How often do you investigate incidents where NFF or intermittent faults are apparent, even if this is not recorded in the final report?	That is a difficult question. I am trying to get a feel. I can't recall one actually. Often we get one, we go to a commercial airline and what have you. If we have done the work, we usually report on it. So, it might be, Dash 8 for example have, are not the greatest aircraft for pressurization systems. So, if we found something which is of interest, we would report it, but if we go down a line that says "someone says this doesn't work, hasn't worked" and we can't actually prove it or disprove it then we probably won't report on it. But if we do the work where these is something - I had a rogue pressurization controller actually which had carried its fault from aircraft to aircraft to aircraft till one day they ended up having to do an emergency decent, which is always a bit teasy for the passengers cause the masks come down, and that always upsets people, 'were doomed' is the usually, you are not, Pilot pushes the stick out.
21. Are there any regulations / procedures / process that you have read regarding NFF?	No. That is what I thought.
22. Are there any other points you wish to raise regarding intermittent faults or NFF that have not been mentioned so far, they may be relevant to my research?	Hopefully, I have covered everything that you wanted answered. I cannot think of anything else. No, they are just frustration, they get, and certainly in my previous life, with the remarkably unreliable harrier, no faults found were a real pain. And it was usually avionics – old fashioned avionics, electronics. And of cause in small squadrons, no small communities like squadrons, you know, there's the sort of banter that goes on between the engineers and the pilots. To the extent I will tell you one tiny little story that years ago on 800 Sqn I think it was a very junior pilot landed on with a very senior commanding office. The very junior pilot sort of stood and said, "I think the reversing gungell snocket [interviewee's fictitious term] is not working properly." To which the CO said, he was quite a character, "Don't be ridiculous you don't know what you are talking about. You've only been flying it for 10 minutes. Put the book away. Don't bother the engineers with trivia." Good old school of navy. It isn't like that anymore. So just an add on question as it is in the survey for the pilots, which systems would you say are the most likely to have intermittent / no fault found and

	the follow-on question which system do you think would impact airworthiness the most or air safety? Yeah that is a good question. Most likely to have no fault found, the most unreliable but reliable system if you like I suppose, I think probably navigation systems in my opinion. And of course, that can have something to do with airworthiness in so much if you consider airworthiness the whole picture of aviation safety with the aeroplane then if it is sending it where it should go, it could send it into path of something else. The thing about a lot of systems, very interesting systems, is where a manufacturer considers that there might be a risk, they often put two in. So, engine control for example, there maybe two engine control units, FADEC so full authority digital engine control systems. They will compare with each other what is the art of the possible. And in some cases, you can have a triplet system so there is a vote. Two of us think it is this. You are wrong, is the box saying. So, where there is a risk of that, they tend to, where there is an airworthiness risk, they will do something like that. So really, I can't give you an example of other.
Permission	
23. Can I quote you by name / post?	So final one I have got is can I quote you by name / post? You are free to say no. You can quote me by name if you want and post actually. If you goggle me that is what will come up. That finishes my question but I will just give you a few things from the interviews.

A.5.6 Interview 6

Question	Answer
Categorization	
1. How many years have you been involved with aviation?	So professionally I would define it as professional involvement as opposed to sort of interest, so from when I graduated which was 1995; so that is now 24 years. But you had an interest before that? Yes, I have been flying since I was 16. Plane mad. I grew up down the runway from Woodford. I used to see Vulcans and 748s climbing up the garden. My dad worked at Manchester airport as a marshaller, nothing fancy, so I had an interest in aviation. In the air cadets, loads of flying when I was 16, glider pilot. I couldn't drive a car until I was 21 but I had been flying gliders from when I was 16; you know from 14 now. Yes, so I was always keen on aviation. I sort of had aspirations of being a military pilot or may be a test pilot but my eyesight was not good enough. So, I pursued a career in aircraft design.
2. How many years have you been involved with aircraft accident investigations?	Nine. So, I joined here in May 2010. Having said that I did do a couple of years as a British Gliding Association [BGA] accident investigator before then, for the BGA, as an amateur, volunteer basis. 10 gusting 12 may be, argue.

3. What is your specialist field? Your Specialisation?	I am an engineering inspector; a bit like XXX [Interviewee 5] before. We are not really specialists as such, we are I would say engineering generalists here. It is anything from the accident site and interpretation of what the wreckage is telling you at an accident site, how the aircraft arrived there. If it is all there or if bits have fallen off and then all the way back through the physical inspection of the wreckage, forensic investigation of any failures or instruments or systems through to then writing the report and producing the evidence in court, or coroner court if it is required, which it usually is if it is a fatal accident. If it is a serious incident where, and these would be typically commercial-air-transport aircraft which have got into a degree of distress for some reason where safety has been eroded but an accident hasn't occurred, we still investigate those if there is a safety lesson to be learned, we still investigate them. And in my experience, as limited as it is the no fault found investigations tend, seems to crop up more on the commercial-air-transport serious incidents for us rather general-aviation accidents; that's what I have found so far. I would say they are not particularly frequent in our work, but when I have done them, I have a case study here which I can give you if you like, which I can run through. They do tend to occur more on the commercial side.
4. Engineer or aircrew?	I am a professional engineer. I am also a private pilot, 2500 hours, a private pilot, PPL, but I am professionally an engineer.
5. What type of aircraft accidents do you normally investigate? E.g. jet, passenger, helicopter.	There is not much normal to it. So, in terms of frequency, general aviation give us more accident investigation work. I'd say if I get given 15 jobs a year, of different levels, of which perhaps six might be even fatal accidents or commercial-air-transport serious incidents the bulk are going to be general aviation events, in terms of numbers, but the amount of work I actually have put is probably about 50:50, commercial transport: GA, because the commercial events, even though they are fewer in number deserve more effort because, we are here really to protect the travelling public. The Government pay for this function not solely to investigate Joe Blog's Cessna or 72 accident. That's well worth investigating but we are here to protect the travelling public. So, we put more effort into the commercial air transport. We used to help the military, which I really enjoyed, on service inquiries, but since Haddon-Cave and then about 2010 the Mil Air really got going, that level of assistance has dropped right off. I did do three fast-jet accidents in about 18 months at the beginning when I joined, we were still helping. Tornado mid-air in Scotland, Tornado that caught fire in the Minches (?? Unclear) and then the Red Arrow at Bournemouth. Those were quite interesting; military aircraft are fast dense systems, heavy, full of things that go bang. So that was obviously piqued my interest to help with those. Flown differently? Yes.
6. How long have you been working for the AAIB / DAIB?	So that is going to be nine years? Yes.
Faults	
7. How would you describe an intermittent fault?	I would say it was a defect in the aircraft that becomes, or that the aircrew or the maintenance guys become aware of with either through degradation of the system performance or triggering of the warning system, which then goes away and then comes back at some subsequent point, perhaps more than once.

	Is that within a flight or across flights? It could be across flights. There is nothing to stop it happening more, more than one occasion in a single flight but if there is an intermittent fault it could occur and then reoccur a few flights or many flights later.
8. What is your knowledge, ignoring everything I have said, of no fault found?	When I think about a no fault found you typically think about an avionics LRU, line replaceable unit, which develops some type of fault which is detected by the aircraft system or by the crew observing a reduction in performance or off flags, or something like that. Which then requires, triggers a maintenance input and that box is then pulled from the aircraft and either bench tested, but typically sent away to be looked at, and then comes back with a Fit-For-Flight, green placard on it, saying tested, no fault found. Tested in accordance with CMM [Component Maintenance Manual] chapter blah, blah, blah. So, they will follow some form of procedure to actually release it again, what the CMM said it needed to and then it is returned to serviceable, and then put back in an aircraft and then maybe goes wrong again. In terms of no fault found that is what was screaming in my mind. It is the sort of avionics box which goes wrong, comes back and then goes wrong again. Now it doesn't have to be exclusively avionics. You could have perhaps a transient fault in the hydraulic system or you know a servo control for a trim tab or something like that, but the typical cases that I have come across are avionics boxes that develop faults. So that is what I would think with no fault found. I would like to just caveat that by saying I am more a mechanical, aeronautical engineer and not an avionics bod. So, my personal interface with avionics, beyond a bit of soldering, is pretty limited. So as an AAIB investigator, I have to rely heavily on outside expertise to investigate avionic maladies.
9. So how did you become aware of NFF?	How did I become aware of it? I can't remember when I first came across it but I have been an aircraft maintenance inspector for gliders since I was 24, with my maintenance ticket. It may have cropped up in some of the training around that initial issue of that. It may have come up in my degree because we did an avionics module. I can't' remember but from fairly early on in my professional career I have been aware of the term. I would say in my job, because I was an aircraft designer for 15 years, more on sort of project management and overall sort of programme. The projects I have been involved with, apart from aerodynamics, have been more at the sort of programme management level. Of aircraft development, we were developing new stuff so it didn't really come across in-service problems much. It is not like I worked for an operator. So, in terms of my professional engagement with no fault found, I would say it was when I became an AAIB inspector. You get given any particular case which lands on your desk. It might be this Dash 8 has got a pressurization control problem, which seems to come and go a bit so investigate it. So, it is at that stage when I became more involved with it. Having said that though, the number of no fault found cases that I do a year you can probably count them on two fingers or maybe fewer than that. So, it is not a particularly common occurrence for us to investigate. I guess because modern aircraft have highly redundant systems so if a single system goes down then there is a backup or two backups or maybe more. So in a commercial airliner if a single system fails and the crew then follow the QRH, and the aircraft works as advertised and it lands safely unless there is something particularly interesting about that single failure we wouldn't investigate because it doesn't really meet the threshold of a serious incident as defined by ICAO, which is an accident nearly occurred. So, the system is working as it should do so the safety lesson is perhaps fairly minimal. So that would have been more or a problem for the operator in terms of the aircraft reliability dispatch rate etc. So, we would only really get involved if there's had been a system failure of

	some sort and the crew don't handle it particularly well, and then perhaps they fly a poor approach and then descend below a minimal approach and then it becomes an AAIB investigations. So that probably is the reason why we don't get many cases of no fault found to look at.
10. So, what experience have you had of an aircraft or aircraft investigation with NFF?	So, I thought you would ask that question so I have picked a recent example. I'll ask if I could give you this. Basically, this is the slide pack of a debrief we produced when we come back from a job. This is an ATP last year, on a night-freight flight from East Midlands down to Stansted and they got into the cruise and then they started losing electrical systems at night and the aircraft landed with about half the DC system missing from memory. So, you have the captain's displays disappeared, you've got lights going on and off and you've got poor radio communications. Now they were lucky that it was nice weather and the first officer's flight indicators worked and his standby instruments worked so they could get back on the ground again. But it was a serious erosion of safety so that was an electrical systems failure investigation. Slightly at arm's length because it was the way it was sort of reported, then escalated internally. It was kept at a fairly low level. So, we generally do it by correspondence with the operator but cut to the chase we went through the entire system, various relays, inverters and TRUs got sent off for test and all came back NFF. And in fact, when the aircraft landed everything came back to life again. It was like a sort of poor contact somewhere. You would have required two independent failures for that system to behave in the way it had done, which is odd in itself because that smells wrong. So, the investigations got two things wrong at once, which seemingly might be unrelated but the aircraft came back to life again as it touched down and then the subsequent investigation was all no fault found on the components. So that is very frustrating to the investigator because you want to get to the answer. With no fault found investigations unless you have infinite resources and you can just pull everything, destructively test everything, cat scan everything, and do burn-in bench testing for hours on end to try to repeat perhaps what the fault was, you have to stop and just say this is the scenario that would fit this but the component were tested and came back no fault found. So, we stop at a level below at which you can't be definitive quite often and these sorts of investigations where as an investigator you want to drill down right down into the detail to find out what happened. So, it is a bit frustrating. So that was the last one I did and I was trying to think of cases before then and I can't really think of another good example. They don't come up very often and I think for the reasons I stated.
11. When conducting investigations at what point do you scrutinize the aircraft maintenance records?	At what point? Depends on the nature of the investigation. If I am in a field in Wales surrounded by wreckage and the maintenance facility is not nearby, which is quite common, I will normally get a colleague to nip down there and go get the records. Just go and seize everything in the so-called golden window of about three after an accident when all doors are open; the corporate veil hasn't been raised. People are in shock and willing to do anything you ask them to do, without really much thinking about it. And that is sad to say that but it is an opportunity for us to actually go in and quickly go and get things before people might be a bit more defensive. So, seize the records fairly early on but it might not be until a week or two after we get back, I'm going through them in detail. I'll have a quick look, normally from the maintenance records I want to see a) are they all there and they look like the aircraft - are these records in good order, is everything I would expect to see in the boxes. Cause if not then that is telling us something about how the aircraft was maintained. Then if it does look all above board, i.e. work packs are where they should be, the aircraft is all stamped up in the logbook etc., unless I am looking at a particular maintenance issue that is probably it. I'll just look at the hours for the report, airframe hours, engine

	hours blah, blah and when the CofA [Certificate of Airworthiness] was issued. And that's it. I'll only ever deep dive into the maintenance records if there is something I've misunderstood. So, to answer your question anywhere between four and five days and two weeks typically. How do you manage if they are electronic records? We would get the maintenance organization to cut a DVD with everything on, typically. And then there is a question of how far back do you go. So, particularly if you have got a reasonably big complicated aircraft like 787 or an old 737, which is 30 years old, what does asking for the maintenance records mean because those should all be kept until the aircraft is scrapped, seven years or two years I can't remember. So, you are not going to ask for the back-to-birth records. So typically, I would ask for the last six months or the last year's worth of records. Certainly, including the last couple of maintenance checks and tech logs for the last six months or so. So, I can go back and look at what has been raised on tech logs and see if there are any repeat items. Things like that. The level of defects generally being carried. I think it tells you quite a bit about the operator if they are flying around with four or five defects all the time as opposed to clearing them fairly quickly. That was just interesting background for me. What is also interesting is what is not in the aircraft maintenance records. A good example of this, and we know it goes on at lot in the lower end of general aviation – business aviation – to a certain extent in the iron (?? unclear) world as well, but the bigger and better the airline the less of this goes on. What was the word you said? What is not in the maintenance records? You said iron world or something? I can't remember. Which is the shadow tech log. So, this typically is a ratty of paper in the tech log or in the aeroplane somewhere, where the crew are actually recording what is going on. As opposed to what they actual write down in the tech log because once you have raised a defect the operators got to do something about it. Defer it. Ground the aircraft. Fix it within a certain number of days depending on the category of the defect. And so sometimes we will get those records to. I did a King Air accident which was a loss of control on take-off at Stapleford, about 2015. A fatal accident. Both aircrew on-board died. Turned out to be a medical problem. So, the pilot had a massive heart attack, then loss of control and hit the ground. But during the investigation, we uncovered an iPad which had emails on it where the company was actually running a shadow tech log system. So, you have what is in the tech log which is tyre's a bit bald and the mechanic changes the wheel. And then you have 57 defects which the aircraft is actually carrying. Some of which are category A — *Do not fly until this is fixed* — all written down in the shadow tech log. Now that is a particularly gruesome example but I am sure it goes on, a lot in the real world. And getting hold of that information is quite hard but sometimes it is available in an email or something like that, or you find the bit of paper in the wreckage where it has survived and it is actually written down and that is gold dust because that is where people are being honest about the aircraft. So, the airline world is different and they are actually doing it properly. But as you go down the food chain the margins are lower and the incentives to actually cut corners in maintenance goes up from a commercial reason. And if it becomes

	ingrained in the organization it is what becomes normal; what is expected. You don't ground aircraft; you just tell us what is wrong and we fix when we get back to base. Those do have various recurring defects which are not necessarily no fault found they just haven't been fixed. Autopilot heading bug is still five degrees off and it has been for the last six months and it is going to get fixed at the annual in December. So, it is not really a no fault found. There are two sorts of maintenance records. What is written down and what is actually going on.
12. Do you look for trends? I.e. repeated technical faults?	Sure, and particularly if it is relevant to the event. If I am doing an investigation and there is a systems which is unrelated on the face of it or to what's happened to this particular flight but they have got defects that are recurring which are not being dealt with in the terms of stopping them it just raises a bit of a flag for me. So, if you are not fixing that particular system and it is coming back again and again and again why is that? What is the reason for that? Is it you are not resourced? Maybe lack of knowledge? You haven't got the parts maybe? Willing to accept a level of degradation of safety for operational benefit? What's the reason for that? So yeah, definitely.
13. If so, how do you analyse them? Is there a process?	So, this is about repeated technical faults, is it? What is the process? Yes. I would analyse as far as I could exactly what the fault was. So, if is it a built-in-test failure on boot up of a unit or something like that, which you might just get a fault code, might not necessarily mean that much to the manuals, might give you a bit more information but perhaps fairly limited in terms of 'if you get this code' you know 'pull the unit'. I would always then go back to the manufacturer if I am pursuing it. So, I would go back to the design organization that actually designed it originally or failing that, the one which is in custodianship of it now, if it is an old unit, and talk to the people who actually deal with it day-to-day. Not necessarily the programme manager but the guy, the avionics technician, who has 15 of these boxes through a month and knows what goes on with them. And pursue it down at that level if I was going that far with the investigation. Cause it is the people with the experience who can really open, they can tell you probably what the fault is and also what they would do to fix it and how frequent it is as well. They might say 'yeah we get this every week'. They might say 'ha, this is the second one I have seen in 10 years. So that is useful information. Obviously, the component maintenance manuals are key in the sort of initial response to what you should do if you get this defect. So, the initial thing is to identify what the defect is at the top level cause any actions you take thereafter depend on that decision being a good one. Assuming you have got the top-level bit right then you are into the CMMs to see how far you can go in the CMMs in terms of fault finding, troubleshooting etc. Some aircraft do have troubleshooting guides as well, so you might want to use the knowledge locked up in those to take the problem further. And if you can't resolve it in those paper documents then I would be back to the OEM for sure. And having an AAIB badge gets you a bit more attention. If you are an operator and you have a box that keeps going wrong, unless you are a big customer, you are not necessarily going to get the traction. And if you have got a single aircraft you are at the bottom of the list and you might not get dealt with very well.

Training	
14. Moving onto the next bit which is training. During your training (AAIB or similar) can you explain what you were taught about intermittent faults and NFF? How to spot them?	I think this is quite easy, almost, I can't remember any specific training on the aircraft accident investigation course at Cranfield, six weeks long, which specifically look at no fault found. It may have been mentioned in passing in the odd case study. I can't, that doesn't stick in my mind. My engineering degree, I did an MEng at Imperial College in London, Aeronautical engineering, four years. We did an avionics systems module for that, there was nothing in there about no fault found. My re-current training for my maintenance rating for senior inspector for the BGA, British Gliding Association, so every two years we do recurrent training, including human factors training, the last one I did there was nothing in there about no fault found. So, its on-the-job training. You know, it is learning by doing, which is probably not the best way of doing it. But having said that, I must caveat that, by, it is only a minor part of our job in terms of man-hours per year, no fault found investigations for the reasons I have stated. So, I can kind of see why the Cranfield course is oriented the way that it is. It is more about field work or organizational investigation as opposed to deep diving no fault found investigations but yeah, perhaps something that could be improved. It is pretty minimal. And if you have not got an avionics background then the learning curve is quite steep, I think. Who took you for that module? My degree? No, the six-weeks course at Cranfield. It is under Graham Braithwaite sort of empire. I'm sure he wouldn't mind me describing it as such. And then there is a course administrator who deals with the day-to-day. The nice thing about that course is there are a load of different instructors so some foreign instructors instruct on it (vague). You've got people from all around Europe basically, just coming and giving talks for a day. So, I couldn't say it was one particular person, it is a very varied course which makes it so good.
15. If you think there is a problem, who to talk with?	If you think there is a problem with an intermittent fault or a no fault found, who would you talk with? Well, I would start with the operator, so, and normally if there's been a problem in flight your dealing initially with the aircrew, so I would read what the air-safety report said and typically my operations colleague would have interviewed them, so I would then read the interview transcript which almost never exists, cause they should produce a transcript or there should be notes but it is a bit sketchy, so I'll sit down and talk to them and try to understand a bit more about the nature of the fault. I normally would do then, talk to the aircrew directly, one-to-one over the phone to get their view on things. And again, getting people to repeat their story of the event sometimes brings out other features of it, which may perhaps have got missed at the time, in the memory. Maybe they remember the sequence of events a bit better. Typically, not because memory gets worse with time. From there I would normally go to the maintenance function within the operator, talking about commercial then, with the maintenance department. And ask them, obviously got the paperwork, so the history of the aircraft before, and then I would ask them what actions they have taken to restore the aircraft to an airworthy standard, to put it back into service. What boxes they have pulled? Where those components are now? They should quarantine them because of the air safety investigation, which we're involved with. If they haven't then they will get them quarantined rather than

	shipping them straightaway. I'd probably, if it is serious enough, then I would probably go up and see them. Sit there just one-to-one. Just explain our function and what we are trying to get out of the investigation and also the help we can give them in terms of, if that box goes back to an OEM, it might go to the States or somewhere, then we can get oversight of that in the US with an NTSB [National Transportation Safety Board], equivalent of me, to follow the unit through. So, it is not just having a standard bench test. It might be getting a bit more attention than it would otherwise. And then follow any findings from there. So, if there is a fault within the box, or the component, whatever it is, then we, if it is not working, or if it is working intermittently, then the next question is 'why is that occurring?' Then we might do things like CT scan, x-ray, if it is a contact or relay, something like that, before we take it apart. We would, in this day and age, in the last five years or so, as a matter of routine, CT, x-ray scan, that electromechanical component to capture the detail of it, in terms of where the springs are, what the clearances is between various internal parts is, if there are any foreign objects or debris within that component, which if you just took it apart on the bench, something falls out, well where was it, was it lodged in somewhere. And that can be crucial sometimes. It is not really a no fault found investigation but that has proved real, paid big dividends, on certainly in some investigations. And it is informed tests which you wouldn't necessarily have done just simply following the CMM, which you think 'that's not right', 'let's do this test'. I had an attack sensor on a Citation II that froze at altitude, and it was New Year's Eve 2015 I think it was, and there was a loss of control from 42,500 feet, through Birmingham CTA [control area] airspace, and the aircraft rolled five times, pulled 4.5g, recovered at about 13,000 feet lower, permanently damaging the wings so it was very lucky to get away with it. And the reason the angle of attack vane had frozen was because a PTFE [Polytetrafluoroethylene] seal inside it which have been installed slightly non-concentrically. So there was a bit of pre-load in it and it had a simple disc with a flange, which then sealed against the spindle which was the rotating part of the RA vane and you could see this flange had worn all the way round the perimeter, all 360 degrees, and when they do it in the factory they do a leak test on the unit to see if the seal is good, and it had been good and you could see it had been good because of the even wearing surface and then at some point in service, and it was only four years old this aircraft, it had oil-canned out probably because of this non-concentric mounting and then this leak path had developed and got moisture in the bearing. Gets high, gets cold, freezes, you've got no AoA and the pilot didn't notice the speed. He was in autopilot, vertical speed, top of the envelope and sort of lost control. And so, when I took that back to the OEM in the States, Safe Flight, having CT scanned it I knew that there was a problem with it and I shared everything. All books were open, shared, all those images sent all that ahead of time, so before we striped it down and bench tested it, we put it back on the leak tester and it failed by a factor of 3.5 of the leak rate. So, CT scanning electrical components, particularly electromechanical components, very, very helpful sometimes, particularly when explaining why things aren't working properly. Now if we are tearing down that contact for a relay, then we will take it apart, photograph everything and maybe look at the contacts under the SEM, scanning electron microscope graphs, look at why it might not be making a reliable contact. So, a deep-dive down but starting sort of through the official route and into the CMM and then maybe where most organizations would then stop and repair the unit or put is back into service, we might then go deeper with imaging or tearing it down
16. Do you discuss	You have answered the next question which was, do you discuss intermittent faults with the aircrew who have flown the aircraft?

intermittent faults with the aircrew who have flown the aircraft?	Absolutely yes. Which I think was your point 1 made before.
17. Do you check with the aircraft engineers for intermittent faults or the OEM?	Well as I said before both. So, I would start with the maintenance guys because they know the aeroplane better than anyone really. So, they would be familiar with how often they are pulling components if they are unreliable from that particular serial number of aircraft and think for aircraft and across their fleet, if they have a fleet. So, we will start with them but typically our investigations then need to go to the OEM and as I said before within the OEMs it is the guys or girls who have been there a long time and know the units and know what the CMMs say. They almost don't need the CMMs cause they are so familiar with fault-finding processes but of course they should follow the OEM CMMs. And then when we go for our investigation you can see they have got them out and are blowing the dust off. And then following it bit by bit, you know, so I would think day-to-day if they are very familiar with the equipment, yes they should use the CMMs but they probably just running the tests almost from memory typically you have a proforma to fill in; so that is a guide to help them. They have got to do it in the right sequence. So, you would follow the CMM as far as you can and then see if you could take it further. Also ask around here, particularly the older inspectors; we have one who has done 47 years, seen lots of stuff. So, if you have got a particular investigation and it is an intermittent fault on a particular item then you talk to the colleagues here. You know there is a lot of experience and a lot of it is now retiring so we are losing some of our very experienced inspectors. So, we have people here with 35, 40 years' worth of experience who will retire now so there is a bit of a gap cropping now, so perhaps 15, 20, 10 sort of my level but even so there is a lot of experience so I will to talk to colleagues.
18. Is your investigation impinged by time or technology?	Let's start with time. The answer is of course yes. We haven't got an infinite amount of time to investigate and we do have nominal time scales to perform to in terms of our reports. So, you could say commercial-air-transport event might get nine months between, if it is not a big accident, if it is just a run of the mill sort of incident investigation, from the day that the occurrence happens to the report release nine months. Perhaps a year if it is a bit more wider in scope. So, the clock is ticking. Now that normally is enough time to identify the fault. So, use this as an example again, a slightly frustrating one. You know we could look at the system, look at the symptoms, look at the fault-test reports of the components that have been sent off and come back no fault found to identify a likely sequence of failures that would have developed to produce that level of degradation in an electrical system. To kind of explain to the reader what probably happened. Now as an AAIB inspector I don't like the word '*probable*' even though the whole world in an uncertain place. I like a high level of confidence in what the reports says. So in that case there really wasn't enough time or money in the pot or will to actually take the safety of the electrical system down to the sort of nano level to work out exactly why these two components had probably failed in an intermittent fashion but came back to life when the aircraft landed. So normally there is enough time to produce the report but there isn't enough time to do the level of work which you perhaps might want to, to be highly confident about what failed. For an old converted ATP doing freight at night, when there is a fleet of about 20 and they are going to go out of service soon. If it was a 787 with a box that has a no fault found and then a serious event then there would be more time. There would be a lot more will I think, in terms internally here to supply more resources and also, I think the OEM I think would be keener to get to the bottom of it as

	well. So, there is that factor going on as well. Old aircraft don't get the same degree of attention as aircraft that which are in production or there are big fleets of them because the safety risk is a lot higher to the travelling public. So that is a factor as well. Normally there is enough time to do a job, there is not enough time to do the best job; there is a compromise. The classic question you know is how far is far enough in an investigation because you can always go further. There is a judgement to be struck there which is what I am trying to say in 15 minutes of talking. Technology, how does technology, what was the question? How does it hinder or how does it help? Is your investigation impinged by time or technology? Which is interesting in the current era where you are using technology so much more. Yes, is it impinged by technology? I think technology can help. When, having said that, the negative of having lots of data in this day and age, in modern aircraft like the 380s got 3500 parameters recorded, not all of them on the FDR [flight data recorder] but the quick access recorders have a lot of data on them all at high rates, so you know from historical compared with what you had 30 years ago with what you have got now, you have got discretes, you've got variables of 6, 8, 10 times a second, masses amounts of data. So, you are drowning in data to a certain extent. On the face of it, it does allow you to narrow it down and look at a system in detail. Generally, technology is very helpful. So, we have electronic maintenance records that we can go back and do statistical analysis more readily than if you have just got a room full of logbooks, that we have to go, 'how many times has this part number failed?' Well it is all on the database now so we can ask for that data and hopefully it will come through relatively quickly from the operator or from a maintenance facility; they will have it on a computer. So that is good. Imaging as I said, non-destructive testing, modern basic imaging, can be highly instructive on investigations from time to time. Manuals are available if we are in the field; we can get maintenance manuals, CMMs, emailed to me. I can't remember when that actual made a difference but we can have it sort of at the click of a button in this day and age. I can read a maintenance manual on my iPhone in a field. You couldn't do that 20 years ago or 10 years ago. So, technology is good.
19. Does this type of accident affect the search of the maintenance records?	Affect the? Search of the maintenance records? The search, yes. Sure, if it is a whole loss of an airliner then we would be going through all possible scenarios with a fine toothcomb again with what is written down and also what is not written down, in terms of interviewing people. If it is a PA28 (?) running into a hangar cause someone has tried to pull, swing the prop and hasn't managed to get back in the aircraft before it has hit the hangar. Other than working out why they couldn't start the engine in the first place I might just look at the maintenance records for the number of hours on the airframe and that's it. As I have hopefully explained as an inspector, we do what suits.
20. How often do you investigate incidents where NFF or intermittent faults are	I think you have answered this but how often do you investigate incidents where NFF or intermittent faults are apparent, even if this is not recorded in the final report? Pretty infrequently. Again, statistically I don't know how I compare in general here, but I would think based on nine years' experience we are not doing a lot of no fault found investigations. You are probably aware, when you read

apparent, even if this is not recorded in the final report?	a report it is the top of an iceberg a lot of work that's done that may not make it into the report or might warrant two or three lines that could be months of work to eliminate lines of enquiry from the investigation. Most of our work is doing that to be honest. If you are thorough, then you are not looking at everything, but you are looking at the systems of the aircraft as far as you can to eliminate the potential causes of an accident. By its natural that absorbs a lot of time compared to the mythical golden rivet, the cause of the accident. "I found the golden rivet, look it's what is broken." It is never that simple but we spend a lot of our time eliminating stuff, which I think, I guess, must involve some no fault found investigation. It is just not common in mine.
21. Are there any regulations / procedures / process that you have read regarding NFF?	Well, I am thinking really in the manuals here, so guidance in the maintenance manuals and then troubleshooting guides would be my answer. It is probably not a very complete answer because it is not really my specialism. That's where I have come across written guidance. It is not really a regulation; it's just guidance material on how to investigate particular components where you've got an intermittent failure
22. Are there any other points you wish to raise regarding intermittent faults of NFF that have not been mentioned so far, they may be relevant to my research?	I guess the point you picked up on training is an interesting one. So there probably is a need for training for investigators for how to best approach no fault found investigations because it is probably is a little bit hit and miss. You know, if you get a really good maintenance organization and you have got a good proactive OEM who are willing to put the effort in, you would probably go a lot further than if it is an old box and the guys who designed it have retired years ago and it is just on someone's capability list and they don't really know much about it. So, there can be different approaches to how you might get round the investigation. So, I think, yeah, more training would be good and perhaps in that training you could have people from military backgrounds, civil backgrounds and the design, production and maintenance organizations to actually have an input so you are not just getting one flavour of no fault found. Obviously, the operators, aircraft operators small, large, more like a one-day conference perhaps could be ideal. You could get everyone in the room and talk about no fault found investigations. I think we would go to that for sure. You can tell me now there was probably one last year. Yes, I will tell you.
A.	This is an add-on question because it came out of the last interview and I thought of it at the time. Are there any particular systems that you think are more prone to intermittent faults, no fault found and then if there are do you think any are more like to impact airworthiness or air safety, and I do have definitions for you to view? So, any particular systems that are more prone and which are more likely to impact airworthiness and air safety? Well in my experience, it is electrical systems, electrical power distribution systems but I am clearly biased by that investigation because it is in my immediate memory. Because if you lose half the electrical system on an aircraft then you have a clearly degraded aircraft. Mix that in with some bad weather and perhaps an inexperienced crew, that is not good. So, there is a level of risk there. But having said that this is an old aeroplane, 1986, something like the 787s, which has got electrical power generation coming out of its ears, you could lose multiple electrical systems on the 787 and still be in pretty good shape in terms of the redundancy in the aircraft. So, I am going to answer with power distribution systems with contactors and batteries, TRUs and corroded connectors. But this is not a definitive answer. Okay.

Permission	
23. Can I quote you by name / post?	Both if you like. Brilliant.
Additional Discussion	
In follow-on discussion	There is one other thing which you just triggered my thought process, which is probably worth exploring is bench testing equipment, or the environment the testing is done does not reflect the environment that the box was in, or the component was in. So how often does the CMM actually put the unit in the vibration, the pressure, the temperature environment that it was actually in when it went wrong? Probably not very often. I think as it is quite expensive to do that. Is there a relationship there between failure to identify faults and the environmental conditions the testing is done in?

A.5.7 Interview 7

Question	Answer
Categorization	
1. How many years have you been involved with aviation?	Over 33. Military? Military, yes.
2. How many years have you been involved with aircraft accident investigations?	3 Years.
3. What is your specialist field?	Aerosystems engineer. Is that what your specialist field is for investigations? Actually, it's accident Investigator bracket Eng. [Accident Investigator (Eng)]
4. Engineer or aircrew?	You are an engineer; do you fly as well? No. I did 15 months on a Nav course but got chopped. So, I have got some background of flying and working in an aircraft, but not as a profession.
5. What type of aircraft accidents do you normally investigate? E.g. jet, passenger, helicopter.	I've got down jet, passenger, helicopter but it might be the whole gambit? Anything that's on the military aircraft register that we've got liability for, so that includes unmanned air systems within that, to Watchkeepers and I'm doing some work currently on the Zephyr, which is on it as well. Is that a recent one? March. XXX [Interviewee 8] might be able to give you some more on that.
6. How long have you been working for the DAIB?	3 years again. Okay, that's the background general knowledge.
Faults	

7. How would you describe an intermittent fault?	It's probably something that shows symptoms that are not persistent and not repeatable. Typically, I would consider it something that happens to an electronic system rather than to a physical system. That said, software shouldn't have intermittent faults. Software is predicated on a set rules and logic. So, you would get an electronic system maybe failing not because of software, but because of the way the hardware is working. If that makes sense.
8. What is your knowledge, ignoring everything I have said, of no fault found?	A typical one that I've seen? We had one on a Sea King. I was actually in the avionics and their commodities PT [Project Team], so I had a whole range of equipment that was required to fit across a number of different platforms. One of those was an INS receiver. The antennas for the receiver were in the bottom of the aircraft, and one particular aircraft they kept coming back to me and saying we've got an issue with your kit. And I said, well this is the 3rd or 4th DASOR [Defence Air Safety Occurrence Report] that's come in against this system, but they've all been on this tail number. I don't think it's the equipment; it's the installation that's at fault. I suggest that when you put that next into Depth maintenance you raise a card for having a good check of all your wiring and cabling etc. They came back to me afterwards and said they'd found a bit of chafed coax which had been giving some erroneous readings on the display. So, although it wasn't there all the time, and when they changed all the control units and displays in the system it would still pop up occasionally. They eventually traced it back to it. So, when the box went back that was saying to you it was no fault found? No, because I'm not sure that we traced NFFs into a repair loop. It was a performance based logistic, a filter bench test and send it back out again. I think nowadays we would be more effective and looking into that space more and looking to highlight no fault founds. Especially if we'd had DASORs raised against them, and trying to trend those and understand what they are. I have some experience from when we did a report about 3 years ago now and it wasn't happening as it wasn't in the contract to do it. Yes, that would then come down to the Equipment Engineering Authority, so well no, we getting quite a few of these. So how would you differentiate an Intermittent Fault with a no fault found? I think a no fault found is what we apply to get the aircraft flying again. So, when we've done the test, whichever test that was, it may not have been looking in the right direction, it might not have been looking at the correct systems data or whatever else to ascertain there was a fault. Some of that will come back to the design stage understanding the failure modes and the FMECA and the FHA and making sure that you've got the test equipment designed and effective to highlight those issues either on first line or second line. Would you get something on the P bit, I bit (?? unclear) that would give you a marker? I don't know.
9. How did you first become aware of NFF?	I worked on Phantoms for two and a half years and the MCS, the Missile Control System, on the Phantom was particularly problematic in that the board… Was that 1998?

	That would be 87 through to 90. The connections where the boards sat in the racks and everything else were not really secure enough and due to vibration, the boards would often unseat. So sometimes it would be raised as No Fault Found and sometimes it would be raised as LRU such and such, 'reseated satis', 'tests carried' out etc. Obviously being an engine man and seeing what the MCS boys did, giving them lots of banter about it and it was the cause for lots of joviality.
10. So, what experience have you had of an aircraft or aircraft investigation with NFF?	Directly, in this job no. Probably the Sea King where I was the EA supporting the project team in the squadron was the main one. How long did that go on for? Probably 6 months or so before they get it into a depth maintenance and then did that. I'm trying to think what we would do differently with that nowadays. Maybe with ASIMS [Air Safety Information Management System] being a little bit more mature and the transfer of ownership with a DASOR that might have been managed differently and the duty holder oversight for ASIMS and DASORs may have changed the way that was managed a little bit now. Have any of your colleagues talked about a no fault found during an investigation at all? Not since I've been here, no. I think - would we go looking for no fault founds? I don't think offhand it's something we'd do. What we tend to look at is what did happen, what normally happens and what should happen. And if we find the 'what did happen' indicates there is something within those lines of inquiry where there's a system that's maybe not behaving as anticipated or consistent with failure for various reasons, then we may look at that, and then look for specific trendline, via tech log, 700, analysis or such like.
11. When conducting investigations at what point do you scrutinize the aircraft maintenance records?	We will have a look through initially as a first scan. How soon is that after the incident when you are called in? We'd look to try to get that within the first few days. One of our aims is to get to the DG, the initial assessment before the triage report. DG? The Director General. So that's Air Marshall Gray. DGDSA [Director General Defence Safety Authority]. Sue Gray? Yes. To get to her a triage report which will advise initial lines of inquiry, but also advise if there's anything that needs to be passed out as urgent safety advice. So, looking to see if there's any recent maintenance work been carried out, and if you cast your mind back there was an incident in Valley of a Hawk where we didn't do the aileron transfer rod and then it had a roll runaway didn't it? So, looking to see what's in there, whether there were some activities that were likely to have influenced the accident. I try to treat every accident as a fault tree. Aircraft flies, aircraft fails to fly. Why has it failed to fly? Because it's got a loss of lift. Why has it got a loss of lift? Because of loss of thrust. Why has it got a loss of thrust? A bird strike, cause it run out of fuel, because the engine surged, all things like that. By doing that you can highlight the potential systems of interest. The one with

	the Hawk where it had a runaway roll, you've got to look at the aerodynamic control services for that activity. So, if you've got some markers that indicate where that may be, you would look at those bits within the 700. In the longer time, we would probably have a closer look at the 700; possibly even send it out to an external organization that's familiar with the aircraft. So, for the Griffin we didn't, but for 204, the Hawk, which is just about to be published we sent that into Culdrose because they had Hawk, they were familiar with the 700 and they could do an extended 700 QA for us. Give them some particular areas of interest to look at including the normal bits from the JAP etc. to make sure that's compliant, maybe if they've got any leaflets in their 2R1 or whatever else they need to follow, specifically for Form 700 QA or things like that, and then looking if there's any persistent and repeated faults on this particular airframe or such like. So, we sort of get there and close a loop on it, but it wouldn't be something prime we would go into. What about for electronic publications now? Voyager, for example. We haven't done with Voyager and we're just considering how we're going to ahead with ALIS [Autonomic Logistics Information System] for JSF, because electronic tech logs, I presume you mean there, how that's locked down, how that's captured and how we have the ability then to review that is also that little bit different from an old hard copy 700 and a whole stack load of job cards. We're just sort of getting into that space to do that. Voyager, I couldn't tell you exactly what they did for that. Spike wanted the investigation along with Justin Blackie. That was before my time. What they did to look at that and whether there was anything I don't know. Is Justin still in Canada? I think he went across there, yes. Interestingly I bumped into Justin at the same meeting last year that I went to. He said he was going out there. Yes, I heard he was going.
12. Do you look for trends? Repeated technical faults?	I think the answer's yes, but do you look for trends and repeated technical faults? You might want to caveat the answer. I think as an engineer, yes. You'll always flick through things and say that's interesting, that's interesting. Is it germane to the investigation? Maybe another thing and we will often come out of an investigation and say okay we observed this, we observed that, we observed the other. That maybe the duty holder, the CAMO, the TAA may wish to, or should, consider but it's not strong enough to make a recommendation because it's not causal or contributory. So, we found in some instances that certain things weren't being fully complied with. With their own instructions, where the form 700 QA highlighted a whole load of problems that just config and control and oversee and things like that so we sent that as a letter off, and the report off to the CAMO and to the duty holder. So, it's a yes. The other bit is that when I'm on an investigation I will also dip into DASORs and then flag up for the Fleet. So I don't get everything for all the Fleet all the time, but if I'm doing an investigation into a particular type I will then get the messages straight into the box for that type as they come in, and then try and assess whether that's something that's a trend and impacts and whether that's something I need to deal with or whether to leave it to with the duty holder to manage as part of their normal occurrence management activity.
13. If so, how do you analyse	If so, to do with repeated technical faults, have you had any repeated technical faults? No?

them? Is there a process?	Not that I can see. If so, how do you analyse them? Is there a process? We haven't got a laid down process for that. I think we would go back to fundamentals. Quite clearly going back into the MAP and using that as a guide or something like that to carry out our investigation, because what we might observe is that the appropriate authorities, the CAMO and the TAA, haven't been doing their investigations and that then would, probably at best, be an observation and maybe even causal or contributory. So, we would need to go back to something that was meaningful and repeatable so the MAP would probably give us a guidance how to do that. So that when, if we were challenged, we'd say well no, we only did what maybe you should have been doing in those circumstances. As an aside, you know the MAP is being reissued soon? I didn't know that. Yes, it's being reviewed and reissued. It came out at the Royal Navy Air Engineering Conference.
Training	
14. Moving onto the next bit which is training. During your training (AAIB or similar) can you explain what you were taught about intermittent faults and NFF? How to spot them?	Can I explain it? What training? Did you have training? I am trying to think now. There must have been something. Probably the AP100B-01. It's gone? So that became MARs and then MAP, RAs. I can't recall any specific training. I've forgotten many things over 33 years but as I suppose again that it would be that I would probably go back to see what policy was and see what comes. It is out there. I think the ones I would refer to would be 95 and 98 by John Peacock. That's a name I've not heard for ages.
15. If you think there is a problem, who to talk with?	Just say you thought there was a problem with an intermittent fault or a no fault found within your investigation, who would you talk to about it? I think first port of call within the organization. We've got quite an open and robust chat within the organization and we're always talking about everything else and I'll look at something and maybe say that doesn't seem right to me, pass it over to one of the other engineers to think about and they'll probably think something similar. If we think it presents a real and ongoing risk then we have to raise that, either via the SI Panel President, because their obligation is to raise urgent safety advice and risk to life via the DG to the duty-holder chain. So, we would probably go via that route. That usually then comes out in a drafted letter signed off by the DG that the panel have had a look at, have discovered, have found an area where there is an ongoing risk that needs to be managed. I don't know whether there's a difference here between what we do in the duty-holder chain that we set up and what the civilians would do and how they would raise that. Because if you go to a single operator it's completely different isn't it, whereas your fleet responsibility in the military is probably more managed.

	It did come out. It was more a case of who they would talk to as part of the investigation. That's the OEM Do you go back to OEM or is it different? Directly I don't think - we deal quite closely with the OEM in terms of understanding the systems and how they're configured etc. We may discuss areas of concern with them and it may be that, but that's in a safety and investigation aspect. Not going back to the design organization part of it. It's quite a little niche within the OEM. So, it's not going back to people who can suddenly start chucking out Mods or things like that. Would we put the onus back on the TAA to do that? Potentially, I think. I think, if we've got issues, it would be the Panel President that would be looking to set up meetings with interested parties, including the duty holders and the TAA, and potentially the routing then to industry and to others, because you've got to address the safety issue so the privilege and retaining some of the information of the investigation becomes secondary at that point as you have to make sure the systems are safe to operate and can carry on operating. So, it's difficult to say how we balance it directly, but it will be urgent safety advice by the duty holder, discussed with the TAA. Before the report's been published? Yes. If it was going to be a risk to life, absolutely. If it was going to be a nuisance or something like that, I think, I would be tempted to still be in that same space I think, if it was just going to be a nuisance. I try and split things between fit-to-fly, fit-to-operate. And fit-to-fly is all your standard avionics and bits and pieces like that, your engines, your lift systems and whatever else. Where fit-to-fight might be your other systems like weapon aiming systems and things like that. But as we found out in the Gulf not having a warning to say the IFF failed cost us a Tornado. So that fit-to-fight, fit-to-fly bit, it can be quite masked, or quite blurred. So, Alistair [Saddington] might jump in if I get this wrong, in the interviews this morning it gave the impression that the AAIB, he did say the word, I can't remember what the word was but basically they are legally able to go in and get the documentation and get other stuff and do the investigation because they are authorized by the government to effectively do that. Are you hampered in your investigations because of the set-up, in that you don't run the investigation, the DG sets up a panel and the panel does the investigation, you just feed into the investigation? I don't think so. We're always acting on the request of the SI Panel President; we are specialist advisers to the panel, so we work for them. The industrial partners we work with, and having been out to component manufacturers for actuators, we've been to Rolls Royce, British Aerospace and such like, their support has always been unqualified. They're absolutely on side as always. Bell on the other hand started off in quite a good position but then after a while they would just put a little distance between themselves and ourselves. I think they probably felt it was going on a bit too long, so we were not given some information we asked for from Bell and it's that IPR piece, which I can get internally, the Intellectual Property Right, and also the ITAR, the export which is the International Trade in Arms, I can't remember what the R is.

	Probably research. [International Traffic in Arms Regulations (ITAR)] So, they played a little bit of that in the end. I think partially because they wanted to disengage. They were quite content to support the technical inquiry but when the inquiry went into a little bit more the human factors and understanding of those areas they weren't in that space. That said, there wasn't a no fault found concern there. There was a known fault that wasn't managed particularly well in terms of the gearbox support case cracking, which was a different issue and comes back to the TAA really.
16. Do you discuss intermittent faults with the aircrew who have flown the aircraft?	In your investigation, and it might not be you, if it is the Service Inquiry Panel, do you discuss intermittent faults with the aircrew who have flown the aircraft? I haven't. I haven't interviewed aircrew; that tends to be with the operators. They tend to do that. Is that operators? As in aircrew from here. Our focus when we're on the ground usually is getting the physical evidence; the perishable evidence on the ground as the engineers. The aircrew members, or operating member of the team, will go and do those initial interviews with the relevant parties and that will probably start off with the Squadron boss, the authorizers, the pilots that were in the sortie and if possible, the pilot that was in the aircraft itself and view all of that, and take some measurements. We speak during that process. With the DAIB operator? Yes, so if there's any hot poop that comes out of the discussions that they've had or anything that may indicate where we may like to put a bit of focus in terms of looking at the wreckage, or securing some of that wreckage early doors, we would probably expect that to come back in so we can look at it. Once the panel's in… So do the DAIB operators, do they write a report which you see before it goes to the panel? The triage report, so we'll go out the door, we'll do the triage investigation, we've got a 48/72-hour time line on that to get that back to the DG. So that's a report that's co-authored by the DAIB investigators, Ops and Eng together. So, what we saw, what the occurrence was, a very brief time line and then whether there's any existing hazards and it changing a little bit because of the personalities in the DG slot. When it was Dick Garwood it was very clear it was only for his consumption and we were quite candid in some of our comments in there, and probably put some things that were quite speculative but legitimate lines of inquiry. When the DG changed over and we then got a position where the DG was passing the triage reports straight across, we were a little bit more circumspect because we felt we couldn't put some of that open thinking when we knew it was going to be dispersed throughout defence. Because it was neither supported by an amount of evidence that was tangible or verifiable at that stage. So, we changed that a little bit. I think now with a new DG, I think we're going back a little bit more so we might be in a probably a mid-position somewhere. We've got to be open and honest; we've got to say what we think the risks are, and we've got to say what the lines of inquiry are. Quite clearly, if

	you've got an aircraft that's burnt out and it's trashed, then it's an SI anyway. So, one of the prime reasons to advise Decision Point 2 as we call it, we've gone through that gate anyway because we've got an aircraft that's Cat 5. At worst we've got an injured or killed person, so were already into an SI. That information, as the triage report, will go to the panel and we'll do a handover of the evidence we've got and then support them with it. If it doesn't go to an SI, we write the triage report as a deployment record and then that's a little bit more rounded, and that then goes out to the duty-holder community as well. So, the DAIB went out, this is what we saw, this is what we think and these may be the areas that you wish to consider. Again, there is no attribution, there's no blame, it's just things that peaked our interest and things that were maybe worth a little bit more than a scratch at because the operating authority then, if we're not going to go out the door, may decide to do an OSI [Occurrence Safety Investigation], may decide to do their own SI. They are entirely within their own remit to do that. Or they may just do it via an ORG locally. What's an ORG? Occurrence Review Group. So nominally when you get a DASOR you have an ORG that would do a little bit of an investigation, review that and pass that to the duty holder. I've got a slide which talks about OSI and SI. It's just that I don't know if it's got ORG so that just clarified that.
17. Do you check with the aircraft engineers for intermittent faults or the OEM?	No. Not even if you spot something in the tech log? We wouldn't do it as a matter of course, but as a line of inquiry. Yes possibly. The difficulty is we look at an incident and one aircraft. We may go back to minutes from working groups and things like that; integrity management or such like, if we thought there was a risk, or platform safety working groups etc., and see if there were threads or activity that might indicate there was something that was peculiar or non-specific shall we say. So, it might be if we thought there was something coming along. I'm casting my mind back; we haven't investigated it but it did prompt a change to the aircraft was the AHARs on the Hawk T1 (?? Unclear) freezing, and they got quite a few failures, and it turned out the whole system was old and needed changing. And I think they are monitoring the system now because the maturity of the new system isn't quite as good, so they've still got some issues going forward.
18. Is your investigation impinged by time or technology?	Shouldn't be by time no. There are always aims and intents to get stuff done within a certain time, but there's no limits on that placed down. Clearly, we try to do it in the most effective and efficient manner possible, to ensure that we get the, identify the issues and publish the recommendations, so people can take appropriate rectification action. Limited by technology, in terms of what we have at our disposal? Yes. Do you have the same facilities as the AAIB? No. I mean they've got the fantastic lab next door which they can do CVR, FDR etc. We have a contracted capability via QinetiQ ADRS but at the moment they can't replay all of the recorders in use. It is an ongoing sore. The other side of it is we had some people down, Stu Oliver was speaking to them, from the Air Safety Centre where they were looking at flight data monitoring. I try not to differentiate between flight data monitoring and flight

	data recording. At the end of the day you've got a lot of data going round on data buses it tells you the system state at various stages of the flight. Some of it might be to sustain the fleet, but that same data is going to give you an indication of the system state when you're reviewing it in terms of a crash. So being able to exploit the data better would be key in that. I remember when I was in the MAA, I told you a recommendation came out for CVR fitment, FTR fitment, and there was a decision not to put to in a new regulation (??? Unclear) to retrofit, principally on the basis of cost. I think going forward everything should have, but doesn't have. The AAIB this morning were, explained that they would do CT scans or X-ray scans of equipment before they rip it to bits. Yes, we can do that. We've got organizations that we'll go to, to seek that support. So, 1710 Naval Air Squadron are good for that. Rolls Royce because we have a good working relationship; we will do X-ray tomography via them. I took some actuators up to, I think it was UTC, they called themselves this week up at Wolverhampton before we touched the pitch and roll-trim actuators apart. We got those internally scanned to make sure all the components were in the right place. For the Hawk we sent some emergency flap and undercarriage blowdown levers down to 1710. So yes, we do exploit that quite a bit. It's not in-house, but we've got people who can call that together.
19. Does this type of accident affect the ~~search~~ (34.50) of the maintenance records?	Does the type of incident affect the cert of the maintenance records? The cert? Yes, if you're going to review the maintenance record. Do you only do it if think there's a tech log but...? Once you establish the 'what did happen', 'what should happen' being what normally happens you get those lines of inquiry quite quickly, your aircraft flies, aircraft fails to fly. Aircraft fails to fly because, you know is lost to us. Why is it lost to us? Because of a bird. Then you may then consider that you don't need to do that level of investigation into the paperwork. So yes, I think it does. Do we make a conscious decision? I think so. We don't go in, like historically they did, and say right we need a complete audit of all the paperwork to understand faults that occurred, maybe more than 3 times in 100 flying hours or within the last 28 days. We need fleet information about this and fleet information about that. I wouldn't set off with that intent unless it was required activity. I think the difficulty as well sometimes is that, if I cast my mind back to MACD and MACE activity, where they were doing a lot of that kind of activity just as the norm, and disaggregating that and giving the responsibility to Project Teams, maybe has diminished the quality of some of that information a little bit. There's still a responsibility to do the auditing? Yes. Do you quarantine the paperwork? Yes, we would. From the outset we'd expect the operating organization to quarantine the Form 700, the LITS, the Gold ESP or whatever system it's on, and to say with the JSF is going to be the interesting bit, how we do it with ALIS, Typhoon and the GSS as well. We wouldn't then know quite how to, or then to extract the data set so we can exploit it.

	I was about to say, having looked at this on the Tornado, because the Typhoon uses Gold doesn't it? ESS. To get down to the field that actually said No Fault Found was seven different screens. So, is anybody within the organization capable of doing that, or do you pull in two technicians or others who do it on a daily basis? We have, primarily from the Rotary Wing because we don't have the seniors from the Air Force, so we tend to get the Rotary Wing cover from the REME, Senior Warrant Officers, ASMs, and the Royal Navy, myself and XXX [Interviewee 8] as being Air Force, we work probably on SEMA (?? Unclear). A long time gone isn't it. So, our ability to do that isn't quite there. I would anticipate that if we didn't have that capability in-house, we'd try to get a trusted agent somewhere else, that would give very clear instruction to them what we want to do, and then again it would probably be focused on systems of interest, faults within those systems of interest, and then what activity was carried out. And I think that bit as well about going across the filter bench is interesting personally, because you might reject it off the aircraft, you're sending it back to the second line and if it passes the filter bench, what happens there? Sending it back as a serviceable LRI, when actually they haven't done anything with it, does it go back with any marking, banding? I think I remember something about rogue LRIs getting back into the system, but I'd need to review what that said in probably the documentation. We'll come onto it.
20. How often do you investigate incidents where NFF or intermittent faults are apparent, even if this is not recorded in the final report?	I think the answer to this is no. How often do you investigate incidents where NFF or intermittent faults are apparent, even if this is not recorded in the final report? We investigate a lot of lines of inquiry that don't actually then go into the final report. If I wrote a tech report here and the report was like 50, 150 pages something like that, then the panel might just take away the you know, 'following an investigation by the DAIB the aircraft was considered to be airworthy at the point of'. But not specifically for intermittent faults or no faults found. You can't remember anywhere, any investigation? I wouldn't put a line in there specifically to say we looked at all these. No, but you can't remember any investigation you've done where there was a no fault found or intermittent fault at all? No. No. That's what I thought you'd say.
21. Are there any regulations / procedures / process that you have read regarding NFF?	Possibly. I can't remember where off the top of my head. I've forgotten lots of things in my 30 years. Nothing in your DAIB training or in any recent investigation? No.

	Have you read any ASOs? I'm just casting my mind back to the Tornado. I'm sure there was a 2R1 leaflet in the Tornado for that. Some ASOs may have but I can't remember off the top of my head. It's in that same kind of space as UFCM. If you're doing it and you're at the point of delivery then you'd know about it, you'd know the action you need to take, but no, it's not something I'm up to speed on at the moment. I'm giving myself a slap on the wrist over here. I'll come onto that one. Would you say that an intermittent fault or a no fault found would impact the airworthiness or air safety of the aircraft? The definition for them is there if you need them. To me, my understanding is airworthiness contributes to air safety. Air safety would be undermined if airworthiness is not present. And we've got the 2 types of airworthiness. There's the design airworthiness and the no fault found may be in that scope, but generally not. It's more about the continuing airworthiness isn't it, to the people who are not understanding the failure modes effectively, and how they may present. So, if we took that back a level further and considered the functional hazard of the system of interest, an intermittent fault could undermine the airworthiness. If that was the case would definitely undermine the air safety. I posed the next question to the AAIB because it was something I posed to the pilots but I don't think you'll be able to... no I won't pre-empt it. If you were going to say any particular systems you know where NFF or intermittent faults were going to be more problematic and more prevalent, could you categorize those systems? I appreciate it's difficult if you haven't had that ... I'm just trying to think from a functional hazard perspective. I think if I could I try to characterize it as something that rises from the functional hazard. Actually an intermittent fault would only present a nominally low risk, because that particular failure might be a nuisance or something like that, has the ability to severely divert the attention of the crew and actually takes them away from that general aviate, navigate, communicate, but saps their SA [situational awareness] and can lead to pretty poor occurrences and I think, you know, we've probably seen a few of those on air accident investigation programmes where people have become trapped looking at something and just saying well discard that we've got 2 other instruments there that gives us the right information. Could you characterize the Air France pitot icing (?? Unclear) as an intermittent fault? But it was certainly something that should have been a minor occurrence that led to a loss of a lot of lives. Similarly instruments that crew look at maybe even more recently, you know the Boeing with the 800 Max and rather than being able to just fly it, you've got a sensor out. The system's telling you this and is the sensor on or off? Certainly, in the Tiger Air one where they feel there was something in the flight before not fully understood and not rectified correctly and then the subsequent flight shortly after take-off, they lost the aircraft because of the pitch-down activity. That's based on what I can see from outside. Anything that's going to sap the situational awareness of the crew could exacerbate the situation making it much worse.
22. Are there any other points you wish to raise regarding intermittent	No, I don't think so. I think we recognize there are organizations you mentioned about, you know, the requirement for CAMO to review that activity and things like that. Is there's a resource issue with that? I think I might have discussed about in this bit.

faults of NFF that have not been mentioned so far, they may be relevant to my research?	It's a requirement of the TAA as well. If you've not got the resource to effectively manage that, do we end up going and picking up the bits and highlighting that organizational failure, rather than maybe the technical failure? Because the technical failure then can be fairly benign.
Permission	
23. Can I quote you by name / post?	Either. OK, Thank you.

A.5.8 Interview 8

Question	Answer
Categorization	
1. How many years have you been involved with aviation?	The research came about because years ago, when I was at St. Mawgan, there was a no fault found on an avionics piece of equipment, and it was like, well it's just one of those things; there's nothing we can do about it. So, it was like when I first sort of noticed it. Then my colleague, Wing Commander Chris Hockley, who had left the Air Force but was at Shrivenham, he got involved in some research for EPSRC, don't even ask me what it stands for, it's Research Council. Alistair probably knows; which was looking at through life support and No Fault Found. We ended up going round six different aircraft fleets and basically looking at the LITS data, which is what a guy called Johnny did, and myself and Chris interviewed loads of engineers and from that wrote the report for High Wycombe. What was the source of the request for that from High Wycombe then? It was via the EPSRC because they [the MOD] didn't provide any money into the research but they said, "You can have access to data." So, we said, "Okay data sets." We'd like to go into and find out find out what the real cost of no fault found is because there was a Chief Technician, Stuart Roke, who did a thesis via Coventry University, which was looking at the no fault found rate on the Harrier. So, he ended up going through all the 707Bs by hand, analysing all those and saying well actually this is a recorded no fault found, by his analysis of the system this is the real account. So what we did with Johnny is we took the LITS data for, I think, three other aircraft and the Harrier data and wrote some algorithms, basically two different ways of doing it to actually analyse the original data to then test the systems to make sure we came up with similar results to Stuart, and then to go through the LITS data for other aircraft to work out what the real account of No Fault Found is and then, which was really difficult because no one had a figure, well if this is the cost of a corporal or sergeant or whatever, this is the actually the cost of no fault found. So that's what we provided to High Wycombe as well this is the report and this is what your engineers are actually saying about most prominent systems, whether it's because of pressure, issues with manuals, aircrew interactions, debriefing and everything else. We gave them that and from that we came up with a load of recommendations, and they apparently put together four working groups to work through those. Don't know what's happened to it afterwards. I do know the report has been requested by Waddington and one other group of people to actually look at it. But in doing that and then looking at the no fault found book, which Chris and some others produced, there seems to

	be this block so you have a little line with the operator and the operator feeds in intermittent fault for. He doesn't say does what, he just says whether there's a fault or not. Yes, he's got a fault. Then you get this big block which is what the engineers do. And I said, "Okay so what's happening between the operators and the engineers? You know, to do with the debrief, you know and understanding systems and everything else." So that's where this research has come from to actually say from a pilot's perspective is there an impact on airworthiness or not, as the case may be. But in doing the literature review I came across two AAIB reports. There has been one DAIB report but it would have been a Service Inquiry. One AAIB clearly said no fault found. The other one implied through the intermittent fault, how it had been recorded, it has been recorded as a no fault found, but it wasn't as explicit. And then this morning we were given another one where it said no fault found. There's one in the military domain, which I think is no fault found, but because I don't have the technical information on the breakdown of the component it'd be very difficult for me to get the information unless somebody here had it but it's quite an old one. So that's where I'm going from to try and find out. Okay what's the investigation process to do with intermittent faults and no fault found and is it something to be worried about or not? Does it impact airworthiness? So that will be one of the final questions for you. So, there are some generic questions about you and how long you've been here and then there's some engineering training type questions. So, how long have you been involved in aviation? 38 years, and counting.
2. How many years have you been involved with aircraft accident investigations?	In terms of aircraft investigations as a result of incidents, near misses etc., etc., rather than pure accidents, I'd say since I helped design the MEMS project, which was when I was at Cottesmore in 2010. Then I became an OSI [Occurrence Safety Investigation] investigator, even though what Baines Simmons now claims as DAEMS [Defence Aviation Error Management System], was originally devised by a bunch of RAF Warrant Officers etc. under the Chief Engineer at that time, Julian Young. It was hosted by Baines Simmons who then captured the information and put copyright on it. Anyway so… What does MEMS stand for? Maintenance Error Management System. It's now DAEMS. It morphed, but I was at the forefront of that together with a whole bunch of other people under Julian Young when it was first designed, so we did the odd week in a classroom with brown paper all over the walls and post-it notes and we designed what was a Maintenance Error System based on James Reason's Error Management. We defined it, described it, and then decided what would be needed to make it work, i.e. all occurrence safety investigations, etc., etc., etc. And that became what was then MEMS and that became HFMEMS, then became HFEMS, then became DAEMS. It's just about association with the defence versus maintenance error. Because MEMS became so popular that they started moving it across to other fields such as SHEFs [Safety Health Environment and Fire] and that's not maintenance error. So, any other field where you can have an accident, standing on a stool, so it became a Human Factors Error Management System where people made errors. So, from that regard since 2010. From the terms of accident investigation, which is the job I'm doing now it's just over two years. So, I did a number of investigations at Cottesmore including a couple of

	weeks on Illustrious investigating a Harrier accident that nearly killed somebody. What year was that? 2011 that would have been. I spent two weeks, in fact was it two weeks? In fact, no. It was a week on board Illustrious investigating three occurrences, two that I went on board for and one that occurred while I was on board.
3. What is your specialist field? Specialisation?	Aerosystems.
4. Engineer or aircrew?	Engineer? AS yes. I mean I started off as a Flight Systems Technician so I've got a lot more background in avionics and such like than I have in structures but you taught me the propulsion module for example in the ASEC so you know. Some on propulsion, design. Can you fly? No, I haven't got a PPL.
5. What type of aircraft accidents do you normally investigate? E.g. jet, passenger, helicopter.	Well, if it flies and it's military, all of them. And just to give an example, have you heard of the Zephyr? Yes. Well that was my investigation when it crashed in Wyndham, in Australia. In fact, I'm in the middle of it now. Did you get to go to Australia? No, funnily enough, which actually caused quite a few problems, us not going. I told you I'd take you down some rabbit holes, didn't I. Anyway, that was my investigation so that was a concept demonstrator and I, whilst I've seen pictures of something that looks familiar, I was not aware that it was even on the military register. Because I was about to ask that question, how did DAIB get involved with that? So, it is on the military register? They've got three or they did have. So, two now on the military register. In actual fact it was a convenient thing for Airbus because they wouldn't have got diplomatic clearance to fly in Australia unless it was on the military register, because they weren't compliant with Australian ATC regs. Therefore, mid-air collisions were a distinct possibility. They didn't have the transponder capability and so on and so on. So, because it was on the military register, we did the triage. We didn't do the investigation but I am now doing a follow-up investigation as requested by DE&S because they were not independent. Who at DE&S, just out of interest more than anything? The TAA, Lucy Crowther, Joy Whitlock, Colonel Paul Hughes. Okay that's the background.

6. How long have you been working for the AAIB / DAIB?	See above – two years.
Faults	
7. How would you describe an intermittent fault?	Elusive. Intermittent faults are a problem because you can guarantee the pilot gets up there, he's not telling you a lie when he's found a fault. You go as an engineer, technician, and power the aircraft back up to try and reproduce it and you can't. It doesn't show, and sometimes it may never show. But certainly, intermittent faults are characterized by continuous repetition. So, it will come and go and sometimes it's dependent on what you're doing at the time. I was replacing an inertial platform in the Falklands on a Harrier and we were doing another job entirely and this had an ADF in for an i-Light (?? unclear) which meant your inertial platform had an issue, but it never actually manifested itself in a fault, but just his i-Light kept coming on. So, there was an ADF in there and one of the guys was messing about near the inertial platform and was moving some cables and the R light (?? unclear) came on. So, I said just move that back. On/off, on/off. So, we found that intermittent fault was actually a detached screen on one of the cables, which, therefore, wasn't screened and got interference and came up with the i-light. So intermittent faults depending on what you're doing can be a little tricky.
8. What is your knowledge, ignoring everything I have said, of No fault found?	Having made no faults founds myself and having looked at them from a wet munitions perspective about how they can be used to cover up or to short circuit maintenance, and I'll give you an example. If you look at AMRAAM that we got from the Americans, if that was found to have a fault when you had it loaded on to an aircraft, often what the guys would do and I'm not saying this was deliberate, there would be a fault, so they would then remove the missile. Take it off, repackage it in a box and put another one on; the fault's cleared. It must have been the missile. Send the missile off to America. Three years later it turned up back in the inventory with no fault found. So, you've now got away with not investigating a fault for three years that might have been the aircraft. So, no fault founds can often lead to disguising latent issues that you've got that you may never find, but you're certainly, with the contractorization of equipment stuff just disappears into the ether. No faults found become, you can basically hide a fault. Not deliberately necessarily, but you can hide a fault with a no fault found. You just blame it on the equipment. Send it off, three years later it comes back and nobody can even remember the original fault. When I say without an investigation, someone says we need to get the aircraft serviceable to fly therefore….? What's the quickest thing to do? Get that missile off, save us changing anything. What's the quickest thing to do, and not only that, Armourers these days don't do fault finding on munitions, generally. It's all contractorized. Take it out the box, fit it. Doesn't work, put it back in the box, get another one. That's how we've dumbed down our maintenance generally. So, therefore, you know, we don't often have test equipment etc. to test at first or second line. Stuff is just repacked in a box, sent off and when it comes back with no fault found do you go back to the aircraft? Do you carry on the investigation? The chances are two or three years down the line, no you don't. Unless somebody is trending that on an aircraft or a piece of

	equipment or even the munition itself, then how do you know where it's gone? What's happened to your no fault found? What was it in the end? But it wouldn't even be recorded No Fault Found because...? Well the investigation's gone. Gone, yes.
9. How did you become aware of NFF?	Well, I was a technician before I got commissioned, so I actually worked on aircraft as a technician for several years, on Harriers in fact, and then I worked on flight simulators for a couple of years before I got commissioned. So, I actually designated some things as no fault found. Now, avionics often you can have a line replaceable unit that shows a fault. You take it out, put it back in again and the fault's cleared. Because it's potentially a connector. A bit of grit on the, or dirt on the connector. And the problem goes away. Not only that, but in actual fact when you're trying to reproduce a problem, of course, the last thing you really should do is switch the system off and back on again. Particularly these days with software driven systems you're resetting the system. So, what you really would want is a pilot to come down with a fault, leave his aircraft powered up so you can see it. However, the standard is: you arrive, you shut your aircraft down and you go and report the fault. Particularly with software systems you're just resetting all your data baselines aren't you. Also, when I was on the Jaguar Project Team, what people didn't know at that time was every socket on a LRU has a filter on it to filter out all the things that are going to actually cause your data to trip, particularly if you deal with ones and noughts and digits. You've only got to get a stray voltage that's enough to designate a 1 and you've got a fault, and you've got something happening that shouldn't be happening. The information we got from the manufacturer was that these filters degrade over time and there wasn't a programme to replace those filters. So, what's happening is that your LRUs are degrading over time and becoming more susceptible to stray voltages, which, funnily enough, cause a fault. Switch it back on, switch it back off, switch it off, switch it back on again - goes away. You may not have the system running that's causing the stray voltages, and it may be only under certain conditions. I did that research and I started to get the Jaguar autostab system filters replaced, but they scrapped it. I left and they scrapped the aircraft just after. Funnily enough that was an aircraft that was already susceptible to RF, because we got a rate pod (?? Unclear - clarify) and it made the control surfaces flicker. We found it was because the Jaguar was particularly susceptible to one frequency, and that was one of the frequencies that the rate pod could be set to. So you will get faults as a result of stray voltages, if your filters and, that are not as good as they will be and as an aircraft ages, you do more repairs, you do more box in, box out, plugs and sockets become loose, you're going to get faults that you reseat the item, so it works. As an aside, is that part of the aging aircraft audit then to look at filters? Have I asked a question you don't know? I don't know. That's a good question. I suppose that would be one for the project teams or DAT. I'm going down to DAT in a couple of weeks' time. Say hello to Col. Critchard would you. I don't know. I've been out of that repair world for some time now.

10. So, what experience have you had of an aircraft or aircraft investigation with a NFF?	Multiple on Harriers. Not so much since I got commissioned because you don't do that much in terms of hands-on engineering. Although when I was at Bruggen, when I was on 31 Squadron as JEngO, we did have aircraft that had all sorts of intermittent and no fault founds. Sometimes, in actual fact, it would be the way the aircrew used the equipment. I'll give you an example. For inertial platforms, what you're supposed to do for the older ones, mechanical gyros in particular, was do a planned fix at some point through the sortie. That would update the system, update the inertial platform and the systems, and improve the accuracy. Now if you didn't do that, then you would come back and your gyro would drift off, and so would of course all your track information and so on and so on. So, the pilots would come down and say, this would happen over a period of a few weeks or a few months depending on how good the aircraft system was, and how good the platform was. Eventually you would get errors in your inertial platform that would stay there and, therefore, you would just keep getting drift and drift and drift. So, we used to log how far inertial platforms had drifted and as soon as you got to a certain stage you'd say right, we'll pull that and sent it to the bay for maintenance. But often what we found was when said to pilots, reminded the pilots that you know you're supposed to do a planned fix, this was the same on Jaguar by the way, part way through the sortie. Funnily enough the no fault found and the fault arises reduced. It was difficult to find a fault with a drift unless it's huge while it's sat on the ground, because it's not going anywhere; you're not flexing the system. Hence, we used to do trend analysis and every time they came back and reported that CLC ??? (unclear) was drifting, but that's the only way you could find it. But often it's because the pilots actually weren't doing what the manufacturers were saying they should do. Even though they knew about it, with everything else they're doing it's one of those things they used to conveniently forget, not realise how important it was. But certainly, when we started doing those planned fixes, or they did, the fault arises on inertial platforms stopped, and they were hugely reliable. But that's an education issue for the pilots. Of course, you need credibility with pilots in order for them even take notice of what you've asked them to do. Sadly, pilots do have a bit of disdain for engineers at times. So anyway, there you go. There's an example.
11. When conducting investigations at what point do you scrutinize the aircraft maintenance records?	When you're looking for trending information. You do it for all sorts, engines, for oil consumption but you know. Often what you get is a certain fault on an aircraft, okay. You go and fix it and then sometime later you'll get the same fault, and you'll think I recently fixed that, it shouldn't be back, then you get it enough times where it starts to pique your interest and you think hang on a minute this is the same fault. We're not really talking about no fault finding now because they might have tried to fix it, rather than no fault finding it. It might be an intermittent fault though. Might. Is that as your time as a Harrier technician or as a JEngO or have you had experience in DAIB? No, when I was a technician we had a number of arisings where we had a no fault found and you'd go on a sortie and came back the same fault, couldn't reproduce it on the ground, you send it again, after a while you get to the point where you can't just keep just no fault finding it. You've got to actually start ripping things apart. Wiring checks, even to the point where we did insulation checks, which were the worst of all things to do to an

	aeroplane. But we did do it if there were enough arisings of no fault found. So, we didn't just leave it but that was more us just being conscientious than somebody from records, or Eng Records saying you've got a recurring fault you need to do a deeper investigation. It would be left to us as technicians to go 'okay this is happening too often'. We were unable to reproduce it. To be honest this is one of the reasons that Tornado did hot-pit refuelling. A number of times they'd come down with a fault, shut the aircraft down and then they'd end up not being able to fly the next sortie because as soon as you start the aircraft up again it would come up with the fault. Or they'd come and report a fault. You'd start the aircraft system up and not find anything and, in the end, they found that the fault arisings were so much lower if they just kept the engines, just kept the systems running. So hot-pit refuel would turnaround and go again. That's how they solved some of the reliability issues with the Tornado actually, because avionics don't like being switched on and off. But you've not had any as part of a DAIB investigation? That's interesting isn't it? I've only done one service inquiry since I've been here, that was the C130 hard landing out in Iraq, and funnily enough it's not really a no fault found story. It's an issue of maintenance procedures. So, the reason the aircraft crashed, well I say crashed, had a hard landing - 4.25g was pretty hard, wrote the aircraft off Cat. 5 — but they managed to fly it for an hour to get it to Erbil. The reason it crashed was it couldn't see the runway, and it was an upslope and he was coming in and using his RADALT because of an upslope on a run in, the RADALT gave him false, well gave him correct readings, he just didn't know that as far as the threshold was concerned he was a lot lower than he thought, and it was pitch black, his NVGs were not capable of operating in these low-light conditions. So, the Hercules has got LED spotlights for illuminating the ground in front of the aircraft, and they weren't effective, but there was no test to determine how effective they should be. So effectively you'd got a new light, the only time you'd change the light was if it was unserviceable, either on or off. So, you'd put a new one on and you didn't know what condition the light that you were putting on was in. You'd think the manufacturers could do it. Well our investigations turned up the fact that in actual fact, even the ones that were in stores that had been repaired, were actually barely capable. And the ones that fitted the aircraft there was no way of… the only thing they did was say right get set of NVGs, are the lights on, are they off? That was it. But not how far the brightness is in front of the aircraft? That's fairly critical. The luminance of something. Correct. I'll get out my torch I need to actually… Yes. Luminance is exactly the right word was not effective and the deeper we delved the more we realised that the manufacturers didn't even test to a particular standard. So, they might repair it, the lights might come on but the luminance intensity wasn't tested. Yes, the effectiveness of it.

	And, therefore, the crews assumed that the lights were effective, when in some instances they were not at all. Not really a no fault found story but when you're looking at lights and you don't know what intensity they should be, it's either on or off. I told you there'd be a few rabbit holes. I think there's been an investigation here that's found or commented on no faults found but I don't know because it wasn't mine. See, I went through the whole of the Service Inquiries and the Board of Inquiries. I went through all of those and I couldn't find any. I found one which was to do with an engine fuel component, which the way I read that, I read that as that was a no fault found. It hadn't been recorded as such when I went through it but I couldn't find anything, but if you have a chance to interrogate your system to interrogate it differently than I can for anything to do with intermittent faults or no fault found, that would be useful. The AAIB I found one clear no fault found and one intermittent. That's the trouble with no fault found they're very tricky things to track down especially as they're not really recorded as an issue. Hence that's why that's one of the questions coming up. It's just something somebody said about as part of an investigation, but it wasn't mine so you only sort of hear it in the periphery but I don't know. I can ask around but it depends on whether the guys who did it are still here. XXX [Interviewee 7] might have known but I'm sure he would have said if that was the case.
12. Do you look for trends? Repeated technical faults?	So, in the DAIB you would do, but you haven't had any. The answer is yes, we do. Yes, we did. The C130 we looked for trends. We did look for trends, yes. And that's trends for technical? Well for example, whilst it seemed obvious, and it's often the case with proper crashes, not something where it's landed and had a fault and a near miss but proper crashes, often it seems clear that the fault lies with the crew for example, pilot flew it wrong or he flew it into the ground like the C130, but experience in the investigation tells you that there's often more than one factor at work. So, you have to seek out those factors and that means often testing stuff that's not necessarily anything to do with the accident on the face of it. So, what I did with the C130 was that I looked at the avionics to see whether when he lined up for his approach his Hercules avionics put him in the right place. And the answer is no, it didn't really. There were inaccuracies there and they weren't at all alluded to as part of the initial triage or crash investigation. It was just me looking at it and saying okay, so he lined up on the approach. Was he where he thought he was? Did his avionics put him where he should be? And the answer was that we found an aircraft in the Herc. fleet where the head-up displays were misaligned, by up to half a degree. That might not be a lot but when you're on a two and half degree approach and you're either at 2 degrees or 3 degrees, your approach is not what you expect, and particularly a shallow approach will more than likely end up with landing short and a hard landing are a fairly common thing. So, we looked at trends on things like the RADALT because that was one of the things involved, the RADALT. We checked RADALT readings. RADALT have a bit of a chequered history. You look at trends; you look at trends not just of course RADALT in the fleet

	but for that particular LRU that's fitted to that aircraft. Can be a bit tricky because you've got to ring up manufacturers and they don't often do trend analysis. They get an LRU, they repair it, they might know how many times it's been repaired for a particular fault but I'm not sure that they're all diligent enough to do trend analysis say in that the LRUs have the same fault over and over again. This is something that you'd expect the CAMOs to pick up on and sure enough they do if it's a regular occurrence. Landing short, CAMO at Brize Norton did some analysis at the same time we did because they'd had another one 12 months before that Cat. 4'd the aircraft. It wasn't far off Cat. 5. And it wasn't discovered for about 3 months till after the accident because it was just reported as a hard landing. It did bend the airframe somewhat but anyway. So trending analysis, what I see CAMOs doing now is doing that work, whereas at one point it was left to, I'm not sure. It wasn't really done unless the technicians themselves or the supervisor decided they'd seen a fault often enough to need to trend it. Certainly, we did when we worked in DLO [Defence Logistics Organization], you know there were times when we looked at the trending of the faults, but again it was more due to the diligence of the individual engineer authorities. Than to the memory of the individual. Correct. And then that's where LITS helped, cause you could go back and have a look at the issue. So, whilst people hated LITS it was a great tool for trend analysis. I'll come back to that.
13. If so, how do you analyse them? Is there a process for a repeated technical fault?	So, within the DAIB investigation is there like a process you would go through? Not one that is defined, I think it relies very much on the experience of the investigators. Which is why you wouldn't put somebody straight from training into a job like this. Because I know that's where you need to look. You need to look not just at the particular component and its history, but the history of those components on that fleet. That can steer you into looking at things that you might not otherwise have looked at. Especially if there's a common fault occurring on something as critical like a RADALT or something like that, and the head-up display fault I found, they weren't even aware of it. And, in actual fact funnily enough, we found this fault and then reported it in a letter, a report, a short one-page report to the Hercules fleet. We then sent Northrop Grumman man, because it's a Northrop Grumman aircraft, to have a look at the aircraft. He said, "There's nothing wrong with it." So, we went back for a second time, same aeroplane, got the manufacturer and said, "There's the problem, how come you couldn't see it?" "Ah, that wasn't what I was looking for." So often these faults are hidden by actually people not looking for this issue, and all we did was line it up on the horizon. And one was like this and one was like that. And there's two issues with that. One is the head-up display system itself, the optics not being lined, and possibly the inertial platform not being lined but you get slightly different faults and what we found is there's no fixed mechanism for reasserting that alignment. During the maintenance or say you change the head-up display optics or the PDU, there's some voltages that you checked but that's what the manufacturer told you to do when the aircraft was designed, or released for service. It's never tested after that. Now, you and I know that a big aeroplane like that will bend over time. The more time it lands it will bend. So, what happens to your head-up display, and what happens to your inertial platform in terms of the actual longitude and lateral fuselage data?

	Even the tolerance of fitting a component there's always slight movements, you know. So, the answer is yes. Yes, I did and I'm sure XXX [Interviewee 7] diligent enough to do it but whether other people do it is down to experience.
Training	
14. Moving onto the next bit which is training. During your training (AAIB or similar) can you explain what you were taught about intermittent faults and NFF? How to spot them?	Slightly different subject - training. During your training (AAIB or similar) can you explain what you were taught about intermittent faults and NFF? How to spot them? Or just anything to do with no fault found. Nothing whatsoever. Do you think, so the HUMS leaflet, the RA leaflet talks about trending and the need for trending and the responsibility of the…? Ah well HUMS is a particular system for trending, that's the thing. The reason I'm talking about it is it talks about the responsibility of the TAA to determine what needs to be monitored, the recording of the aircraft serviceability state against the HUM status, so that's just an example of a system. But, in there it clearly says about trending, but it's pretty obvious that trending doesn't occur. So, do you think that some training should be put in place? For whom? Engineers. I just give that answer, but you could choose somebody else. You see, it depends how you look at this, from the accident investigator's perspective versus an experienced engineer. Go for accident investigator. That's the investigators. Not even covered. As far as aircraft engineers are concerned, I'm pretty sure it's alluded to, it's a long time since I did my engineering officer training. Pretty sure it's alluded to during EOT, and if you've ever worked a squadron, you're going to encounter it. So, you're going to have some practical experience of it but because your guys will come to you and say I've no fault founded that. As the JEngO or something like that then you will encounter it, absolutely no doubt about that. Or if you're in the engine bay or you're in the avionics bay you will find, you will encounter no fault founds. And, if you're trending it from that perspective, which you should be doing you'll probably end up with having to make some decisions on whether to reissue the LRU to an aircraft of whether to send it back to the manufacturer for in-depth testing. So, I would say is even if it's not emphasised during training, you will encounter it on an aircraft. Especially complex aircraft like military aircraft. No doubt about it. Particularly now with CAMOs, if you end up in a CAMO you will do trend analysis. Or, having not been in a CAMO, that was my encounter with the CAMO at Brize Norton.
15. If you perceive there to be a problem or you think there is a problem to do	Go with an investigation first of all; who would you talk to about it? From my current post? Yes.

with an intermittent fault or a no fault found who do you talk with?	I would go straight to the shift engineers, technicians. They're the people who do this stuff every day. Why would you go anywhere else? And I'm no SME on Hercules. In fact, thinking about it, there's not an aircraft still in service that I worked on, sadly. So, accident investigators don't profess to be SMEs on aircraft. We rely on the actual aircraft engineers themselves; however, it's about asking intelligent questions, and not being fobbed off. And if we can't get that out of the shift engineers, we'll go to the CAMO. If you don't get the right answer or sufficient information out of CAMO, we'll go to the Project Team or the Delivery Team. As accident investigators that's what you do. If you don't get the answer you want or you think there's something there and you're not getting what you need, you just keep plugging away at the hierarchy. Do you talk much about that, or would you with your colleagues in the DAIB or do they? No fault found? Or intermittent faults or anything? Is it something you would or wouldn't? This is something that's bread and butter stuff for engineers so, if something came up as a particular thing, then yes. But, by and large, no. I have been asked, in fact XXX [Interviewee 7] asked me about an investigation he was doing. I think it was the Hawk one where funnily enough, and this goes towards the filtering bit, and noise on the system that can cause intermittent faults or the resulting no fault found. They didn't have an accident and data recorder fitted; however, the system still recorded data from all sorts of different systems. Because, you run an engine up which requires a generator, that generator puts noise on even the earth system, and the earth systems only filtered to a certain extent. It won't filter everything, just the major stuff. So, you will still get the engine run-up noise on the earth busbar. So, what it was recording on the cockpit voice recorder, not the flight data recorder as noise. Because in actual fact the connection to the flight data recorder wasn't fitted, acts as an antenna. So, it's picking up all that noise, you can still see what your systems are doing providing it produces noise and it's not filtered. And you can translate that noise into something? Well, you get enough noise and it will trigger things happening in your system particularly if it's a software binary data, because that noise eventually ends up as transient voltages, which will trigger stuff. So, you can get intermittent and no fault found because a fault's occurred because of noise on your system and maybe your filters are not working. So, this is advice I gave XXX [Interviewee 7] during one of his investigations. He came to me with a plot that had all sorts of things on it and I said yes, that's absolutely, you're getting your engine wind-up from the start recorded on your voice recorder as a frequency because of that antenna that's there because you've not got ADR. So, I said yes, there are absolute data you can point to and go that is highly likely to be the engine roar or a generator or gearbox or whatever. Interesting. Does that answer your question?

	Yes. Avionics is very noise susceptible, and if you're going to get a no fault found generally that's where it's going to be. As you get some spike on noise and you get triggers. Yes, it's looking for it so.
16. Do you discuss intermittent faults with the aircrew who have flown the aircraft?	And the answer's probably depending on which stance you're going to take; do you discuss intermittent faults with the aircrew who have flown the aircraft? Yes, particularly if the crew constantly fly the same aeroplane, because he will know his aeroplane, and he'll see the same fault and say I told you about this before and you didn't fix it. And we'll say, well you shut it down, you started it up, we tested it, we did all these tests in accordance with the maintenance, the MRP [MAA Regulatory Publications] and we couldn't reproduce the fault so how do you fix a fault that you can't reproduce? So, it's a well-worn path of them telling you the fault, you confirm the fault, you then fix the fault. If you can't confirm the fault how do you know what to fix? How do you know if it's a connection problem? If it's an earthing problem? Or it's actually an LRU that's causing the problem, without every time they report a fault you can't reproduce keeping the aircraft down. They don't want you to do that because your aircraft is out of action for days at a time. On the other hand, they want you to fix it so, sometimes, you have to be a miracle worker and just magically fix it. And like I say, often when you shut an aircraft down, modern aircraft in particular, then you will clear all the faults. Yes, absolutely. In fact, it's a well-known path isn't it? You shut your computer down and clear the fault. Yes, at work, have you done this, have you done that? I'm thinking of the A400 now which is a flying Windows computer. And they're constantly shutting the damn thing down and clearing faults. So, what are they? Are they no fault founds, or are they? What are they? Data latches? I'll say something afterwards. That's just about that issue and… Just anecdotally I've heard the A400 is a particular sensitive aeroplane. Yes, I'll talk about the Typhoon and F35 so.
17. Do you check with the aircraft engineers for intermittent faults or the OEM?	That depends on what answer you get. If you get a quizzical look when you ask him about a fault, then chances are they don't know it's a trend. Is that the technicians, a quizzical look? Yes, you know you ask somebody a question about something and you get that blank look you know that you've asked them about something they're not aware of. And again, your trend analysis might point to this. You might go to your OEM and go okay so, how many of these are we using, how many have we got in the system, how many have this fault? And I do know from the Herc investigation, the manufacturer doesn't always trend analyse faults on LRUs. But you can look at engines and say that's very much

	critical is to do data trending on engines because, of course, that's your oil consumption, you know stage faults, ??? (unclear) bearings and soaps and so on and so on. So yes, trending is done, it's just not done across the board. The IR lights on the C130 that had never been highlighted as an issue because it was never trended. There was no way of testing it. So, the one thing about not testing something is it's great because you never know you've got a fault. Until you crash an aeroplane of course, then it becomes a bit of an issue. So is there an airworthiness issue, yes absolutely. But you've got to know you've got a fault.
18. Is your investigation impinged by time or technology?	Yes. You can go down rabbit holes with crash investigations and there is a time, you know because, particularly when you're write off an aeroplane. People want to know why, what are the factors involved and is there anything they can do about it and you can't take three or four years to do a full and thorough investigation of all the avionics and engines and so on and so on. When in actual fact, they're maintenance issues rather than any factors involved in the accident. So, it's easy to go down rabbit holes. So, there is a time factor which leads to pressure and there are some practicalities involved, but that's a judgement call. So yes, it's AMJ. What is AMJ? Applied military judgement. You know, I started off with the RADALT on the Herc. The issues I found from looking back at the past usage were typical of RADALTs to be honest, on Jaguar, on Harrier, on the C130. There's nothing to see there other than what you already know. And does it affect airworthiness? Wasn't sufficient, it either goes U/S or it doesn't. Whereas other things I looked at, like the head-up display, were worth further work. So, you take an initial look at the critical systems like RADALT, the Baro altimeter, head-up display, those things that are going to be critical to him positioning his aircraft for the visual approach. And you take an initial look at, and again you apply your judgement and you go yes, there's nothing new there; however, I found something here that needs a bit more work, a bit more work, and eventually you get to the heart of the matter. And that was certainly the case on the last SI I did. What about technology? Technology's worrying isn't it, in that? Are you impinged by lack of technology or too much technology? Yes. I don't know whether it's just irrational fear of things like the F35 for example is a hugely, hugely integrated 5th generation aircraft, and whilst I did some work on that when I was in Defence Intelligence, and I am pretty aware of systems and how they operate, but the question would be okay, there's an awful lot of data pinging around that aircraft, gigabytes of data. How do you do an analysis on that? How do you look at what's latched and what faults it's had across the board? There's gigabyte of data of faults, who has the ability to be able to analyse that? For the moment for example, flight data recorders, we haven't got the indigenous capability to analyse all the data from flight data recorders for every aircraft we've got on our inventory. We have to go to the manufacturer to do that. So, are we impinged by technology? I'm sure we will be when we have our first F35 issue. Security for one is going to be a big factor, but then how much will the Americans disclose about what the aircraft's doing.

	How much did they disclose on the Japanese one? I don't know. I've got a name. I gave a name to XXX [Interviewee 7]. It's one of my big concerns. It's something I've raised with the boss before saying it's alright to fly an F35 but how do we exploit the system to get the information we need to do accident investigations when it's shrouded in technology, or shrouded in security? I mean one of the questions I asked XXX [Interviewee 7] which I didn't ask you I don't think was actually if you've got a LITS system or Gold? ESP. ESP and ESS? I think the Typhoon had ESS. What specialisation do you actually have within the team to analyse LITS data? I did it for C130 because I was LITS. I've got a LITS background, buts nobody in the office had it. XXX [Interviewee 7] had a little bit, but often people are surprised when they're saying, "We haven't any trending data on the Adour." And I'm saying, "Oh yes you have, that's LITS engine. So how come you're not going to LITS to milk that data?" But the LITS Team's been disbanded now hasn't it? Does that mean that everything that was on LITS is no longer on LITS? Or whether someone knows where it is to access it. Yes, and that's normally the issue. Yes, and ESS I've had nothing to do with, nor Gold ESP because I've no reason to. I've not worked on Typhoon. Will we need to, yes, if there's a crash and I'm on duty and there's a Typhoon crash tomorrow, and yes absolutely, but we would have to go to the SMEs in that area.
19. Does the type of accident affect the search of the maintenance records?	It's a bit difficult if you've not done one for over a year. Yes. In what way? Well, if you get a major catastrophic accident that involves deaths, there's a legal requirement to investigate that fully. So, you'd have to get into everything that you think might have been a factor. If you have, I went to a Grob Tutor at Wittering that the engine seized in flight, he landed the aircraft, no damage other than the fact that the engine was actually cracked on the head. And that was because the contracted technician who changed the engine didn't torque the sump plug up. It fell off in flight – oil, no oil, doesn't do well. How far do you go down looking at faults on that aircraft? Yes. Not much, don't need to. That was a human factor error by the engineer. The fact that he said I've never torqued that system since I've been fixing these aircraft didn't help either.

	But then the question for you is who else isn't torqueing them, whether it's him or whether it's a common occurrence. Is it because the manual's not clear or is it he's not got the manual out; he's not reading it? The manual is pretty clear on the torque settings. Otherwise I wouldn't have asked him. "What torque setting do you put these to?" "Never torque them." Thought it a wind up or joke that one. So, it depends and of course, you would then go look at training. You would then look at what he did on his training course. Yes, he was taught it. Yes, it's in the manual. Why wasn't he doing it? Using, as us engineers tend to do, we tend to use knowledge and experience and not bother looking at the manual. We might not like it but that's what... you're familiar with the job, you're doing it for years, that tends to be what you do. And if someone doesn't tell you the manual's been updated? All of that. Yes.
20. How often do you investigate incidents where NFF or intermittent faults are apparent, even if this is not recorded in the final report?	And this comes out of my AAIB investigation. In this job no, not at all. I'd have to come across it as an issue as I sort of did with the C130. I'd have to be looking for something, and find it while I was looking. So, I did look at ETEDS which is the monitoring system on the Herc, for monitoring all the systems. To see if there were issues there, and there were latching issues that came and went. So, I went and spoke to the Ground Engineers, the GEs, and they'd say yes that's common because this is happening and it's the system switching on, and in particular order while the system... the data bus is looking for information. It looks, doesn't find, looks, doesn't find. It reports that as a… Timing issue with data coming …? All that sort of stuff. And that's where you'd go and look for the SMEs and say okay, so what am I looking at here? You could class them as no fault founds. You could class them as well, whatever you want. Just system. I'll give you some notes.
21. Are there any regulations / procedures / process that you have read regarding NFF?	Are there regulations on no fault found? That's my question to you. I'm not aware that there are. Not an RA, not a regulation as in a regulatory procedure. I wouldn't say that there's not some procedure in a maintenance manual, but in terms of a regulation that's something different. Is there a regulation saying you can only ignore an NFF once, but twice? I would imagine that's a little too long screwdriver for regulators. I'm not aware that there is. Okay. The answer to that, sorry it's of a long-winded way of saying… No. That I don't know.

	Before I come on to that one there, do you think that an intermittent fault, and you can separate these two out if you like, or a no fault found impacts on airworthiness or air safety? I have definitions if you want to refresh, so do they, or does one or the other, impact airworthiness or air safety? All I know is, it's not definitions of no fault found that versus intermittent this is definition of airworthiness. It's interpretation whether you think it is an airworthiness, air… It has the potential, absolutely. It absolutely has the potential, not least of which, from an operator's perspective is the frustration it causes when you're in a cockpit and something doesn't work the way it should. You've reported it, it's still not working, and it starts to affect your capability and is a distraction at a critical time. So, there's no doubt in my mind that faults can be a distraction and if it's a fault that you can't find i.e. NFFd, then if it keeps recurring it will be a frustration to the crew. Therefore, a distraction, and, therefore, an airworthiness issue affecting air safety and flight safety. Could or do you think there are certain systems that you could categorize as more problematic for, you know, intermittent fault, NFF and, therefore, airworthiness? A lot of this depends how much credence the aircrew put on their avionic systems, because I would say that's where probably you get most of your NFFs. Because they're complex, they're subject to noise; they're subject to dust and all sorts, vibration and so on and so on. And as I found with the Herc., you know, and I had a pretty good idea before I went and investigated this area, that there were inaccuracies in the system that they weren't aware of. Is that aircrew or engineers? Both. You see, the thing is the engineers will look for a fault under two circumstances, the aircrew have told them about it or they find it during system testing. You don't actively go and look for faults because you're just creating work for yourself, so do you go and look for faults that you've not been reported, no you don't. Do you go looking for faults while you're trying to do a test, no it occurs while you're doing the test or functional check or you change something you're doing, functional check. You find a fault then and date it, to chase it down until you've fixed it. So, they're the two circumstances really where you'll look for faults. Either that or your visually see something wrong with the aircraft. An AF, BF type thing. Yes, or approach or whatever. Okay.

22. Are there any other points you wish to rise regarding intermittent faults of NFF that have not been mentioned so far, they may be relevant to my research?	I don't think so. I would say that one area that's probably not looked at is the frustration of aircrew, when they do get NFFs. I've made a note. That is an absolute distraction and, therefore, anything that distracts the pilot from his main task of flying the aircraft is a bad thing. So, if you spoke to aircrew ask them about stuff that keeps happening in the air. The ground crew keep NFFing. I know aircrew will pipe up after a couple of occasions and go you've no fault founded this again. It's broken, find it. Then you start stripping the aircraft down. One final question and I'll go through my notes but I'll leave this running just in case you say something else which is pertinent.
Permission	
23. Can I quote you by name / post?	Yes, nothing to hide. Lots of experience and knowledge and lots of stories, some rabbit holes, but there you go.

Appendix B - Questionnaire

B.1 - Email text for questionnaire distribution

Hello,

I am undertaking my PhD with Cranfield University to examine any links between No Fault Found and airworthiness but from an aircrew perspective. The survey is aimed at both military and civilian aircrew, whether serving or retired.

As part of this research, I am approaching as many aircrew as possible across all three service to gather data gauging the wider knowledge and understanding of No Fault Found and perceptions of its impact.

I would be very grateful if you could find the time to complete a short survey that aims to capture your views and experiences of No Fault Found and encourage your colleagues to do the same. The survey will be open until 15th November 2019.

The survey is anonymous. I will not be able to identify the source and responses are not attributable to a specific individual. No information will be available to any third parties.

Participants may withdraw at any time during the completion of the survey. Once submitted you will not be able to retract your answers.

The survey can be accessed via Take the Survey

Or copy and paste the URL below into your internet browser:

https://cranfielduniversity.eu.qualtrics.com/jfe/form/SV_3WYgZnvs8HaPjnv

Thank you for your assistance and please do make contact if you have any concerns or would like further details. You can contact me at: l.lacey@cranfield.ac.uk

Kind regards,

Laura Lacey

B.2 - Questionnaire

The questionnaire presents the category and specific airworthiness and NFF experience questions.

Airworthiness and No Fault Found
Survey Flow

Standard: SURVEY INSTRUCTION (2 Questions)
Standard: Informed Consent (1 Question)
Standard: Finding out about you (9 Questions)
Standard: Airworthiness (1 Question)
Standard: No Fault Found (NFF) (17 Questions)
Standard: Afterflight and Maintenance (5 Questions)
Standard: Training (6 Questions)
Standard: Aircraft Logbook (9 Questions)
Standard: Trust (1 Question)
Standard: Thoughts (1 Question)

Start of Block: SURVEY INSTRUCTION

Q1 Welcome to the research study.

This survey is aimed at members of aircrew.

I am conducting this research as part of my PhD with Cranfield University. I am an ex Royal Air Force Engineer with over 20 years' aviation experience. Within this period I became aware of the engineering phenomenon of No Fault Found (NFF). I am interested in understanding how aircraft engineering faults diagnosed as NFF affect aircrew and the airworthiness and safety of the aircraft and aircrew. You will be presented with information relevant to airworthiness and NFF and asked to answer some questions. Please be assured that your responses will be kept completely anonymous. The main aim of the research is to clearly prove that there is, or is not, a definitive link between NFF and airworthiness. The survey should take you around 12 minutes to complete. Your participation in this research is voluntary. You have the right to withdraw at any point during the study, for any reason, and without any prejudice. If you would like to contact the Principal Investigator for this study to discuss this research, please e-mail l.lacey@cranfield.ac.uk. By clicking the button below, you acknowledge that your participation in the study is voluntary, you are 18 years of age or over, and that you are aware that you may choose to terminate your participation in the study at

any time and for any reason. Additionally, you acknowledge that the data will be used as follows:

1. I confirm that I have been informed about the aim and objectives of this research project and agree to give my inputs.
2. I understand that all personal information that I provide will be treated with the strictest confidence and my name will not be used in any report, publication or presentation. I have been provided with a participant number to ensure that all raw data remains anonymous.
3. I understand that the information I provide will be used by Cranfield University for the purpose of research only. The data will be stored on the University's network that can only be accessed by authorized users, in line with UK Data Protection Act 2018.
4. I understand that anonymised results of the research may be published.

Please note that this survey will be best displayed on a laptop or desktop computer. Some features may be less compatible for use on a mobile device.

Q2 Are you a member of aircrew?

- O Yes (1)
- O No (2)

Skip To: End of Survey If Q2 = 2

End of Block: SURVEY INSTRUCTION

Start of Block: Informed Consent

Q3 Consent

- O I consent. Begin the survey. (1)
- O I do not consent. I do not wish to participate. (2)

Skip To: End of Block If Q3 = 1
Skip To: End of Survey If Q3 = 2

End of Block: Informed Consent

Start of Block: Finding out about you

Q4 Are you a serving or retired member of aircrew?

- O Serving (1)
- O Retired (2)

Q5 What is your gender?

- o Male (1)
- o Female (2)
- o Other (3)
- o Prefer to not say (4)

Q6 What is your age in years and months?
Years

▼ 18 (1) ... 80 (63)

Q7 Months

▼ 0 (1) ... 11 (12)

Q8 Are you, or were you military or civilian aircrew?

- o Military (1)
- o Civilian (2)
- o Both (3)

Display This Question:
If Q8 = 1
Or Q8 = 3

Q9 What is / was your military rank / status?

	OR4-9 (e.g. Corporal) (1)	OF-1 (e.g. Flying Officer) (2)	OF-2 (e.g. Lieutenant RN) (3)	OF-3 (e.g. Squadron Leader) (4)	OF-4 (e.g. Lieutenant Colonel) (5)	OF-5 (e.g. Group Captain) (6)	OF-6 and above (7)	Prefer not to say (8)
Army (1)	o	o	o	o	o	o	o	o
Royal Air Force (2)	o	o	o	o	o	o	o	o
Royal Navy (3)	o	o	o	o	o	o	o	o

Display This Question:

If Q8 = 2

Or Q8 = 3

Q10 What is / was your civilian rank / status?

	First Officer (1)	Senior First Officer (2)	Captain (3)	Senior Captain (4)	Other (5)	Prefer not to say (6)
Civilian Aircrew (1)	o	o	o	o	o	o

Q11 How many years have you been a member of aircrew?

▼0 (64) ... 70 (53)

Q12 Months

▼0 (1) ... 11 (12)

End of Block: Finding out about you

Start of Block: Airworthiness

Q13 For the purposes of this survey the following definition of airworthiness will be used.
“Airworthiness is the ability of an aircraft or other airborne equipment or system to be operated in flight and on the ground without significant hazard to aircrew, ground crew, passengers or to third parties; it is a **technical attribute** of materiel throughout its lifecycle; the activities (e.g. design, operate, maintain) to achieve airworthiness are to be to be undertaken by competent and authorized individuals, according to approved procedures and instructions."
In any of your training has a definition of airworthiness been explained to you?

- o Yes (1)
- o Maybe (2)
- o No (3)
- o Do not know (4)

End of Block: Airworthiness

Start of Block: No Fault Found (NFF)

Q14 Do you understand the term No Fault Found (NFF)?

- o Yes (1)
- o No (2)

Skip To: Q16 If Q14 = 2

Q15 Briefly explain what the term No Fault Found means to you.

_____

Page Break

Q16 Have you received any training on the phenomenon of No Fault Found?

- O Yes (1)
- O No (2)
- O Not sure (3)

Page Break

Q17 For the purposes of this survey No Fault Found (NFF) is defined as:

“the output of a diagnostic process where the root cause of the reported fault cannot be verified" (Khan et al., 2016).
Some faults are intermittent and an intermittent fault is defined as: A fault which starts and stops irregularly over the period of a flight or across flights that may not be sequential.
Have you ever experienced a fault that the engineers have fixed and it has reappeared?

- O Yes (1)
- O No (2)
- O Not sure (3)

Skip To: End of Block If Q17 = 3

Q18 What was the system or systems?

- O AFCS (1)
- O Armament (2)
- O Avionics (3)
- O Communication (4)
- O Fuel System (5)
- O Propulsion (6)
- O Structure (7)
- O Other (Please state) (8)

_____

Q19 Briefly describe the fault or faults that reappeared.

_____

Page Break

Q20 Did the engineers record the original fault or the subsequent reappearance of the fault as No Fault Found (NFF)?

	Select answer		
	Yes (1)	No (2)	Not Sure (3)
Original fault after initial flight (1)	o	o	o
Reappearance of the fault on subsequent flight. (2)	o	o	o

Q21 State three words or three phrases to express what you thought when you read the fault had been recorded as NFF.

_____

Page Break

Q22 For a fault you reported that the engineers have fixed and it has reappeared were you concerned about this?

- o Yes (1)
- o No (2)
- o Not sure (3)

Q23 Please explain why you were or were not concerned about the reappearance of the fault.

_____

Page Break

Q24 This question relates to the reappearance of the fault on the **same** aircraft.

Did the fault or the reappearance of the fault (intermittent or otherwise) curtail the flight?

	Yes (1)	No (2)	Not sure (3)
Original fault on the Initial Flight (1)	o	o	o
Reappearance of the fault on subsequent Flight(s) (2)	o	o	o

Q25 Did the reappearance of the fault (intermittent or otherwise) affect the handling of the aircraft?

- o Definitely yes (1)
- o Probably yes (2)
- o Might or might not (3)
- o Probably not (4)
- o Definitely not (5)

Page Break

Q26 For the purposes of this question the following definition of **airworthiness** will be used.
“Airworthiness is the ability of an aircraft or other airborne equipment or system to be operated in flight and on the ground without significant hazard to aircrew, ground crew, passengers or to third parties; it is a **technical attribute** of materiel throughout its lifecycle; the activities (e.g. design, operate, maintain) to achieve airworthiness are to be to be undertaken by competent and authorized individuals, according to approved procedures and instructions."

Did the reappearance of the fault (intermittent or otherwise) affect the **airworthiness**?

- o Definitely yes (1)
- o Probably yes (2)
- o Might or might not (3)
- o Probably not (4)
- o Definitely not (5)

Q27 For the purpose of this question the following definition of **air safety** will be used.
Air safety is the state of freedom from unacceptable risk of injury to persons, or damage, throughout the life cycle of an Air Systems."

Did the reappearance of the fault (intermittent or otherwise) affect the **air safety** of the aircraft?

- ○ Definitely yes (1)
- ○ Probably yes (2)
- ○ Might or might not (3)
- ○ Probably not (4)
- ○ Definitely not (5)

Page Break

Q28 Have you ever reported an ongoing reoccurring fault (intermittent or otherwise) that the engineers state they have fixed to any of the following? Select those applicable.

- ○ No (1)
- ○ Engineering Management (2)
- ○ Flight Safety Officer (3)
- ○ Operations Management (4)
- ○ Squadron Flight Commander (Duty Exec) (5)
- ○ Other - please state (6)

_____

Skip To: End of Block If Q28 = 1

Q29 Briefly explain why you reported an ongoing reoccurring fault.

_____

Q30 Briefly explain the outcome following your reporting of the ongoing reoccurring fault?
If no outcome please write No.

_____

End of Block: No Fault Found (NFF)

Start of Block: Afterflight and Maintenance

Q31 Do you ever pressurize the engineers to complete the maintenance to enable you to fly?

- ○ Definitely yes (1)
- ○ Probably yes (2)
- ○ Might or might not (3)
- ○ Probably not (4)
- ○ Definitely not (5)

Q32 Do you allocate sufficient time for the post-sortie engineering debrief? The technical aspect of the flight and any faults you experienced.

- ○ Definitely yes (1)
- ○ Probably yes (2)
- ○ Might or might not (3)
- ○ Probably not (4)
- ○ Definitely not (5)

Display This Question:

If Q32 = 4

And Q32 = 5

And Q32 = 3

Q33 If not please state why.

_____

Q34 On **average** how many minutes do you spend giving the post-sortie debrief to the engineers? The technical aspect of the flight and any faults you experienced.

_____

Q35 Does the aircraft you *normally* fly have an electronic logbook?

- ○ Yes (1)
- ○ No (2)

End of Block: Afterflight and Maintenance

Start of Block: Training

Q36 Have you received any training explaining how to provide a post-sortie engineering brief? This is regarding the technical aspect of the flight and any faults you experienced.

- ○ Yes (4)
- ○ No (6)
- ○ Not sure (5)

Skip To: Q41 If Q36 = 6

Display This Question:

If Q36 = 4

And Q36 = 5

Q37 Approximately how many years into your aircrew career did you receive this training?

E.g if two and a half years write 2.5)

_____

Display This Question:

If Q36 = 4

And Q36 = 5

Q38 Who provided this training?

_____

Display This Question:

If Q36 = 4

And Q36 = 5

Q39 Briefly explain when within your career you received this training.
E.g during aircraft conversion training

_____

Display This Question:

If Q36 = 4

Q40 How useful was this training?

- ○ Extremely useful (1)
- ○ Moderately useful (2)
- ○ Slightly useful (3)
- ○ Neither useful nor useless (4)
- ○ Slightly useless (5)

Q41 Do you feel you would benefit from training (or further training) on how to conduct a post-flight sortie engineering brief? This is regarding the technical aspect of the debrief.

- ○ Definitely yes (1)
- ○ Probably yes (2)
- ○ Might or might not (3)
- ○ Probably not (4)
- ○ Definitely not (5)

End of Block: Training

Start of Block: Aircraft Logbook

Q42 Do you read / review the aircraft technical logbook to understand how the engineers cleared a fault? (Prior to a flight)

- ○ Always (1)
- ○ Most of the time (2)
- ○ About half the time (3)
- ○ Sometimes (4)
- ○ Never (5)

Skip To: Q43 If Q42 = 5

Display This Question:

If Q42 = 5

Q43 Briefly explain why you do not read the aircraft logbook.

_____

Skip To: End of Block If Condition: Briefly explain why you do ... Is Not Empty. Skip To: End of Block.

Display This Question:

If Q42 = 1

And Q42 = 2

And Q42 = 3

And Q42 = 4

Q44 How far back do you read?

- ○ Last flight (1)
- ○ Last day (2)
- ○ 7 days (3)
- ○ All that is available (4)
- ○ Other (5) _____

Q45 Do you understand the engineers' terminology for how a fault has been rectified / cleared?

- ○ Always (1)
- ○ Most of the time (2)
- ○ About half the time (3)
- ○ Sometimes (4)
- ○ Never (5)

Q46 Do you think it matters if you do not understand the engineers' terminology?

- ○ Yes (1)
- ○ No (2)
- ○ Not sure (3)

Q47 Please explain your answer. Why you do or do not think it matters if you understand the engineers' terminology?

_____

_

Q48 Usually, do you seek clarification from the engineers on what they mean?

- ○ Always (1)
- ○ Most of the time (2)
- ○ About half the time (3)
- ○ Sometimes (4)
- ○ Never (5)

Q49 Do you think it is necessary to know if the aircraft has or has had a No Fault Found?

- ○ Yes (1)
- ○ No (2)
- ○ Not sure (3)

Q50 Please explain your answer.

_____

End of Block: Aircraft Logbook

Start of Block: Trust

Q51 What level of trust do you have in the engineers to investigate faults you report?

- ○ A great deal (1)
- ○ A lot (2)
- ○ A moderate amount (3)
- ○ A little (4)
- ○ None at all (5)

End of Block: Trust

Start of Block: Thoughts

Q52 If you would like to share any other experiences or thoughts regarding No Fault Found and airworthiness please write them here.

_____

End of Block: Thoughts

B.3 - Origin of survey questions

Question No	Source	Comment / Theme
1	CURES Team (2017)	Ethics criteria
2	New	Eligibility check
3	CURES Team (2017)	Consent
4	Align with interviews	Categorization check
5	Align with interviews	Categorization – gender
6	New	
7	Align with interviews	Categorization
8	Align with interviews	Categorization
9	New	
10	New	
11	Align with interviews	Categorization – Q11
12	Haddon- Cave (2009, p.473) Align with interviews	Categorization – Q11
13	New	
14	Interviews	Q5 - Definition of airworthiness
15	Hockley, Lacey and Pelham (2016) Interviews	Q6 – Definition of NFF
16	Hockley, Lacey and Pelham (2016) Interviews	Q11a Training
17	Interviews	Q6, 7 8 Airworthiness and air safety
18	Hockley, Lacey and Pelham (2016) Interviews	Q7b Q24 - Airworthiness and air safety
19	Interviews	Q8 - Airworthiness and air safety
20	New	
21	New	
22	Interviews	Trust/Time available
23	New	
24	Interviews and New	Q8 – Impact on flight programme
25	AAIB (2012b)	

26	Interviews	Q22 - Airworthiness and air safety
27	AAIB (2012b) Interviews - New	Q27 - Airworthiness and air safety
28	Interviews – New	Q9, Q14 – Continuity and management
29	Interviews	Q5, Q9, Q12a - Continuity and management
30	New	
31	Hockley, Lacey and Pelham (2016)	Q8, Q9c,Q10
32	Hockley, Lacey and Pelham (2016) Interviews	Q1a, Q1b, Q1c, Q1d Q18 – Time available
33	Hockley, Lacey and Pelham (2016) - Interview	Q1a, Q1b, Q1c, Q1d Time available
34	Hockley, Lacey and Pelham (2016) - Interviews	Q1a, Q1b, Q1c, Q1d Q18 – Time available
35	Interviews	Documentation
36	Hockley, Lacey and Pelham (2016) Interviews	Q1a, Q1b, Q1c, Q1d Q12 - Training
37	New	
38	New	
39	New	
40	New	
41	New	
42	Hockley, Lacey and Pelham (2016) Interview	Q1c, Q1d Q10 – Fault understanding
43	New	
44	Interview	Q10 - Fault understanding
45	ARINC (2008, p.16) Interview	A-2.1 Time available
46	Interview	Time available
47	Interview	Documentation
48	New	
49	New	
50	New	
51	Hockley, Lacey and Pelham (2016) Interviews	Q1c, Q1d Trust theme
52	New – any additional information	

B.4 - Questionnaire Results

Table B-1: Split of question types within the survey

Question type	Interval (scale)	Nominal (category)	Ordinal (ranked)	Qualitative
Question Number	6	4	25	15
	7	5	26	19
	11	8	27	21
	12	9	31	23
	34	10	32	29
		13	40	30
		14	41	33
		16	42	37
		17	45	38
		18	48	39
		20	51	43
		22		47
		24		50
		28		52
		35		
		36		
		44		
		46		
		49		
TOTAL	5	19	11	14

- Q4. Are you a serving or retired member of aircrew?

	Frequency	Percent
Serving	42	93.3
Retired	3	6.7
Total	45	100.0

- Q5. What is your gender?

	Frequency	Percent
Male	43	95.6
Female	2	4.4
Total	45	100.0

- Q6 and Q7. What is your age?

Statistics		Age (months)	Age (years and months)
N	Valid	45	
	Missing	0	
Mean		505.80	42 years 0.01 months
Std. Error of Mean		17.66	
Median		506.00	42 years 0.2 months
Mode		565	47 years 1 month
Std. Deviation		118.48	
Variance		14039.62	
Range		565	47 years 1 month
Interquartile range		161	13 years 5 months
Minimum		248	20 years 8 months
Maximum		813	67 years 9 months

- Q8. Are you, or were you military or civilian aircrew?

	Frequency	Percent
Military	37	82.2
Civilian	5	11.1
Both	3	6.7
Total	45	100.0

- Q9. What is / was your military rank / status?

	Army		RAF		Royal Navy			
	Frequency	Percent	Frequency	Percent	Frequency	Percent	Total Frequency	Valid Percent (out of 32)
OR4-9 (e.g. Corporal)			2	6.3			2	6.3
OF-1 (e.g. Flying Officer)			1	3.1			1	3.1
OF-2 (e.g. Lieutenant RN)			9	28.1	1	3.1	10	31.3
OF-3 (e.g. Squadron Leader)	1	3.1	8	25.0			9	28.1
OF-4 (e.g. Lieutenant Colonel)	2	6.3	6	18.8			8	25.0
OF-5 (e.g. Group Captain)			1	3.1			1	3.1
Prefer not to say			1	3.1			1	3.1
Total	3	9.4	28	87.5	1	3.1	32	100

- Q10 What is / was your civilian rank / status? – Civilian aircrew

	Frequency	Percent
Senior First Officer	2	25.0
Captain	2	25.0
Senior Captain	3	37.5
Other	1	12.5
Total	8	100.0

- Q11 and Q12. How many years have you been a member of aircrew?

	Months	Years	Years and months
Minimum	11	0.9	11 months
Maximum	493	41.1	41 years 1 month
Range	482	40.2	40 years 2 months
Interquartile range	0	10	10 years
Mode	216	18	18
Median	252.5	21.0	21 years 1/2 months
Mean	286.2	23.8	23 years 10.15 months
Standard deviation	88.6		

- Q13. In any of your training has a definition of airworthiness been explained to you?

	Frequency	Percent
Yes	20	45.5
Maybe	7	15.9
No	15	34.1
Do not know	2	4.5
Total	44	100.0

- Q14. Do you understand the term No Fault Found (NFF)?

	Frequency	Percent
Yes	44	97.8
No	1	2.2
Total	45	100.0

- Q15. Briefly explain what the term No Fault found means to you?

Description / Theme	Number
Unable to replicate the fault	33
No rectification / remedial action	7

No cause for fault determined	6
Can't find fault	6
Engineers determine it is serviceable	4
Engineers found nothing significant	1
No indication fault has or will occur again.	1
Within design tolerance	1
Implies fault will remain	1
Specifically, unable to replicate the parameters that led to the fault.	1
Noted fault would be airborne faults would not appear on the ground not	1
TOTAL	62

- Q16. Have you received any training on the phenomenon of No fault Found?

	Frequency	Percent
Yes	1	2
No	43	96
Not sure	1	2
Total	45	100

- Q17. Have you ever experienced a fault that the engineers have fixed and has it reappeared? For the purposes of this survey No Fault Found (NFF) is defined as:

“the output of a diagnostic process where the root cause of the reported fault cannot be verified" (Khan et al., 2016).

Some faults are intermittent and an intermittent fault is defined as: A fault which starts and stops irregularly over the period of a flight or across flights that may not be sequential.

	Frequency	Percent
Yes	43	95.6
No	2	4.4
Total	45	100.0

- Q18. What was the system or systems? (for a fault that the engineers have fixed and the fault reappeared?)

System	Number
AFCS	21
Armament	6
Avionics	29
Communication	24
Fuel System	14
Propulsion	18
Structure	6
Other	10
Other TEXT	
• Hydraulics	2
• Lighting and pressurisation systems	1
• Control notching, radios/avionics	3
• Rear mission system	1
• Braking system	1
• Seat	1
• Multiple but will concentrate on a current issue	1
TOTAL	138

The other text was then further analysed and where possible put into one of the main categories or the description was aligned to another aircraft system, e.g., Hydraulic to hydraulic power. The results are shown in the table below in order of frequency.

System	Revised number
Avionics	33
Communication	25
AFCS	22
Propulsion	18
Fuel System	14
Armament	6
Structure	6
Other	
Hydraulic power	2
Lighting	1
Landing gear	1

Air conditioning	1
Equipment and Furnishings	1
Other TEXT	
• Multiple but will concentrate on a current issue	1
TOTAL	138

- Q19. Briefly describe the fault or faults that reappeared.

The aircrew description of a fault was reviewed with an aircraft engineer.

Alphabetical order.

Examples provided	Number
AFCS	12
Air conditioning	1
Air Radar	1
Avionics	19
Communication	14
Control surface	2
Electrical power	1
Electronic Warfare	3
Engine	4
Engine Control	2
Engine Fuel and Control	4
Fire protection	1
Flight controls	2
Fuel	1
Hydraulic power	1
Instruments	10
Landing gear	1
Lights	1
Maintenance Error	1
Navigation	2
Structure	1
Survival equipment	1
Warnings and Cautions	1
Weapons	3

Faults that cannot be reproduced on the ground	1
Too numerous to list	12
TOTAL	102

Frequency order

Examples provided	Number
Avionics	19
Communication	14
AFCS	12
Instruments	10
Engine	4
Engine Fuel and Control	4
Electronic Warfare	3
Weapons	3
Control surface	2
Engine Control	2
Flight controls	2
Navigation	2
Air conditioning	1
Air Radar	1
Electrical power	1
Fire protection	1
Fuel	1
Hydraulic power	1
Landing gear	1
Lights	1
Maintenance Error	1
Structure	1
Survival equipment	1
Warnings and Cautions	1
Faults that cannot be reproduced on the ground	1
Too numerous to list	12
TOTAL	102

- Q20. Did the engineers record the original fault or the subsequent reappearance of the fault as No Fault Found (NFF)?

Original fault after initial flight		
	Frequency	Percent
Yes	31	72.1
No	3	7.0
Not Sure	9	20.9
Total	43	100.0

Reappearance of the fault on subsequent flight		
	Frequency	Percent
Yes	19	45.2
No	5	11.9
Not Sure	18	42.9
Total	42	100.0

- Q21. State three words or three phrases to express what you thought when you read the fault had been recorded as NFF.

Theme	Number
Expected outcome / acceptance	15
Don't trust the engineers	14
Frustrated	11
Not taking it seriously	9
Expletive (about not being fixed)	7
Confused	5
Engineering (System unreliable)	4
Trust (don't trust aircrew)	5
Annoyed	4
Engineers' arrogance / poor attitude	4
Will reappear	4
Engineers' best / manuals	2
TOTAL	84

- Q22. For a fault you reported that the engineers have fixed and it has reappeared were you concerned about this?

	Frequency	Percent
Yes	29	69.0
No	12	28.6
Not sure	1	2.4
Total	42	100.0

- Q23 For a fault you reported that the engineers have fixed and it has reappeared were you concerned about this? Please explain why you were or were not concerned about the reappearance of the fault.

	Q22 response			
Theme	Yes	No	Not sure	Total
Availability of resources	1			1
Aircrew judgement		2		2
Competence of engineers	2			2
Don't trust aircrew	1			1
Doubt	1			1
Engineering decision	2	6	1	9
Engineers' poor attitude	1			1
Flight safety issue	5			5
Impact on aircraft performance	1			1
Incomplete manuals	5			5
Insufficient engineering diagnostics	10			**10**
Trust in Engineers	1			1
Lack of Trust in Engineers	5			5
Not Flight safety issue	2	1		3
Poor engineering competence	2			2
Reduce apathy	1			1
Require more remedial action		1		1
Waste of aircrew time	2			2
Not first time		1		1
TOTAL	44	11	1	56

Table B-2: Reason why aircrew were or were not concerned about the reappearance for the fault

	Q22 response					
Theme	Yes	No	Not sure	Total	Related to Engineers (negative)	Related to Resources
Insufficient engineering diagnostics	10			**10**	10	
Engineering decision	2	6	1	9	9	
Lack of Trust in Engineers	5			5	5	
Incomplete manuals	5			5		5
Flight safety issue	5			5		
Not Flight safety issue	2	1		3		
Competence of engineers	2			2	2	
Engineering decision -	2			2	2	
Poor engineering competence	2			2	2	
Waste of aircrew time	2			2		
Aircrew judgement		2		2		
Availability of resources	1			1		1
Don't trust aircrew	1			1		
Doubt	1			1		
Engineers' poor attitude	1			1	1	
Impact on aircraft performance	1			1		
Trust in Engineers	1			1		
Reduce apathy	1			1		
Require more remedial action		1		1		
Not first time		1		1		
TOTAL	42	11	1	54	29	6

- Q24. This question relates to the reappearance of the fault on the **same** aircraft. Did the fault or the reappearance of the fault (intermittent or otherwise) curtail the flight?

Original fault on the Initial Flight		
	Frequency	Percent
Yes	27	67.5

No	11	27.5
Not sure	2	5.0
Total	40	100.0

Reappearance of the fault on subsequent Flight(s)		
	Frequency	Percent
Yes	28	68.3
No	8	19.5
Not sure	5	12.2
Total	41	100.0

- Q25 Did the reappearance of the fault (intermittent or otherwise) affect the handling of the aircraft?

	Frequency	Percent
Definitely yes	13	31.7
Probably yes	5	12.2
Might or might not	11	26.8
Probably not	4	9.8
Definitely not	8	19.5
Total	41	100.0

- Q26. Did the reappearance of the fault (intermittent or otherwise) affect the airworthiness?

	Frequency	Percent
Definitely yes	12	29.3
Probably yes	11	26.8
Might or might not	11	26.8
Probably not	5	12.2
Definitely not	2	4.9
Total	41	100.0

Confidence Interval using median values

Proportion answering ‘probably or definitely not’ = 7/41 = Point Estimate
For 95% confidence interval

$$PointEstimate \pm 1.96\sqrt{\frac{(7/41)(34/41)}{41}}$$

$$0.17 \pm 0.12$$

A fairly small proportion of respondents thought that airworthiness was not affected by the reappearance of the fault.

- Q27. Did the reappearance of the fault (intermittent or otherwise) affect the air safety of the aircraft?

	Frequency	Percent
Definitely yes	13	31.7
Probably yes	9	22.0
Might or might not	9	22.0
Probably not	7	17.1
Definitely not	3	7.3
Total	41	100.0

Proportion answering 'probably or definitely not' = 10/41 = Point Estimate
For 95% confidence interval

$$PointEstimate \pm 1.96\sqrt{\frac{(10/41)(31/41)}{41}}$$

$$0.24 \pm 0.13$$

A fairly small proportion of respondents thought that air safety of the aircraft was not affected by the reappearance of the fault.

- Q28. Have you ever reported an ongoing reoccurring fault (intermittent or otherwise) that the engineers state they have fixed to any of the following? Select those applicable.

Selection	Frequency	Percent
No	11	16.9
Engineering Management	16	24.6
Flight Safety Officer	13	20
Operations Management	5	7.7
Squadron Flight Commander (Duty Exec)	15	23.1

Other DASOR Operations Duty Authorizer Aircraft owners Following crew	5	7.7
TOTAL	65	100

- Q29. Briefly explain why you reported an ongoing reoccurring fault.

Description	Number
Raise awareness / escalate	**18**
Flight safety (DASOR)	9
Statistics	3
Risks acknowledgement (manage risk)	1
Disparity between aircrew and engineering (manuals / FRCs)	1
Reduction in output	1
Engineering term (NFF) used not acceptable	1
TOTAL	34

- Q30. Briefly explain the outcome following your reporting of the ongoing reoccurring fault? If no outcome please write No.

Theme	Number	
No outcome	5	
No in terms of extra fault diagnosis.	1	
No - due to perceived EA Arrogance	1	7
Further engineering investigation	9	
Further engineering investigation - following higher aircrew assessment	2	
Further engineering investigation - Successful rectification	1	
Further engineering investigation - with Failed Engineering Solution?	1	11
Raised awareness	2	
Build evidence to fund solution	1	
Failed Engineering Solution	1	
Fault fixed	1	
Handling advice given to aircrew	1	
Noted	1	
Positive advice from hierarchy	1	

Risk managed	1	
Statistics	1	
Unsure	1	
TOTAL	31	

Response in numbedr order.

Description	Number
Further engineering investigation	9
No outcome	5
Further engineering investigation - following higher aircrew assessment	2
Raised awareness	2
No in terms of extra fault diagnosis.	1
No - due to perceived EA Arrogance	1
Unsure	1
Fault fixed	1
Risk managed	1
Handling advice given to aircrew	1
Build evidence to fund solution	1
Further engineering investigation - Successful rectification	1
Further engineering investigation - with Failed Engineering Solution?	1
Failed Engineering Solution	1
Noted	1
Statistics	1
Positive advice from hierarchy	1
TOTAL	31

- Q31. Do you ever pressurize the engineers to complete the maintenance to enable you to fly?

	Frequency	Percent
Definitely yes	4	10.0
Probably yes	8	20.0
Might or might not	4	10.0
Probably not	8	20.0
Definitely not	16	40.0
Total	40	100.0

- Q32. Do you allocate sufficient time for the post-sortie engineering debrief? The technical aspect of the flight and any faults you experienced.

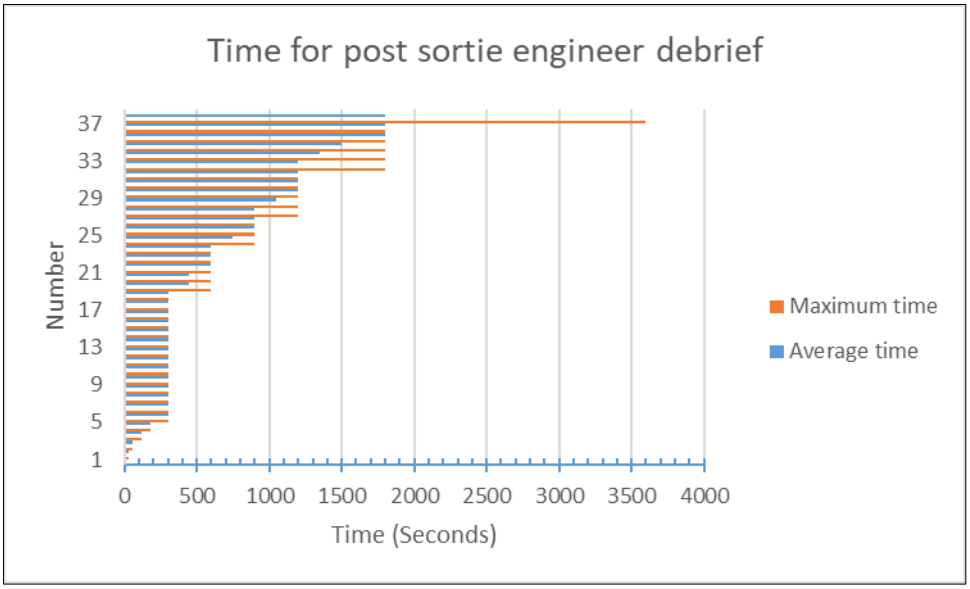
	Frequency	Percent
Definitely yes	25	62.5
Probably yes	9	22.5
Might or might not	3	7.5
Probably not	3	7.5
Total	40	100.0

- Q33. Do you allocate sufficient time for the PSED? The technical aspect of the flight and any faults you experienced. If not please state why.

This question should have been answered by respondents who selected ‘Might or might not’, ‘Probably not’ and ‘Definitely not’ in Q32 but was not answered by any respondents. The logic used within Qualtrics® does not indicate there was a problem with this question. (See 0)

- Q34. On **average** how many minutes do you spend giving the post-sortie debrief to the engineers? The technical aspect of the flight and any faults you experienced.

	Average (s)	Maximum (s)
Minimum	0	30
Maximum	1800	3600
Range	1800	3570
Q1 -	300	300
Interquartile range	787.5	900
Q3	1087.5	1200
Mode	300	300
Median	375	600
Mean	653.68	780.81
Standard Deviation	525.21	733.02



- Q35. Does the aircraft you *normally* fly have an electronic logbook?

	Frequency	Percent
Yes	9	22.5
No	31	77.5
Total	40	100.0

- Q36. Have you received any training explaining how to provide a post-sortie engineering brief? This is regarding the technical aspect of the flight and any faults you experienced.

	Frequency	Percent
Yes	13	32.5
No	24	60.0
Not sure	3	7.5
Total	40	100.0

- Q37, Q38 and Q39 should have been presented to respondents who selected Yes of Not sure to Q36. No responses were recorded. The logic used within Qualtrics® does not indicate there was a problem with this question. (See 0)

- Q40. How useful was this training? The PSED.

	Frequency	Percent
Extremely useful	3	23.1

Moderately useful	5	38.5
Slightly useful	3	23.1
Neither useful nor useless	2	15.4
Total	13	100.0

- Q41. Do you feel you would benefit from training (or further training) on how to conduct a post-flight sortie engineering brief? This is regarding the technical aspect of the debrief.

	Frequency	Percent
Definitely yes	8	20.0
Probably yes	15	37.5
Might or might not	6	15.0
Probably not	9	22.5
Definitely not	2	5.0
Total	40	100.0

- Q42. Do you read / review the aircraft technical logbook to understand how the engineers cleared a fault? (Prior to a flight)

	Frequency	Percent
Always	27	67.5
Most of the time	9	22.5
About half the time	1	2.5
Sometimes	2	5.0
Never	1	2.5
Total	40	100.0

- Q43. Briefly explain why you do not read the aircraft logbook.

This question was only open to the one respondent who answered Never to Q 42. She stated “Read... what's read...”, which did not make sense to the question posed.

- Q44. How far back do you read?

Due to an error in the set-up of Qualtrics this question was not answered. This question should have been presented to those respondents who selected Always, Most of the time, About half the time and Sometimes for Q42.

- Q45. Do you understand the engineers' terminology for how a fault has been rectified / cleared?

	Frequency	Percent
Always	5	12.8
Most of the time	26	66.7
About half the time	3	7.7
Sometimes	5	12.8
Total	39	100.0

- Q46. Do you think it matters if you do not understand the engineers' terminology?

	Frequency	Percent
Yes	33	84.6
No	3	7.7
Not sure	3	7.7
Total	39	100.0

- Q47. Please explain your answer. Why you do or do not think it matters if you understand the engineers' terminology?

	Question 46			
Theme	Yes	No	Not sure	Total
Assessment of engineering undertaken	11			11
Aid Communication (including good communication)	9		1	10
To assist further debriefs (of same fault)	7			7
Personal understanding	5			5
Personal understanding / responsibility	5			5
Risk assessment	4			4
Ask engineers for clarity	3	1		4
Assurance	2	1		3
Understanding	2		1	3
Does not matter		2	1	3
Adequate risk assessment?	1			1
Enhance knowledge	1			1
Sortie success	1			1
Rarely have engineer to ask	1			1

No typed explanation	1		1	2
TOTAL	53	4	4	61

- Q48. Usually, do you seek clarification from the engineers on what they mean?

	Frequency	Percent
Always	15	38.5
Most of the time	13	33.3
About half the time	2	5.1
Sometimes	8	20.5
Never	1	2.6
Total	39	100.0

- Q49. Do you think it is necessary to know if the aircraft has or has had a No Fault Found?

	Frequency	Percent
Yes	37	94.9
No	1	2.6
Not sure	1	2.6
Total	39	100.0

- Q50. Do you think it is necessary to know if the aircraft has or has not had a No Fault Found? Please explain your answer.

	Question 49			
Theme	Yes	No	Not sure	Total
For further occurrences	22			22
Manage / mitigate - (Modify sortie profile)	10			10
Awareness of fault history	8			8
Provide further information to aid diagnosis (following next occurrence)	7			7
Preparedness	3			3
Flight safety	2	1		3
Assess engineering diagnostics	2			2
Risk assessment	1		1	2
Assurance	1			1
Mission effectiveness	1			1
Otherwise it reduces likelihood of any more in-depth diagnosis	1			1

So not surprised with reoccurrence	1			1
Statistics / trending	1			1
Did not provide typed response	5			5
TOTAL	65	1	1	67

- Q51. What level of trust do you have in the engineers to investigate faults you report?

	Frequency	Percent
A great deal	15	37.5
A lot	19	47.5
A moderate amount	4	10.0
A little	2	5.0
Total	40	100.0

- Q52. If you would like to share any other experiences or thoughts regarding No Fault Found and airworthiness, please write them here.

Description	Number
Engineer issue	14
Aircrew issues	4
More fault history required if NFF recorded	4
Resources	3
Impact operations	3
Process	2
Flight safety	1
Team work	1
Humour	1
TOTAL	33

Description	Number		Total
Engineers' lack of knowledge / understanding - diagnostics skills	2		2
Engineers have insufficient time and or resources to complete full diagnostics e.g. operational pressures	2		2
Engineers appear to be under more pressure than aircrew.	1		1
Engineers unable to consider 2nd or 3rd order effects	1		1
Engineers' reluctance to do more	1		1

Improve engineer's understanding of the relationship between systems and how a failure in an unrelated component may affect a system.	1		1
Change engineers' training - go to OEM. Improve knowledge of systems Improve diagnostic skills	1		1
Decline in engineers' morale	1		1
Engineers are pressurized to meet flying commitment	1		1
Poor engineering culture and work pressure causes NFF too often	1		1
Engineers' lack of knowledge / understanding - diagnostics skills/ inexperience (organization)	1		1
Engineers' issues - poor watch handovers - unwillingness (or genuine inability) by engineers to call and interrogate further with the crew are, I suspect, contributory	1		1
Full diagnostics to be recorded to aid future occurrences (aid aircrew assurance)	2		2
NFF doesn't give enough information. Needs more detail and history if recorded.	1		1
Awareness/reassurance for proper risk assessment?	1		1
Impacted operational employability of platform	1		1
Perception mission will be curtailed	1		1
Would impact of flight programme - due to lack of resources	1	1	2
Engineering manuals insufficient	1		1
Inability to replicate many faults on the ground	1		1
Aircrew will accept responsibility for aircraft / flight delay to get more information	1		1
Aircrew wanted clarity of fault?	1		1
Better aircrew fault reporting training required - Poor descriptions by aircrew	1		1
Education needed aircrew and engineers. - Better appreciation of NFF causes - Poor descriptions by aircrew	1		1
Trigger process required after 2 NFF	1		1
Lack of data identified and Copernicus suggested to trawl through data as they did with Chinook AFCS	1		1
NFF can have either minor and major implications on airworthiness or safety	1		1
Created team ethos which improved dealing with faults and NFF	1		1
Humour	1		1

TOTAL	32	1	33

B.4.1 Cross question - Chi-squared test for independence

Test relationship between two nominal (categorical) variables.

- Q8-Q10

Q8-Q10**Crosstab**							
			For the purposes of this survey the following definition of airworthiness will be used.				Total
			Yes	Maybe	No	Do not know	
What is / was your military rank / status? – Combined services	OR4-9 (e.g. Corporal)	Count	0	0	2	0	2
		Residual	-.8	-.3	1.2	-.1	
	OF-2 (e.g. Lieutenant RN)	Count	3	4	3	0	10
		Residual	-1.2	2.7	-.9	-.6	
	OF-3 (e.g. Squadron Leader)	Count	4	0	4	1	9
		Residual	.2	-1.2	.5	.4	
	OF-4 (e.g. Lieutenant Colonel)	Count	6	0	2	0	8
		Residual	2.6	-1.0	-1.1	-.5	
	OF-5 (e.g. Group Captain)	Count	0	0	1	0	1
		Residual	-.4	-.1	.6	-.1	
	Prefer not to say	Count	0	0	0	1	1
		Residual	-.4	-.1	-.4	.9	
Total		Count	13	4	12	2	31

Chi-Square Tests			
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	31.698[a]	15	.007
Likelihood Ratio	24.573	15	.056
Linear-by-Linear Association	.001	1	.980
N of Valid Cases	31		
a. 24 cells (100.0%) have expected count less than 5. The minimum expected count is .06.			

Symmetric Measures		
	Value	Approximate Significance

Nominal by Nominal	Phi	1.011	.007
	Cramer's V	.584	.007
N of Valid Cases		31	

B.4.2 Cross-question pivot tables

Table B-3 shows the questions that were cross analysed.

Table B-3: Questions combined for pivot-table analysis

Combined Questions		
Q9 – Q13	Q10 – Q13	Q16 – Q49
Q9 – Q14	Q10 – Q14	Q21 – Q51
Q9 – Q22	Q10 – Q22	Q22 – Q49
Q9 – Q28	Q10 – Q28	Q25 – Q26
Q9 – Q36	Q10 – Q36	Q25 – Q27
Q9 – Q46	Q10 – Q46	Q36 – Q40
Q9 – Q49	Q10 – Q49	Q45 – Q49
Q9 / Q10 – Q32	Q14 – Q16	Q48 – Q49
	Q14 – Q49	

- Q8-Q10

	What is / was your civilian rank / status?					
Are you, or were you military or civilian aircrew?	**Senior First Officer**	**Captain**	**Senior Captain**	**Other**	**(blank)**	**Grand Total**
Both	1		1		1	3
Civilian	1	1	2	1		5
Military					37	37
Grand Total	**2**	**1**	**3**	**1**	**38**	**45**

- Q9 and Q13 – combined services

	In any of your training has a definition of airworthiness been explained to you?					
Count of Combined service	**Yes**	**Maybe**	**No**	**Do not know**	**(blank)**	**Grand Total**
OF-1 (e.g. Flying Officer)					1	1
OF-2 (e.g. Lieutenant RN)	3	4	3			10
OF-3 (e.g. Squadron Leader)	4		4	1		9
OF-4 (e.g. Lieutenant Colonel)	6		2			8
OF-5 (e.g. Group Captain)			1			1
OR4-9 (e.g. Corporal)			2			2
Prefer not to say				1		1
(blank)						
Grand Total	**13**	**4**	**12**	**2**	**1**	**32**

- Q9 and Q14 combined services

	Do you understand the term No Fault Found (NFF)?		
Count of Combined service	**Yes**	**No**	**Grand Total**
OF-1 (e.g. Flying Officer)		1	1
OF-2 (e.g. Lieutenant RN)	10		10
OF-3 (e.g. Squadron Leader)	9		9
OF-4 (e.g. Lieutenant Colonel)	8		8
OF-5 (e.g. Group Captain)	1		1
OR4-9 (e.g. Corporal)	2		2
Prefer not to say	1		1
(blank)			
Grand Total	**31**	**1**	**32**

- Q9 and Q22 combined services

	For a fault you reported that the engineers have fixed and it has reappeared were you concerned about this?				
Count of Combined service	**Yes**	**No**	**Not sure**	**(blank)**	**Grand Total**
OF-1 (e.g. Flying Officer)				1	1
OF-2 (e.g. Lieutenant RN)	7	2		1	10
OF-3 (e.g. Squadron Leader)	5	3	1		9
OF-4 (e.g. Lieutenant Colonel)	5	3			8
OF-5 (e.g. Group Captain)	1				1
OR4-9 (e.g. Corporal)	1			1	2
Prefer not to say		1			1
(blank)					
Grand Total	**19**	**9**	**1**	**3**	**32**

- Q9 and Q28 combined services

	Have you ever reported an ongoing no fault found problem to any of the following? - Selected Choice Engineering Management						
What is / was your military rank / status? – combined services	**No**	**Engineering Management**	**Flight Safety Officer**	**Operations Management**	**Squadron Flight Commander (Duty Exec)**	**Other**	**Total**
OR4-9 (e.g. Corporal)	1	1	1	1	1	1	5
OF-2 (e.g. Lieutenant RN)	2	2	1	1	3	3	12
OF-3 (e.g. Squadron Leader)	3	5	2	1	6		17
OF-4 (e.g. Lieutenant Colonel)	3	3	3	0	2		11
Prefer not to say	1						1
Total	**9**	**11**	**7**	**3**	**12**	**4**	**46**

- Q9 and Q36

	Have you received any training explaining how to provide a post-sortie engineering brief?				
Services Combined	**Yes**	**No**	**Not sure**	**(blank)**	**Grand Total**
OF-1 (e.g. Flying Officer)				1	1
OF-2 (e.g. Lieutenant RN)	3	6		1	10
OF-3 (e.g. Squadron Leader)	2	3	3	1	9

OF-4 (e.g. Lieutenant Colonel)	3	5			8
OF-5 (e.g. Group Captain)				1	1
OR4-9 (e.g. Corporal)		2			2
Prefer not to say	1				1
(blank)					
Grand Total	**9**	**16**	**3**	**4**	**32**

- Q9 and Q46 Combined services

	Do you think it matters if you do not understand the engineers' terminology?				
Combined service	**Yes**	**No**	**Not sure**	**(blank)**	**Grand Total**
OF-1 (e.g. Flying Officer)				1	1
OF-2 (e.g. Lieutenant RN)	7	1	1	1	10
OF-3 (e.g. Squadron Leader)	8			1	9
OF-4 (e.g. Lieutenant Colonel)	6	1	1		8
OF-5 (e.g. Group Captain)				1	1
OR4-9 (e.g. Corporal)	2				2
Prefer not to say	1				1
(blank)					
Grand Total	**24**	**2**	**2**	**4**	**32**

- Q9 and Q49 combined services

	Do you think it is necessary to know if the aircraft has or has not a No Fault Found?				
Combined service	**Yes**	**No**	**Not sure**	**(blank)**	**Grand Total**
OF-1 (e.g. Flying Officer)				1	1
OF-2 (e.g. Lieutenant RN)	9			1	10
OF-3 (e.g. Squadron Leader)	7		1	1	9
OF-4 (e.g. Lieutenant Colonel)	7	1			8
OF-5 (e.g. Group Captain)				1	1
OR4-9 (e.g. Corporal)	2				2
Prefer not to say	1				1
(blank)					
Grand Total	**26**	**1**	**1**	**4**	**32**

- Q10 and Q13

	In any of your training has a definition of airworthiness been explained to you?					
What is / was your civilian rank / status? - Civilian Aircrew	**Yes**	**Maybe**	**No**	**Do not know**	**(blank)**	**Grand Total**
Captain	1					1
Other			1			1
Senior Captain	2		1			3
Senior First Officer	1	1				2
(blank)						
Grand Total	**4**	**1**	**2**			**7**

- Q10 and Q14

	Do you understand the term No Fault Found (NFF)?		
What is / was your civilian rank / status? - Civilian Aircrew	**Yes**	**No**	**Grand Total**
Captain	1		1
Other	1		1
Senior Captain	3		3
Senior First Officer	2		2
(blank)			
Grand Total	**7**		**7**

- Q10 and Q22

	For a fault you reported that the engineers have fixed and it has reappeared were you concerned about this?				
What is / was your civilian rank / status? - Civilian Aircrew	**Yes**	**No**	**Not sure**	**(blank)**	**Grand Total**
Captain		1			1
Other	1				1
Senior Captain	3				3
Senior First Officer	1	1			2
(blank)					
Grand Total	**5**	**2**			**7**

- Q10 and Q28

What is / was your civilian rank / status? – combined services	Have you ever reported an ongoing no fault found problem to any of the following?						
	No	Engineering Management	Flight Safety Officer	Operations Management	Squadron Flight Commander (Duty Exec)	Other	Total
First Officer							
Senior First Officer	1	1	1	1			4
Captain			1				1
Senior Captain			2		1		3
Other						1	1
Total	1	1	4	1	1	1	9

- Q10 and Q36

	Have you received any training explaining how to provide a post-sortie engineering brief? This is regarding the technical aspect of the flight and any faults you experienced.				
What is / was your civilian rank / status? - Civilian Aircrew	**Yes**	**No**	**Not sure**	**(blank)**	**Grand Total**
Captain		1			1
Other		1			1
Senior Captain	1	2			3
Senior First Officer		2			2
(blank)					
Grand Total	**1**	**6**			**7**

- Q10 and Q46

	Do you think it matters if you do not understand the engineers' terminology?				
What is / was your civilian rank / status? - Civilian Aircrew	**Yes**	**No**	**Not sure**	**(blank)**	**Grand Total**
Captain	1				1
Other	1				1
Senior Captain	2		1		3
Senior First Officer	1			1	2
(blank)					
Grand Total	**5**		**1**	**1**	**7**

- Q10 and Q49

	Do you think it is necessary to know if the aircraft has or has not had a No Fault Found?				
What is / was your civilian rank / status? - Civilian Aircrew	**Yes**	**No**	**Not sure**	**(blank)**	**Grand Total**
Captain	1				1
Other	1				1
Senior Captain	3				3
Senior First Officer	1			1	2
(blank)					
Grand Total	**6**			**1**	**7**

- Q9 and Q10 v Q32

	Do you allocate sufficient time for the post-sortie engineering debrief?					
Aircrew ranks	**Definitely yes**	**Might or might not**	**Probably not**	**Probably yes**	**(blank)**	**Grand Total**
Captain				1		1
OF-1 (e.g. Flying Officer)					1	1
OF-2 (e.g. Lieutenant RN)	6	1	1	1	1	10
OF-3 (e.g. Squadron Leader)	3	1		4	1	9
OF-4 (e.g. Lieutenant Colonel)	5		1	2		8
OF-5 (e.g. Group Captain)					1	1
OR4-9 (e.g. Corporal)	2					2
Other	1					1
Prefer not to say	1					1
Senior Captain	2					2
Senior First Officer			1	1		2
(blank)						
Grand Total	**20**	**2**	**3**	**9**	**4**	**38**

- Q14 and Q16 cross analysis

	Have you received any training on the phenomenon of No Fault Found?			
Do you understand the term No Fault Found (NFF)?	**Yes**	**No**	**Not sure**	**Grand Total**
Yes	1	42	1	44
No		1		1
Grand Total	**1**	**43**	**1**	**45**

- Q14 and Q49

	Do you think it is necessary to know if the aircraft has or has not had a No Fault Found?				
Do you understand the term No Fault Found (NFF)?	**Yes**	**No**	**Not sure**	**(blank)**	**Grand Total**
Yes	37	1	1	5	44
No				1	1
Grand Total	**37**	**1**	**1**	**6**	**45**

- Q16 and Q49

	Do you think it is necessary to know if the aircraft has or has not had a No Fault Found?				
Have you received any training on the phenomenon of No Fault Found?	**Yes**	**No**	**Not sure**	**(blank)**	**Grand Total**
Yes	1				1
No	35	1	1	6	43
Not sure	1				1
Grand Total	**37**	**1**	**1**	**6**	**45**

- Q21- Q51

	Level of trust in engineers to investigate reported faults				
State three words or three phrases to express what you thought when you read the fault had been recorded as NFF	A great deal	A lot	A moderate amount	A little	No selection
Expected outcome / acceptance	5	5		1	
Don't trust the engineers	5	3	1	1	
Frustrated	2	6			2
Not taking it seriously	2	4		1	1

Expletive (about not being fixed)	2	3	2		

Top five responses for Q21 listed.

- Q22 and Q49

	Do you think it is necessary to know if the aircraft has or has not had a No Fault Found?				
For a fault you reported that the engineers have fixed and it has reappeared were you concerned about this?	**Yes**	**No**	**Not sure**	**(blank)**	**Grand Total**
Yes	23	1	1	4	29
No	12				12
Not sure	1				1
(blank)					
Grand Total	**36**	**1**	**1**	**4**	**42**

- Q25 and Q26

	Did the reappearance of the fault (intermittent or otherwise) affect the airworthiness?						
Did the reappearance of the fault (intermittent or otherwise) affect the handling of the aircraft	**Definitely yes**	**Probably yes**	**Might or might not**	**Probably not**	**Definitely not**	**(blank)**	**Grand Total**
Definitely yes	7	3	3				13
Probably yes	2	3					5
Might or might not	1	2	6	2			11
Probably not		1	2	1			4
Definitely not	2	2		2	2		8
(blank)							
Grand Total	**12**	**11**	**11**	**5**	**2**		**41**

- Q25 and Q27

	Did the reappearance of the fault (intermittent or otherwise) affect the air safety of the aircraft?						
Did the reappearance of the fault (intermittent or otherwise) affect the handling of the aircraft?	**Definitely yes**	**Probably yes**	**Might or might not**	**Probably not**	**Definitely not**	**(blank)**	**Grand Total**
Definitely yes	7	3	2		1		13
Probably yes	2	2	1				5
Might or might not	1	2	5	3			11

Probably not		1	1	2			4
Definitely not	3	1		2	2		8
(blank)							
Grand Total	**13**	**9**	**9**	**7**	**3**		**41**

- Q25, Q26 and Q27

Question / Q25	Definitely yes		Probably yes		Might or might not		Probably not		Definitely not		Q25
	26	**27**	**26**	**27**	**26**	**27**	**26**	**27**	**26**	**27**	**Grand Total**
Definitely yes	7	7	3	3	3	2				1	13
Probably yes	2	2	3	2		1					5
Might or might not	1	1	2	2	6	5	2	3			11
Probably not			1	1	2	1	1	2			4
Definitely not	2	3	2	1			2	2	2	2	8
Grand Total	**12**	13	**11**	9	**11**	9	**5**	7	**2**	3	41

- Q36 and Q44

Not possible to do this analysis as Q44 was not answered.

- Q36 and Q40

This cross tabulation was to ascertain any correlation between training for how to provide a PSED and its usefulness. There were 13 valid response to this cross tabulation and 85% found it useful to a degree. However, caution should be exercised due to the low count of 13. This does not mean a generalized statement about training and usefulness can be made. However, it could be deemed to be indicative and may warrant further research. The mode was that the training was moderately useful.

	How useful was this training?					
Have you received any training explaining how to provide a post-sortie engineering brief?	**Extremely useful**	**Moderately useful**	**Slightly useful**	**Neither useful nor useless**	**(blank)**	**Grand Total**
Yes	3	5	3	2		13
No					24	24
Not sure					3	3
(blank)						
Grand Total	**3**	**5**	**3**	**2**	**27**	**40**

- Q36 and Q44

Not possible to do this analysis as Q44 was not answered.

- Q45 and Q49

	Do you think it is necessary to know if the aircraft has or has not had a No Fault Found?				
Do you understand the engineers' terminology for how a fault has been rectified / cleared?	**Yes**	**No**	**Not sure**	**(blank)**	**Grand Total**
Always	5				5
Most of the time	24	1	1		26
About half the time	3				3
Sometimes	5				5
(blank)					
Grand Total	**37**	**1**	**1**		**39**

- Q48 and Q46

	Usually, do you seek clarification from the engineers on what they mean?						
Count of Do you think it matters if you do not understand the engineers' terminology?	**About half the time**	**Always**	**Most of the time**	**Never**	**Sometimes**	**(blank)**	**Grand Total**
No		1	1		1		3
Not sure			2		1		3
Yes	2	14	10	1	6		33
(blank)							
Grand Total	**2**	**15**	**13**	**1**	**8**		**39**

- Q46 and Q49

	Do you think it is necessary to know if the aircraft has or has not had a No Fault Found?				
Do you think it matters if you do not understand the engineers' terminology?	**Yes**	**No**	**Not sure**	**(blank)**	**Grand Total**
Yes	32		1		33
No	2	1			3
Not sure	3				3
(blank)					
Grand Total	**37**	**1**	**1**		**39**

Appendix C - Origin of Bowtie threats and consequences

Table C-1: Source of Bowtie threat from analysis

Bowtie Threat/Barrier	Developed from			
	Literature review, example source	Interview Theme	Questionnaire	FRAM No
Aircrew are to read aircraft logbook			Q41	18
Aircrew recalled to provide additional PSED information to assist with diagnostics	Hockley, Lacey and Pelham (2016)	???		34
Aircrew to be trained in how to review the aircraft logbook			Q41, Q44	2, 3, 12
Aircrew to complete PSED airworthiness assessment			Q36, Q41	6, 15
Airworthiness training provided for aircrew (From Q13)		I1	Q13	19
Airworthiness training provided for engineers (From Q13)			Q13	19
Analysis of aircraft fault history for NFF and intermittent faults to be conducted	Hockley, Lacey and Pelham (2016)			9, 25
Check to confirm electronic logbook updated with completed maintenance				13
Clear process to be stipulated (i.e. what to do if No of NFF recorded is greater than 1)	Hockley, Lacey and Pelham (2016)		Q52	
Company and OEM review NFF occurrences for lessons learned				
Correct completion of spares labels with inclusion of fault description and equipment serial number.	Hockley, Lacey and Pelham (2016)			
Counsellor available to discuss stress levels with engineers	Hockley, Lacey and Pelham (2016)		Q52	

Current amendment state of engineering manuals to be used and recorded on engineering workcards (FRAM= 18)				29, 30
Design in accordance with applicable standards (CAA)	Literature review			
Designated space for engineers and aircrew to hold the PSED provided (quiet)	Hockley, Lacey and Pelham (2016)			1, 7
Designers QMS to monitor feedback on poor design etc. (CAA)	Hockley, Lacey and Pelham (2016)			
Detailed aircraft system training provided to engineers		Training	Q52	
Electronic Engineering maintenance system to be joined up between the levels, forward to depth	Hockley, Lacey and Pelham (2016)			
Electronic management of stock, including by serial number				36, 37
Electronic stock control to track possible roque items	Hockley, Lacey and Pelham (2016)			36, 37
Engineers to be trained by the OEM (or with OEM input)	Hockley, Lacey and Pelham (2016)		Q52	
Engineers trained on detail required for engineering 'paperwork'		Training		
Engineers at all levels allowed access (read only) to the aircraft fault history (NFF MOD)	Hockley, Lacey and Pelham (2016)			16
Experienced and qualified (trained) engineers and aircrew to facilitate debrief	Hockley, Lacey and Pelham (2016)	Training		
Provide engineers to explain engineering terminology the aircrew do not understand	ARINC (2008)		Q45, Q46	2, 4, 14
Aircrew and engineers to be tested for qualification and experience to conduct PSED				1, 6
FSR to be available (Hockley, Lacey and Pelham (2016))	Hockley, Lacey and Pelham (2016)			
FSR to be available to provide assistance and guidance	Hockley, Lacey and Pelham (2016)			

Functioning NFN/Airworthiness group to be established.	Flow chart			
Manual to cover inflight conditions	NFF research	I1	Q52	
Means to assess history of equipment fault by serial number and description through an electronic system (e.g., by bar code or QRF)				
NFF training provided for aircrew (From Q16 and Q41)			Q16/52	
NFF training provided for engineers	Hockley, Lacey and Pelham (2016)		Q52	19, 23
NFF Training to ensure correctly recognized and recorded			Q52	26
NFF/airworthiness assessment, NFF and intermittent fault assessment and components replaced reported to company management				23, 28
Provide training (and refresher training) for aircrew on engineers' terminology (FRAM = 18)	ARINC (2008)		Q45/Q46/Q47	2, 4, 5
Provided aircraft specific proforma for aircrew and engineers to complete (Hockley, Lacey and Pelham (2016))				2, 5
PSED training provided for aircrew and engineers (FRAM = 18)		I1/2	Q36/Q41	2, 18
Random check to be conducted to ensure aircrew read the aircraft logbook.			Q41	2, 18
Random checks instigated to check Tested satis correctly recorded as NFF				
Redesign aircraft	Literature review			
Regulatory oversight of NFF occurrences to be conducted				
Recorded NFF, intermittent faults, airworthiness levels, trained personnel and fault history assessment to be report to company and analysed				
Supervision conducted to ensure full diagnostics completed			Q52	

Supervision of all engineering paperwork and aircraft logbook				
Test chambers to be available to test for more than one parameter at a time	Literature review			
Test sets designed to test air and ground conditions	Hockley, Lacey and Pelham 2016), Khan et al. (2015).			
Training on stress management to be provided to engineers	NFF Research			
Use inflight recording (including CVR) to assist aircrew				

Bowtie Consequence	Developed from Questionnaire
Crash into ground	
Increased diagnostic / engineering time	Q23
Trust between engineers and aircrew declines (Q21 and Q51)	Q21 and Q51
Aircrew dissatisfaction (Q21)	Q21
Handling of aircraft affected (Q25)	Q25
Perceived air safety of aircraft affected (Q27)	Q27
Perceived airworthiness aircraft affected (Q26)	Q26
Increased reporting to 'management' posts	Q28

Appendix D - FRAM Model

D.1 FRAM NFF/Airworthiness model and analysis

The FRAM NFF/Airworthiness model and Excel spreadsheet NFF-Airworthiness analysis are available at 10.17862/cranfield.rd.24106071.

D.2 FRAM Functions and Aspects Controls

Name of function	1 - To conduct PSED
Description	Qualified engineer and aircrew to attend and conduct the PSED, following the flight. This is to happen soon after the flight.
Aspect	Description of Aspect
Input	Backup qualified and experienced engineers
	Backup of qualified and experienced aircrew
Output	Completed PSED proforma
	NFF/Airworthiness assessment
Precondition	Aircrew SQEP for PSED
	Engineer SQEP for PSED
Resource	Suitable PSED facility
	PSED proforma
	Backup qualified and experienced engineers
	Backup of qualified and experienced aircrew
Control	
Time	

Name of function	2 - To complete training
Description	Aircrew, engineers and logisticians to have completed necessary initial and refresher training
Aspect	Description of Aspect
Input	Aircrew/engineers/logisticians booked training
Output	Trained aircrew
	Trained engineers
	Report of trained engineers
	Report of trained aircrew
Precondition	Trainers
Resource	Training equipment
	Training documents
	Updated training documents

Control	
Time	

Name of function	3 - To understand engineering terminology
Description	Do the aircrew understand the engineering terminology used by the engineers to clear/close a fault?
Aspect	Description of Aspect
Input	Closed engineering workcard
	Flight qualified aircrew
Output	Aircrew requiring training
	Inexperienced aircrew
	Aircrew content with engineering terminology
	Aircrew content with engineering terminology
Precondition	
Resource	
Control	
Time	

Name of function	4 - To explain engineer's terminology
Description	Engineers to be available to provide explanations of their terminology to inexperienced aircrew
Aspect	Description of Aspect
Input	Inexperienced aircrew
Output	More knowledgeable aircrew
	Aircrew requiring refresher training
Precondition	Backup qualified and experienced engineers
Resource	Electronic link to searchable aircraft maintenance database
Control	
Time	

Name of function	5 - To book training
Description	A booking system to allow engineers, aircrew and logisticians to book relevant initial and refresher training.
Aspect	Description of Aspect
Input	Engineers requiring refresher training
	Aircrew requiring training
	Engineers requiring training
	Aircrew requiring refresher training
Output	Aircrew/engineers/logisticians booked training
Precondition	

Resource	
Control	
Time	

Name of function	6 - To conduct SQEP Test
Description	A test to conform the engineers and aircrew are experienced and qualified to run the PSED, without additional support from other aircrew or engineers.
Aspect	Description of Aspect
Input	Aircrew requiring Q&E test
	Engineer requiring Q&E test
Output	Engineer SQEP for PSED
	Aircrew SQEP for PSED
	Engineers requiring training
	Aircrew's SQEP results
	Engineer's SQEP results
Precondition	
Resource	Functioning SQEP test tool
Control	
Time	

Name of function	7 - To find suitable PSED facility
Description	To ensure there is a suitable PSED facility in which to conduct the debrief
Aspect	Description of Aspect
Input	
Output	Suitable PSED facility
Precondition	
Resource	
Control	
Time	

Name of function	8 - To use PSED proforma
Description	The aircrew and engineers are to be trained in how to use the PSED proforma.
Aspect	Description of Aspect
Input	Trained aircrew
	Trained engineers
Output	PSED proforma
	Aircrew requiring refresher training

	Engineers requiring refresher training
Precondition	
Resource	Provided PSED proforma
Control	
Time	

Name of function	9 - To review aircraft history
Description	Following the PSED a review of the aircraft history for similar intermittent or NFF is to be conducted.
Aspect	Description of Aspect
Input	Completed PSED proforma
Output	Intermittent fault assessment
	NFF fault assessment
	History of fault description/equipment serial No
Precondition	
Resource	Electronic link to searchable aircraft maintenance database
	Statement determining if fault occurred before
	Statement of historical frequency of intermittent fault
Control	
Time	Completed PSED proforma

Name of function	10 - To analyse NFF assessment
Description	To assess if the fault on this aircraft or with the component serial number was a fault previously recorded as NFF
Aspect	Description of Aspect
Input	NFF fault assessment
Output	Report for NFF/A working group
Precondition	
Resource	Electronic link to searchable aircraft maintenance database
Control	
Time	

Name of function	11 - To analyse intermittent fault assessment
Description	To analyse the history of fault for previous intermittent occurrences. Is there a history or a trend?
Aspect	Description of Aspect
Input	Intermittent fault assessment
	Statement determining if fault has intermittent history
Output	Statement of historical frequency of intermittent fault
	Report for NFF/A working group

Precondition	
Resource	
Control	
Time	

Name of function	12 - To read aircraft log book
Description	The aircraft (technical) log book is to be read and understood.
Aspect	Description of Aspect
Input	Flight qualified aircrew
Output	Read aircraft log book
	Signed aircraft log book
Precondition	
Resource	
Control	
Time	Aircrew content with engineering terminology

Name of function	13 - To complete maintenance
Description	The engineers are to complete the aircraft maintenance.
Aspect	Description of Aspect
Input	Unserviceable aircraft
Output	Closed engineering workcard
	Serviceable aircraft
	Updated electronic aircraft log book
Precondition	
Resource	Aircraft Engineers
	AMM
Control	
Time	

Name of function	14 - To fly the aircraft
Description	The aircrew are to be able to fly the aircraft once the aircraft logbook has been signed.
Aspect	Description of Aspect
Input	Aircrew content with engineering terminology
	Signed aircraft logbook
	More knowledgeable aircrew
Output	Aircrew requiring Q&E test
	Unserviceable aircraft
Precondition	Read aircraft logbook

Resource	Serviceable aircraft
Control	
Time	

Name of function	15 - To be assessed as qualified and experienced
Description	To check the aircrew and engineers are qualified and experienced for the task they are undertaking.
Aspect	Description of Aspect
Input	Request for backup qualified and experienced engineers
	Request for backup qualified and experienced aircrew
Output	Backup qualified and experienced engineers
	Backup of qualified and experienced aircrew
Precondition	
Resource	
Control	
Time	

Name of function	16 - To provide electronic searchable aircraft maintenance database
Description	A searchable, electronic aircraft database with records of all the maintenance conducted is to be available.
Aspect	Description of Aspect
Input	Updated electronic aircraft logbook
Output	Electronic link to searchable aircraft maintenance database
Precondition	
Resource	
Control	
Time	

Name of function	17 - To provide electronic SQEP test tool
Description	The SQEP tool is to be provided to enable the aircrew and engineers to conduct the SQEP test. Electronic where possible.
Aspect	Description of Aspect
Input	
Output	Functioning SQEP test tool
Precondition	
Resource	
Control	
Time	

Name of function	18 - To be qualified to fly the aircraft

Description	The aircrew are to be qualified to fly the aircraft.
Aspect	Description of Aspect
Input	
Output	Flight qualified aircrew
Precondition	
Resource	
Control	
Time	

Name of function	19 - To provide training
Description	A group is to provide training as necessary (via the training booking system)
Aspect	Description of Aspect
Input	
Output	Trainers
Precondition	
Resource	Training documents
	Training update specification
Control	
Time	

Name of function	20 - To provide training equipment
Description	Training equipment to be provided to enable training to be undertaken.
Aspect	Description of Aspect
Input	
Output	Training equipment
Precondition	
Resource	
Control	
Time	

Name of function	21 - To create PSED proforma
Description	A PSED proforma is to be created (and updated) before it can be provided to PSED team.
Aspect	Description of Aspect
Input	PSED proforma update
Output	Created PSED proforma
Precondition	
Resource	

Control	
Time	

Name of function	22 - To provide PSED proforma
Description	A PSED proforma is to be created or updated and provided to PSED team.
Aspect	Description of Aspect
Input	Created PSED proforma
Output	Provided PSED proforma
	PSED proforma
Precondition	
Resource	
Control	
Time	

Name of function	23 - To be a functioning NFF/Airworthiness group
Description	The NFF/Airworthiness working group - to assess rate of NFF and impact on airworthiness. To function as a working group with positive output.
Aspect	Description of Aspect
Input	Report for NFF/A working group
	NFF/Airworthiness assessment
	Report of trained aircrew
	Report of trained engineers
	NFF fault assessment
	Report of fault history and maintenance
Output	Training documents
	Training update specification
	NFF rates
	PSED proforma update
Precondition	
Resource	
Control	
Time	

Name of function	24 - To assess if fault is intermittent
Description	To assess if the fault is intermittent on this aircraft or with the component serial number
Aspect	Description of Aspect
Input	History of fault description/equipment serial No

Output	Statement determining if fault has intermittent history
Precondition	
Resource	Electronic link to searchable aircraft maintenance database
Control	
Time	

Name of function	25 - To assess if fault occurred before
Description	To assess if the fault has occurred before? On this aircraft or with the component serial number
Aspect	Description of Aspect
Input	History of fault description/equipment serial No
Output	Statement determining if fault occurred before
Precondition	
Resource	
Control	
Time	

Name of function	26 - To update aircrew/engineers' records
Description	Following training the aircrew and engineers records need to be updated to reflect the results (pass/fail).
Aspect	Description of Aspect
Input	Report of trained engineers
	Report of trained aircrew
Output	
Precondition	
Resource	
Control	
Time	

Name of function	27 - To assess if training documents need updating
Description	To establish if the training documents need updating.
Aspect	Description of Aspect
Input	Training update specification
Output	Updated training documents
Precondition	
Resource	
Control	
Time	

Name of function	28 - To monitor NFF rates
Description	To monitor the number of aircraft faults recorded as NFF. Is there a trend by aircraft or component serial number?
Aspect	Description of Aspect
Input	NFF rates
Output	
Precondition	
Resource	
Control	
Time	

Name of function	29 - To conduct aircraft fault diagnostics as per AMM
Description	The aircraft fault diagnostics maintenance is to be conducted as per the Aircraft Maintenance Manual.
Aspect	Description of Aspect
Input	Improved PSED information
	History of fault description/equipment serial No
	AMM amendment state
Output	Serviceable aircraft
	Report of fault history and maintenance
	Brief of fault not found/cleared
	Serviceable aircraft
	Record of components changed
Precondition	Completed PSED proforma
Resource	AMM
	Aircraft Engineers
Control	
Time	Assembled maintenance team

Name of function	30 - To assess if AMM has been updated
Description	A check to find out if the AMM has been updated since the previous 'same' maintenance was conducted.
Aspect	Description of Aspect
Input	
Output	AMM amendment state
Precondition	
Resource	
Control	
Time	

Name of function	31 - To be 'qualified' to work on aircraft
Description	The engineers are to be qualified to work on the aircraft before undertaking any aircraft work.
Aspect	Description of Aspect
Input	Engineers
Output	Aircraft Engineers
	Engineer requiring Q&E test
Precondition	
Resource	
Control	
Time	

Name of function	32 - To provide AMM
Description	The engineers are to be provided with an Aircraft Maintenance Manual (AMM) to enable engineering to be conducted.
Aspect	Description of Aspect
Input	
Output	AMM
Precondition	
Resource	
Control	
Time	

Name of function	33 - To assemble maintenance team
Description	A maintenance team is to be assembled before maintenance is conducted.
Aspect	Description of Aspect
Input	
Output	Assembled maintenance team
Precondition	
Resource	
Control	
Time	

Name of function	34 - To gain more information from aircrew
Description	Following PSED and the start of maintenance more information may be required from the aircrew. To cover when insufficient was established during the PSED.
Aspect	Description of Aspect
Input	

Output	Improved PSED information
Precondition	
Resource	
Control	
Time	

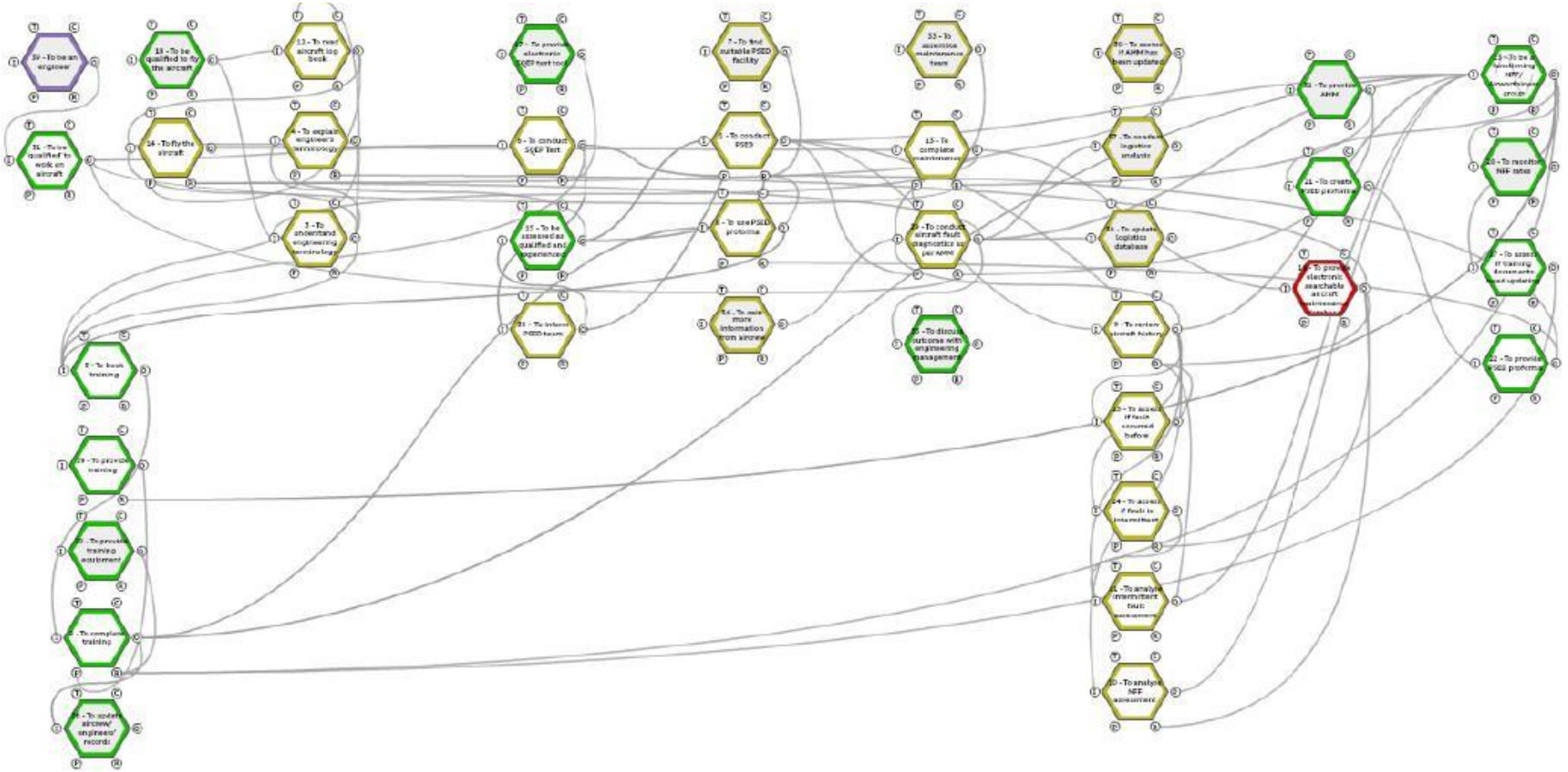
Name of function	35 - To discuss outcome with engineering management
Description	If fault not found and is not going to be recorded as NFF or 'tested satis' (or similar) a discussion with the engineering management is to take place.
Aspect	Description of Aspect
Input	Brief of fault not found/cleared
Output	
Precondition	
Resource	
Control	
Time	

Name of function	36 - To update logistics database
Description	Following any maintenance activity the logistic database is to be updated to reflect components changed and the serial numbers (if applicable).
Aspect	Description of Aspect
Input	Record of components changed
Output	
Precondition	
Resource	
Control	
Time	

Name of function	37 - To conduct logistics analysis
Description	A check of the logistics database for components usage and history.
Aspect	Description of Aspect
Input	Record of components changed
Output	
Precondition	
Resource	
Control	
Time	

Name of function	38 - To inform PSED team
Description	The PSED team is to be informed of the test results from the SQEP test before the PSED commences.
Aspect	Description of Aspect
Input	Engineer's SQEP results
	Aircrew's SQEP results
Output	Aircrew SQEP for PSED
	Engineer SQEP for PSED
	Request for backup qualified and experienced engineers
	Request for backup qualified and experienced aircrew
Precondition	
Resource	
Control	
Time	

Name of function	39 - To be an engineer
Description	
Aspect	Description of Aspect
Input	
Output	Engineers
Precondition	
Resource	
Control	
Time	



D.3 FRAM Task 1 Consent form

Title of the project:	Is there a definitive link between no fault found (NFF) and airworthiness?
Name of the researcher:	Laura Lacey
Researcher's contact details:	l.lacey@cranfield.ac.uk
Participant number:	*SME -*
Date:	

I am interested in understanding how aircraft engineering faults diagnosed as no fault found (NFF) affect aircrew and the safety and airworthiness of the aircraft. You will be presented with information relevant to airworthiness and NFF and asked to provide your opinion. Please be assured that your responses will be kept completely confidential unless you provide consent for me to attribute your comments to you.

The main aim of this research is to clearly prove that there is, or is not, a definitive link between NFF and airworthiness.

The task should take around 3 hours to complete. Your participation in this research is voluntary. You have the right to withdraw at any point during the study, for any reason, and without any prejudice. If you would like to contact the Principal Investigator in the study to discuss this research, please e-mail l.lacey@cranfield.ac.uk.

Part 1: request consent to participate and note the ability to withdraw.

1. I confirm that I have been informed about this research project and I agree to take part as a subject matter expert.
2. I understand that all personal information I provide will be treated with confidence and my name will not be used in any report, publication or presentation unless consent is requested and provided.
3. I have been provided with a participant number as shown above. The researcher will record data against my participant number instead of recording my name. The file linking my name to my participant number will be accessible only to the main researcher and will be securely destroyed after five years.
4. I understand that I can withdraw from this project at any stage by informing the principal investigator named above, for whom contact details have been

provided. I also understand that I can withdraw my data for a period of up to three months from today, as after this time it may not be possible to identify my data from the aggregated results.

Part 2: confirm the security of data storage.

I understand that the data I provide will be used by Cranfield University for the purpose of research. The data will be stored on the University's network that can only be accessed by authorized users, in line with UK data protection regulations.

Part 3: list datasets being created and what will happen to each.

I understand that the aggregated data will be published in support of the research findings. ☐

I confirm that I have read and understood the information provided on this form and give my consent to take part in this research.

Participant's signature:		**Date:**	
Participant's name:			
Researcher's signature:		**Date:**	

One copy of this form must be given to the participant and one copy held by the researcher.

The researcher should keep all consent forms separately from the data in a secure location. They should be securely deleted when the data is anonymized and personal details no longer need retaining.

This form was developed by ethics and research data support staff; for comments or assistance, please email cures-support@cranfield.ac.uk ***(and/or*** researchdata@cranfield.ac.uk ***on the data-specific areas).***

Part 4

Name: _____

Number of years involved with aviation _____years _____months

Date _____

Please mark with a cross to confirm you agree to the following:

I agree for my name to be included in any report, publication or presentation linked to this PhD. ☐

I agree to be acknowledged as a subject matter expert in any report, publication or presentation linked to this PhD. ☐

Appendix E - Fuzzy Logic Inference

E.1 Task 2 – Engineering analysis of airworthiness and NFF levels – consent form

Title of the project:	Is there a definitive link between no fault found (NFF) and airworthiness?
Name of the researcher:	Laura Lacey
Researcher's contact details:	l.lacey@cranfield.ac.uk
Participant number:	*SME -*
Date:	2022

I am interested in understanding how aircraft engineering faults diagnosed as no fault found (NFF) affect aircrew and the safety and airworthiness of the aircraft. You will be presented with information relevant to airworthiness and NFF and asked to provide your opinion. Please be assured that your responses will be kept completely confidential unless you provide consent for me to attribute your comments to you.

The main aim of this research is to clearly prove that there is, or is not, a definitive link between NFF and airworthiness.

The task should take around 30 minutes to complete. Your participation in this research is voluntary. You have the right to withdraw at any point during the study, for any reason, and without any prejudice. If you would like to contact the Principal Investigator in the study to discuss this research, please e-mail l.lacey@cranfield.ac.uk.

Part 1: request consent to participate and note the ability to withdraw.

1. I confirm that I have been informed about this research project and I agree to take part as a subject matter expert.
2. I understand that all personal information I provide will be treated with confidence and my name will not be used in any report, publication or presentation unless consent is requested and provided.
3. I have been provided with a participant number as shown above. The researcher will record data against my participant number instead of recording my name. The file linking my name to my participant number will be accessible only to the main researcher and will be securely destroyed after five years.
4. I understand that I can withdraw from this project at any stage by informing the principal investigator named above, for whom contact details have been provided. I also understand that I can withdraw my data for a period of up to three months from today, as after this time it may not be possible to identify my data from the aggregated results.

Part 2: confirm the security of data storage.

I understand that the data I provide will be used by Cranfield University for the purpose of research. The data will be stored on the University's network that can only be accessed by authorized users, in line with UK data protection regulation.

Part 3: list datasets being created and what will happen to each.

I understand that the aggregated data will be published in support of the research findings. ☐

I confirm that I have read and understood the information provided on this form and give my consent to take part in this research.

Participant's signature:		**Date:**	2022
Participant's name:			
Researcher's signature:		**Date:**	2022

One copy of this form must be given to the participant and one copy held by the researcher.

The researcher should keep all consent forms separately from the data in a secure location. They should be securely deleted when the data is anonymized and personal details no longer need retaining.

This form was developed by ethics and research data support staff; for comments or assistance, please email cures-support@cranfield.ac.uk ***(and/or*** researchdata@cranfield.ac.uk ***on the data-specific areas).***

Post-Sortie Engineering Debrief (PSED) Airworthiness Levels Task

As a subject matter expert (SME) thank you for agreeing to complete this task. Your input to my PhD is appreciated.

This task is to determine how many PSED airworthiness levels (see Figure 1) recorded by pilots over a stated period are required before the overall airworthiness level assessment of the aircraft moves from one level to another (See Table 1). This PSED assessment is based on the airworthiness level recorded by the aircrew following the sortie. The definitions and descriptions used by the aircrew are shown in Figure 1.

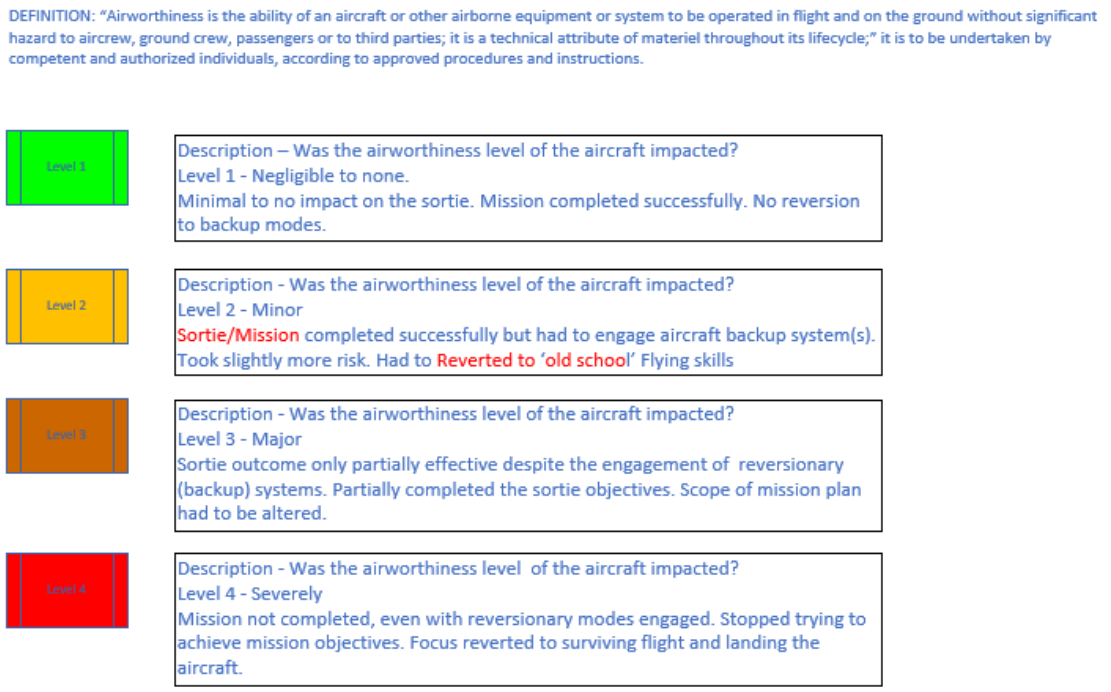


Figure1: Levels of airworthiness recorded by the pilot following the sortie

The engineering aircraft airworthiness levels, shown in Table 1, would be discussed/agreed at the NFF/Airworthiness working group meetings.

Table 1: Levels of Aircraft airworthiness

Level	Description
Negligible	The aircraft is fully airworthy or there is minimal change to the overall airworthiness level. There is a negligible hazard to the aircrew, ground crew and third parties.
Minor	The aircraft's overall airworthiness level has been affected. There is a minor hazard to the aircrew, ground crew and third parties. The situation is to be monitored.
Major	The aircraft's overall airworthiness level has been affected. There is a major hazard to the aircrew, ground crew and third parties. An investigation is required to assess the cause and impact.
Severe	The aircraft is unairworthy. There is a significant hazard to the aircrew, ground crew and third parties. The aircraft is completely unairworthy. A detailed investigation is required before the aircraft can fly.

Example

For example, how many Aircrew PSED level 2 recordings for a fault related to a NFF or intermittent fault would be required within a set period before the combined number moved the overall aircraft airworthiness to level 3 (Table 1)?

The following table is an *example*. It indicates that 4 x PSED Level 2 recorded would **combine** to be classified as minor Aircraft Levels of Airworthiness.

Three-month period

No of occurrences	Level 1	Level 2	Level 3	Level 4
0	N	N	N	N
1	N	N	Mi	S
2	N	N	Mi	S
3	N	N	Mi	S
4	N	Mi	Ma	S
5	N	Mi	Ma	S
6	N	Mi	Ma	S
7	N	Mi	Ma	S
8	N	Mi	S	S
9	N	Ma	S	S
10	N	Ma	S	S

The subject matter expert is required to complete the table for the number of PSED airworthiness levels recorded following a fault being assessed by the maintenance teams as a NFF or intermittent fault. A recording of ‘tested satis’ would be categorized as a NFF.

Then if the **same** (or very similar) fault is reported on the PSED for the **same** aircraft again, indicate how you would assess these subsequent events' impact on the overall aircraft’s level of airworthiness? These may or may not be recorded as NFF or intermittent. The fault has not been found. How many occurrences at one PSED level would be required before the aircraft should be assessed at a higher level?

The task should be considered for the number of faults recorded over four periods.

1. One month
2. Three months
3. Six months
4. 12 months.

So, four tables in total. Justification for the decision is to be provided.

One month

	Overall Aircraft Airworthiness Levels			
No of PSED occurrences	Level 1	Level 2	Level 3	Level 4
0	N	N	N	N
1	N	Mi	Ma	S
2	Mi	Mi	Ma	S
3	Mi	Ma	S	S
4	Ma	Ma	S	S
5	Ma	S	S	S
6	S	S	S	S
7	S	S	S	S
8	S	S	S	S
9	S	S	S	S
10	S	S	S	S

Justification

Three months

	Overall Aircraft Airworthiness Levels			
No of PSED occurrences	Level 1	Level 2	Level 3	Level 4
0	N	N	N	N
1	N	N	Ma	S
2	N	Mi	Ma	S
3	Mi	Mi	Ma	S
4	Mi	Ma	S	S
5	Ma	Ma	S	S
6	Ma	S	S	S
7	S	S	S	S
8	S	S	S	S
9	S	S	S	S
10	S	S	S	S

Justification

Six months

	Overall Aircraft Airworthiness Levels			
No of PSED occurrences	Level 1	Level 2	Level 3	Level 4
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Justification

12 months

	Overall Aircraft Airworthiness Levels			
No of PSED occurrences	Level 1	Level 2	Level 3	Level 4
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Justification

Name: _____

Number of years involved with aviation _____years _____months

Date _____

Please mark with a cross to confirm you agree to the following:

I agree for my name to be included in any report, publication or presentation linked to this PhD. ☐

I agree to be acknowledged as a subject matter expert in any report, publication or presentation linked to this PhD. ☐

E.2 Engineer SME results for Task 2

N = Negligible Mi = Minor Ma = Major S = Severe

1 month – Aircrew level Negligible

Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	N	Mi	Mi	Ma	Ma	S	S	S	S	S
SME B	N	N	N	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME C	N	N	N	N	N	N	N	N	N	N	N
SME D	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME E	N	Mi	Mi	Mi	Mi	Ma	S	S	S	S	S
SME F	N	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME G	N	N	N	N	N	N	N	N	N	N	N
SME H	N	N	N	N	Mi	Mi	Mi	Mi	Mi	Mi	Ma
SME I	N	N	N	N	N	N	Mi	Mi	Mi	Mi	Mi
SME I	N	N	N	N	N	N	N	N	N	N	N
SME J	N	N	N	N	Mi	Mi	Ma	Ma	Ma	Ma	Ma
TOTAL N	11	9	7	7	4	4	3	3	3	3	3
TOTAL Mi	0	2	4	4	6	5	5	5	5	5	4
TOTAL Ma	0	0	0	0	1	2	1	1	1	1	2
TOTAL S	0	0	0	0	0	0	2	2	2	2	2

1 month – Aircrew level Minor

Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	Mi	Mi	Ma	Ma	S	S	S	S	S	S
SME B	N	N	Mi	Mi	Ma	Ma	S	S	S	S	S
SME C	N	N	N	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME D	N	Mi	Ma	S	S	S	S	S	S	S	S
SME E	N	Mi	Ma	S	S	S	S	S	S	S	S
SME F	N	Mi	S	S	S	S	S	S	S	S	S
SME G	N	N	Mi	Mi	Ma	Ma	Ma	Ma	Ma	Ma	Ma
SME H	N	N	N	Mi	Mi	Ma	Ma	S	S	S	S
SME I	N	Mi	Ma	Ma	Ma	Ma	Ma	S	S	S	S
SME I	N	N	N	N	N	Mi	Mi	Mi	Mi	Ma	Ma
SME J	N	N	N	Mi	Mi	Ma	Ma	Ma	Ma	Ma	Ma
TOTAL N	11	6	4	2	1	0	0	0	0	0	0
TOTAL Mi	0	5	3	4	3	2	2	2	2	1	1
TOTAL Ma	0	0	3	2	4	5	4	2	2	3	3
TOTAL S	0	0	1	3	3	4	5	7	7	7	7

1 month – Aircrew level Major

Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	Ma	Ma	S	S	S	S	S	S	S	S
SME B	N	Ma	Ma	S	S	S	S	S	S	S	S
SME C	N	N	Mi	Mi	Ma	Ma	Ma	Ma	Ma	Ma	Ma
SME D	N	Ma	Ma	S	S	S	S	S	S	S	S
SME E	N	S	S	S	S	S	S	S	S	S	S
SME F	N	Ma	S	S	S	S	S	S	S	S	S
SME G	N	Mi	Ma	Ma	S	S	S	S	S	S	S
SME H	N	Mi	Mi	Ma	Ma	S	S	S	S	S	S
SME I	N	Mi	Ma	Ma	Ma	Ma	Ma	S	S	S	S
SME J	N	N	N	Mi	Mi	Ma	Ma	Ma	Ma	S	S
SME J	N	Ma	Ma	S	S	S	S	S	S	S	S
TOTAL N	11	2	1	0	0	0	0	0	0	0	0
TOTAL Mi	0	3	2	2	1	0	0	0	0	0	0
TOTAL Ma	0	5	6	3	3	3	3	2	2	1	1
TOTAL S	0	1	2	6	7	8	8	9	9	10	10

1 month – Aircrew level Severe

Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	S	S	S	S	S	S	S	S	S	S
SME B	N	S	S	S	S	S	S	S	S	S	S
SME C	N	N	S	S	S	S	S	S	S	S	S
SME D	N	S	S	S	S	S	S	S	S	S	S
SME E	N	S	S	S	S	S	S	S	S	S	S
SME F	N	S	S	S	S	S	S	S	S	S	S
SME G	N	S	S	S	S	S	S	S	S	S	S
SME H	N	Ma	S	S	S	S	S	S	S	S	S
SME I	N	S	S	S	S	S	S	S	S	S	S
SME I	N	S	S	S	S	S	S	S	S	S	S
SME J	N	S	S	S	S	S	S	S	S	S	S
TOTAL N	11	1	0	0	0	0	0	0	0	0	0
TOTAL Mi	0	0	0	0	0	0	0	0	0	0	0
TOTAL Ma	0	1	0	0	0	0	0	0	0	0	0
TOTAL S	0	9	11	11	11	11	11	11	11	11	11

3 month - Aircrew level Negligible

Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	N	Mi	Mi	Ma	Ma	S	S	S	S	S
SME B	N	N	N	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME C	N	N	N	N	N	N	N	N	N	N	N
SME D	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME E	N	Mi	Mi	Mi	Mi	Ma	S	S	S	S	S
SME F	N	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME G	N	N	N	N	N	N	N	N	N	N	N
SME H	N	N	N	N	N	N	N	Mi	Mi	Mi	Mi
SME I	N	N	N	N	N	N	N	N	N	N	Mi
SME J	N	N	N	N	N	N	N	N	N	N	N
SME I	N	N	N	N	N	N	Mi	Mi	Ma	Ma	Ma
TOTAL N	11	9	7	7	6	6	5	4	4	4	3
TOTAL Mi	0	2	4	4	4	3	4	5	4	4	5
TOTAL Ma	0	0	0	0	1	2	0	0	1	1	1
TOTAL S	0	0	0	0	0	0	2	2	2	2	2

3 month - Aircrew level Minor

Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	Mi	Mi	Ma	Ma	S	S	S	S	S	S
SME B	N	N	Mi	Mi	Ma	Ma	S	S	S	S	S
SME C	N	N	N	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME D	N	Mi	Ma	S	S	S	S	S	S	S	S
SME E	N	Mi	Ma	S	S	S	S	S	S	S	S
SME F	N	Mi	S	S	S	S	S	S	S	S	S
SME G	N	N	N	N	Mi	Mi	Mi	Ma	Ma	Ma	Ma
SME H	N	N	N	Mi	Mi	Ma	Ma	Ma	Ma	Ma	Ma
SME I	N	N	N	N	N	N	Mi	Mi	Mi	Mi	Ma
SME J	N	N	N	N	N	Mi	Mi	Mi	Mi	Ma	Ma
SME I	N	N	N	N	Mi	Mi	Ma	Ma	Ma	Ma	Ma
TOTAL N	11	7	6	5	2	1	0	0	0	0	0
TOTAL Mi	0	4	2	2	4	4	4	3	3	2	1
TOTAL Ma	0	0	2	1	2	2	2	3	3	4	5
TOTAL S	0	0	1	3	3	4	5	5	5	5	5

3 month - Aircrew level Major

Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	Ma	Ma	S	S	S	S	S	S	S	S
SME B	N	Ma	Ma	S	S	S	S	S	S	S	S
SME C	N	N	Mi	Mi	Ma	Ma	Ma	Ma	Ma	Ma	Ma
SME D	N	Ma	Ma	S	S	S	S	S	S	S	S
SME E	N	S	S	S	S	S	S	S	S	S	S
SME F	N	Ma	S	S	S	S	S	S	S	S	S
SME G	N	Mi	Ma	Ma	Ma	S	S	S	S	S	S
SME H	N	Mi	Mi	Ma	Ma	S	S	S	S	S	S
SME I	N	N	N	N	N	N	Mi	Mi	Mi	Mi	Ma
SME J	N	N	N	Mi	Mi	Ma	Ma	Ma	Ma	S	S
SME I	N	Ma	Ma	S	S	S	S	S	S	S	S
TOTAL N	11	3	2	1	1	1	0	0	0	0	0
TOTAL Mi	0	2	2	2	1	0	1	1	1	1	0
TOTAL Ma	0	5	5	2	3	2	2	2	2	1	2
TOTAL S	0	1	2	6	6	8	8	8	8	9	9

3 month - Aircrew level Severe

Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	S	S	S	S	S	S	S	S	S	S
SME B	N	S	S	S	S	S	S	S	S	S	S
SME C	N	N	S	S	S	S	S	S	S	S	S
SME D	N	S	S	S	S	S	S	S	S	S	S
SME E	N	S	S	S	S	S	S	S	S	S	S
SME F	N	S	S	S	S	S	S	S	S	S	S
SME G	N	S	S	S	S	S	S	S	S	S	S
SME H	N	Ma	S	S	S	S	S	S	S	S	S
SME I	N	S	S	S	S	S	S	S	S	S	S
SME J	N	S	S	S	S	S	S	S	S	S	S
SME J	N	S	S	S	S	S	S	S	S	S	S
TOTAL N	11	1	0	0	0	0	0	0	0	0	0
TOTAL Mi	0	0	0	0	0	0	0	0	0	0	0
TOTAL Ma	0	1	0	0	0	0	0	0	0	0	0
TOTAL S	0	9	11	11	11	11	11	11	11	11	11

6 month - Aircrew level Negligible

Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	N	Mi	Mi	Ma	Ma	S	S	S	S	S
SME B	N	N	N	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME C	N	N	N	N	N	N	N	N	N	N	N
SME D	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME E	N	Mi	Mi	Mi	Mi	Ma	S	S	S	S	S
SME F	N	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME G	N	N	N	N	N	N	N	N	N	N	N
SME H	N	N	N	N	N	N	N	N	N	N	Mi
SME I	N	N	N	N	N	N	N	N	N	N	N
SME J	N	N	N	N	N	N	N	N	N	N	N
SME K	N	N	N	N	N	N	N	Mi	Mi	Mi	Mi
TOTAL N	11	9	7	7	6	6	6	5	5	5	4
TOTAL Mi	0	2	4	4	4	3	3	4	4	4	5
TOTAL Ma	0	0	0	0	1	2	0	0	0	0	0
TOTAL S	0	0	0	0	0	0	2	2	2	2	2

6 month - Aircrew level Minor

Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	Mi	Mi	Ma	Ma	S	S	S	S	S	S
SME B	N	N	Mi	Mi	Ma	Ma	S	S	S	S	S
SME C	N	N	N	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME D	N	Mi	Ma	S	S	S	S	S	S	S	S
SME E	N	Mi	Ma	S	S	S	S	S	S	S	S
SME F	N	Mi	S	S	S	S	S	S	S	S	S
SME G	N	N	N	N	N	N	N	Mi	Mi	Mi	Mi
SME H	N	N	N	Mi	Mi	Mi	Ma	Ma	Ma	Ma	Ma
SME I	N	N	N	N	N	N	N	N	Mi	Mi	Mi
SME J	N	N	N	N	N	N	N	Mi	Mi	Mi	Mi
SME K	N	N	N	N	Mi	Mi	Ma	Ma	Ma	Ma	Ma
TOTAL N	11	7	6	5	3	3	3	1	0	0	0
TOTAL Mi	0	4	2	2	3	3	1	3	4	4	4
TOTAL Ma	0	0	2	1	2	1	2	2	2	2	2
TOTAL S	0	0	1	3	3	4	5	5	5	5	5

6 month - Aircrew level Major

Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	Ma	Ma	S	S	S	S	S	S	S	S
SME B	N	Ma	Ma	S	S	S	S	S	S	S	S
SME C	N	N	Mi	Mi	Ma	Ma	Ma	Ma	Ma	Ma	Ma
SME D	N	Ma	Ma	S	S	S	S	S	S	S	S
SME E	N	S	S	S	S	S	S	S	S	S	S
SME F	N	Ma	S	S	S	S	S	S	S	S	S
SME G	N	Mi	Mi	Ma	Ma	Ma	Ma	S	S	S	S
SME H	N	Mi	Mi	Ma	Ma	S	S	S	S	S	S
SME I	N	N	N	N	N	N	N	N	Mi	Mi	Mi
SME J	N	N	N	N	N	Mi	Mi	Ma	Ma	Ma	Ma
SME K	N	Ma	Ma	S	S	S	S	S	S	S	S
TOTAL N	11	3	2	2	2	1	1	1	0	0	0
TOTAL Mi	0	2	3	1	0	1	1	0	1	1	1
TOTAL Ma	0	5	4	2	3	2	2	2	2	2	2
TOTAL S	0	1	2	6	6	7	7	8	8	8	8

6 month - Aircrew level Severe

Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	S	S	S	S	S	S	S	S	S	S
SME B	N	S	S	S	S	S	S	S	S	S	S
SME C	N	N	S	S	S	S	S	S	S	S	S
SME D	N	S	S	S	S	S	S	S	S	S	S
SME E	N	S	S	S	S	S	S	S	S	S	S
SME F	N	S	S	S	S	S	S	S	S	S	S
SME G	N	S	S	S	S	S	S	S	S	S	S
SME H	N	Ma	S	S	S	S	S	S	S	S	S
SME I	N	S	S	S	S	S	S	S	S	S	S
SME J	N	S	S	S	S	S	S	S	S	S	S
SME K	N	S	S	S	S	S	S	S	S	S	S
TOTAL N	11	1	0	0	0	0	0	0	0	0	0
TOTAL Mi	0	0	0	0	0	0	0	0	0	0	0
TOTAL Ma	0	1	0	0	0	0	0	0	0	0	0
TOTAL S	0	9	11	11	11	11	11	11	11	11	11

12 month - Aircrew level Negligible

Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	N	Mi	Mi	Ma	Ma	S	S	S	S	S
SME B	N	N	N	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME C	N	N	N	N	N	N	N	N	N	N	N
SME D	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME E	N	Mi	Mi	Mi	Mi	Ma	S	S	S	S	S
SME F	N	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME G	N	N	N	N	N	N	N	N	N	N	N
SME H	N	N	N	N	N	N	N	N	N	N	Mi
SME I	N	N	N	N	N	N	N	N	N	N	N
SME J	N	N	N	N	N	N	N	N	N	N	N
SME K	N	N	N	N	N	N	N	N	N	Mi	Mi
TOTAL N	11	9	7	7	6	6	6	6	6	5	4
TOTAL Mi	0	2	4	4	4	3	3	3	3	4	5
TOTAL Ma	0	0	0	0	1	2	0	0	0	0	0
TOTAL S	0	0	0	0	0	0	2	2	2	2	2

12 month - Aircrew level Minor

Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	Mi	Mi	Ma	Ma	S	S	S	S	S	S
SME B	N	N	Mi	Mi	Ma	Ma	S	S	S	S	S
SME C	N	N	N	N	Mi	Mi	Mi	Mi	Mi	Mi	Mi
SME D	N	Mi	Ma	S	S	S	S	S	S	S	S
SME E	N	Mi	Ma	S	S	S	S	S	S	S	S
SME F	N	Mi	S	S	S	S	S	S	S	S	S
SME G	N	N	N	N	N	N	N	N	N	N	N
SME H	N	N	N	Mi	Mi	Mi	Ma	S	S	S	S
SME I	N	N	N	N	N	N	N	N	N	N	N
SME J	N	N	N	N	N	N	N	N	N	Mi	Mi
SME K	N	N	N	N	N	N	Mi	Mi	Mi	Ma	Ma
TOTAL N	11	7	6	5	4	4	3	3	3	2	2
TOTAL Mi	0	4	2	2	2	2	2	2	2	2	2
TOTAL Ma	0	0	2	1	2	1	1	0	0	1	1
TOTAL S	0	0	1	3	3	4	5	6	6	6	6

12 month - Aircrew level Major

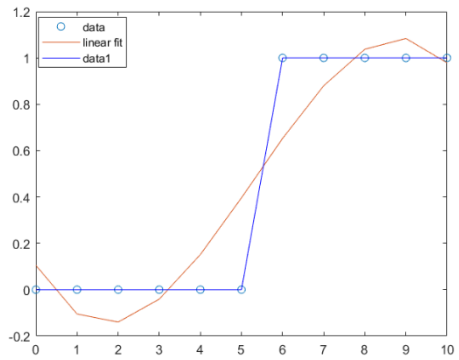
Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	Ma	Ma	S	S	S	S	S	S	S	S
SME B	N	Ma	Ma	S	S	S	S	S	S	S	S
SME C	N	N	Mi	Mi	Ma	Ma	Ma	Ma	Ma	Ma	Ma
SME D	N	Ma	Ma	S	S	S	S	S	S	S	S
SME E	N	S	S	S	S	S	S	S	S	S	S
SME F	N	Ma	S	S	S	S	S	S	S	S	S
SME G	N	Mi	Mi	Mi	Ma	Ma	Ma	Ma	Ma	Ma	S
SME H	N	Mi	Mi	Ma	Ma	S	S	S	S	S	S
SME I	N	N	N	N	N	N	N	N	N	N	N
SME J	N	N	N	N	N	N	N	Mi	Mi	Ma	Ma
SME K	N	Mi	S	S	S	S	S	S	S	S	S
TOTAL N	11	3	2	2	2	2	2	1	1	1	1
TOTAL Mi	0	3	3	2	0	0	0	1	1	0	0
TOTAL Ma	0	4	3	1	3	2	2	2	2	3	2
TOTAL S	0	1	3	6	6	7	7	7	7	7	8

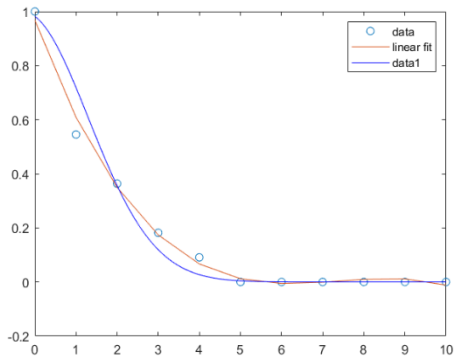
12 month - Aircrew level Severe

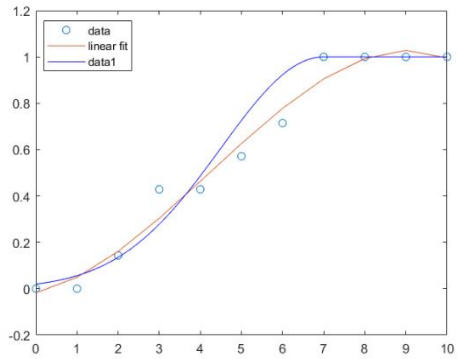
Occurrence	0	1	2	3	4	5	6	7	8	9	10
SME A	N	S	S	S	S	S	S	S	S	S	S
SME B	N	S	S	S	S	S	S	S	S	S	S
SME C	N	N	S	S	S	S	S	S	S	S	S
SME D	N	S	S	S	S	S	S	S	S	S	S
SME E	N	S	S	S	S	S	S	S	S	S	S
SME F	N	S	S	S	S	S	S	S	S	S	S
SME G	N	S	S	S	S	S	S	S	S	S	S
SME H	N	Ma	S	S	S	S	S	S	S	S	S
SME I	N	S	S	S	S	S	S	S	S	S	S
SME J	N	S	S	S	S	S	S	S	S	S	S
SME K	N	S	S	S	S	S	S	S	S	S	S
TOTAL N	11	1	0	0	0	0	0	0	0	0	0
TOTAL Mi	0	0	0	0	0	0	0	0	0	0	0
TOTAL Ma	0	1	0	0	0	0	0	0	0	0	0
TOTAL S	0	9	11	11	11	11	11	11	11	11	11

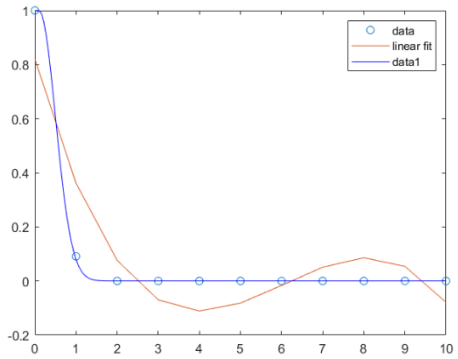
E.3 Example best-fit lines for engineers results for Task 2, from Excel to MATLAB Fuzzy Logic Toolbox.

The results from Task 2 were plotted in Excel and then normalized. It is not possible to import plot points into MATLAB Fuzzy Logic Toolbox. Therefore, first-attempt-heuristic-best-fit lines were created. Where a direct fit was possible, this was used. Otherwise, a polynomial best-fit line was created. This was achieved by extracting the first-attempt-heuristic-best-fit plots from the Fuzzy Logic Toolbox membership functions for each month and comparing these against plots of the Excel data points. The membership function plots were adjusted using a heuristic approach until a close fit was achieved. Examples are shown below.

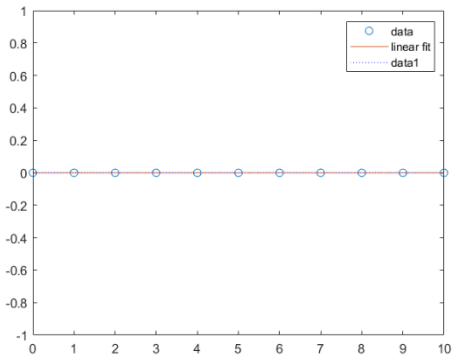
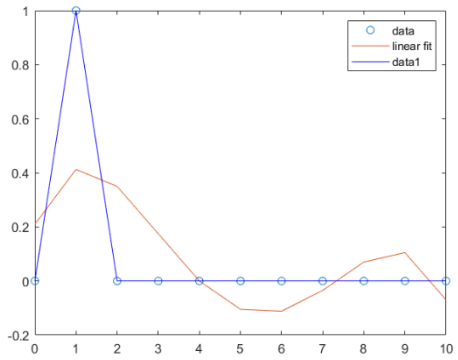
<table>
<tr>
<td>

Aircrew L1 – Engineer Level 4</td>
<td>

Aircrew L2 – Engineer Level 1</td>
</tr>
<tr>
<td>

Aircrew L2 – Engineer Level 3</td>
<td>

Aircrew L4 – Engineer Level 1</td>
</tr>
</table>

	
Aircrew L4 – Engineer Level 2	Aircrew L4 – Engineer Level 3

E.4 Sugeno Fuzzy Logic rules and surface plots for months one, 3, 6 and 12

The following Fuzzy logic designer (Figure E-1) and Aircrew membership functions (Figure E-2) were identical for each Fuzzy logic inference conducted.

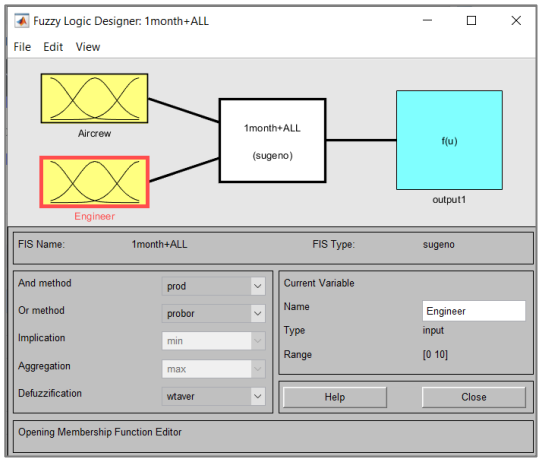


Figure E-1: Designer view for 1 month

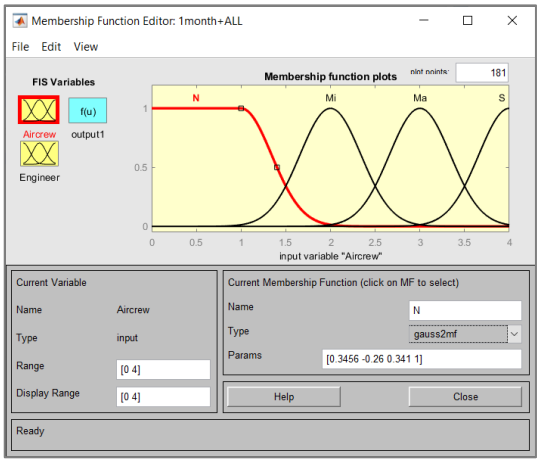


Figure E-2: Aircrew membership functions for 1 month

E.4.1 One month

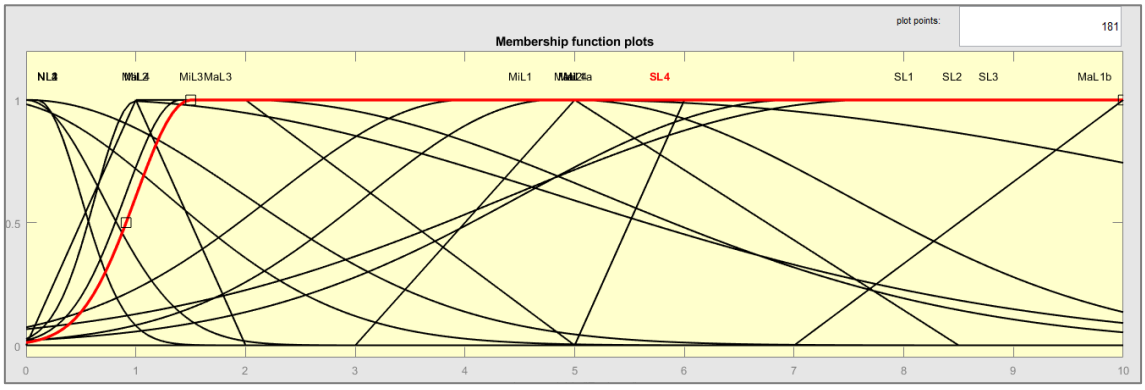


Figure E-3: Engineers' membership function plots - 1 month for risk matrix 1 and 2

Membership function plots x 16. This is the same for a conservative and a less conservative risk approach.

- Risk matrix 1

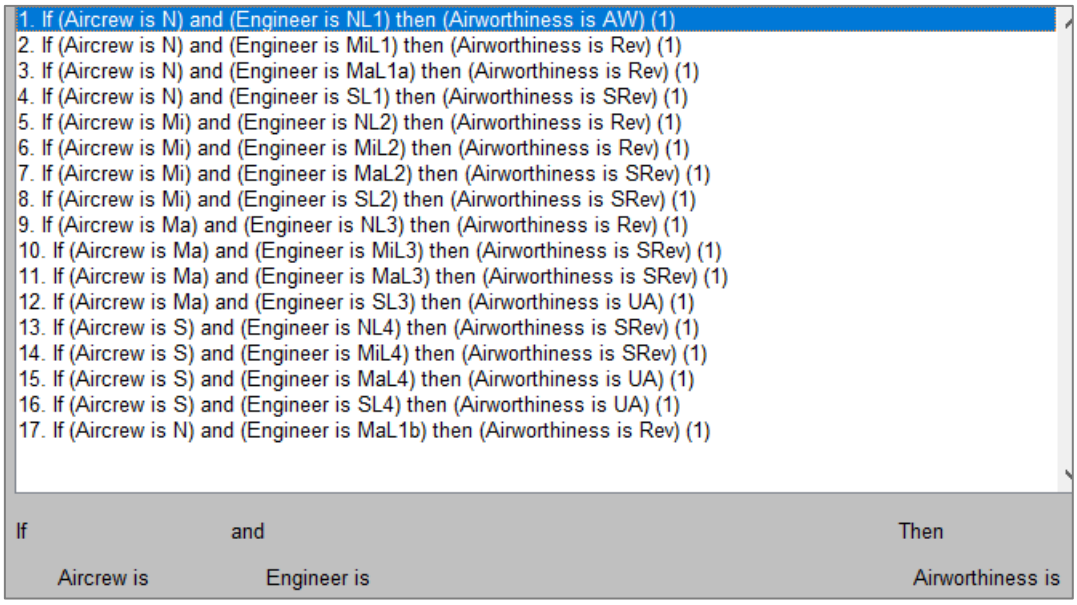


Figure E-4: Rules - 1 month for risk matrix 1

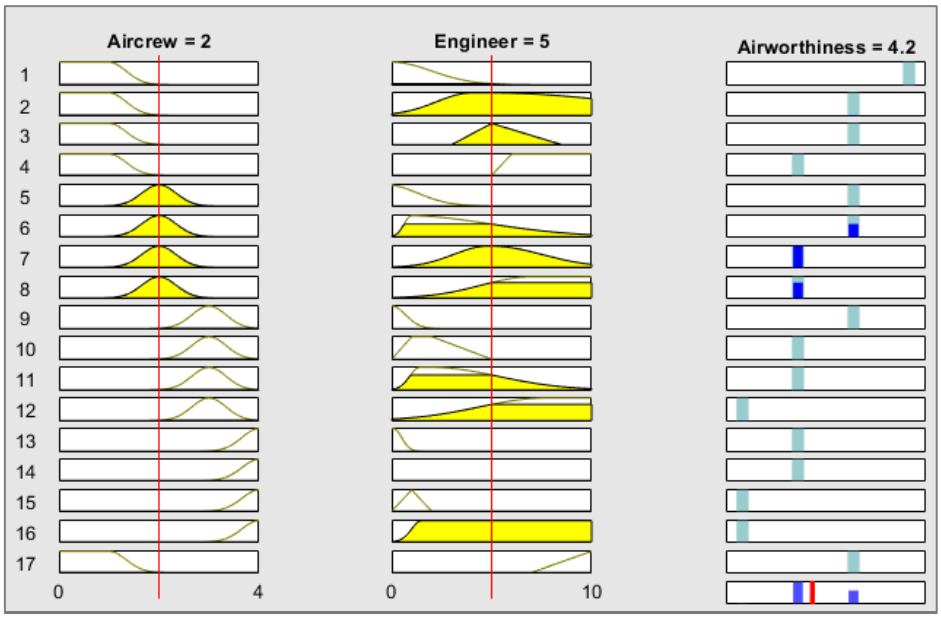


Figure E-5: Rule plots for 1 month for risk matrix 1 aircrew level 2 and engineer level 5

For aircrew level 2 – Engineer – 5 the airworthiness level is 4.2



Figure E-6: Surface plot - 1 month for risk matrix 1

- Risk matrix 2

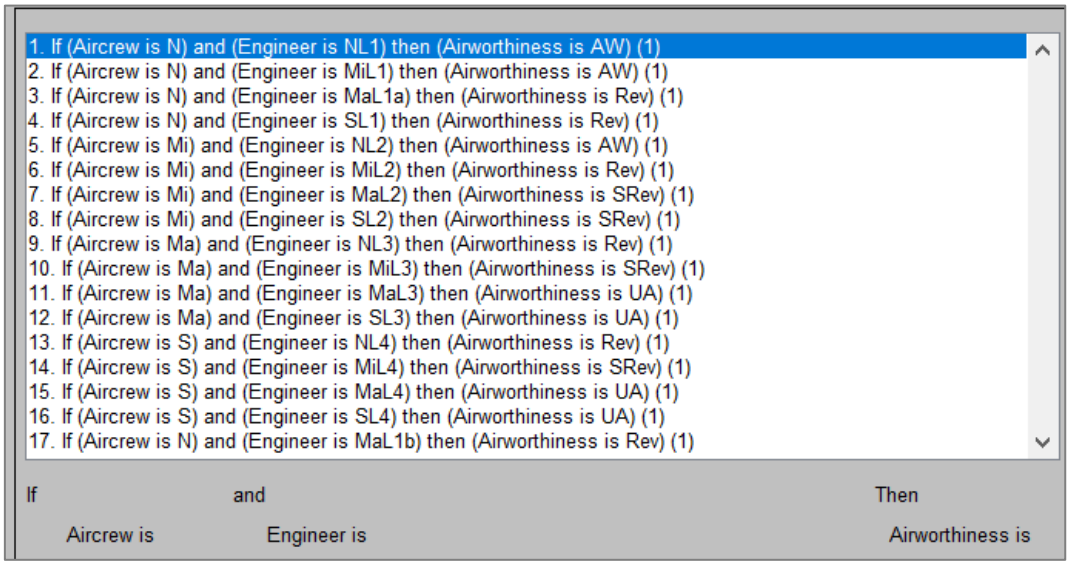


Figure E-7: Rules - 1 month for risk matrix 2

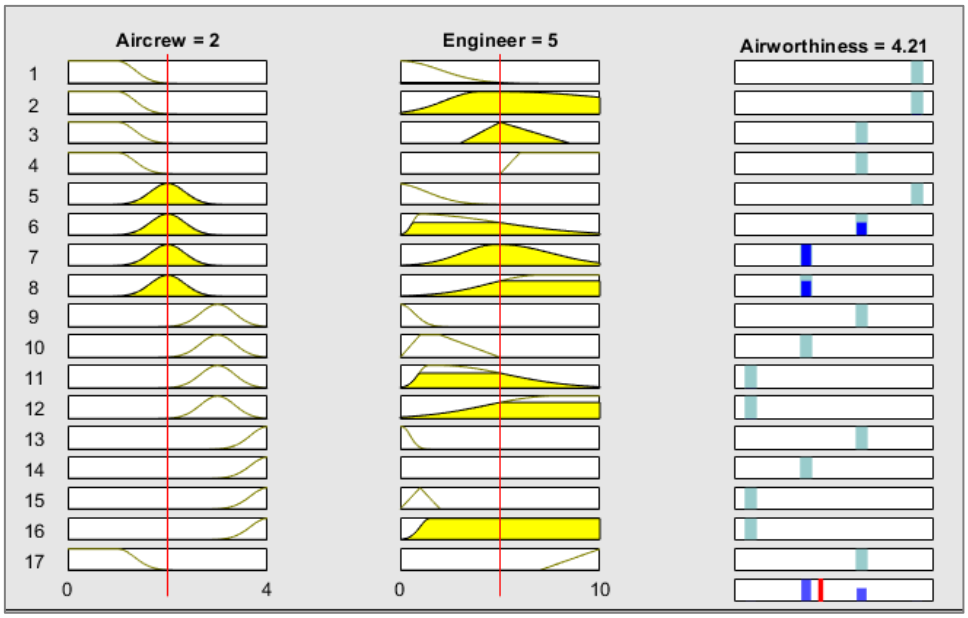


Figure E-8: Rule plots for 1 month for risk matrix 2 aircrew level 2 and engineer level 5

For aircrew level 2 – engineer level – 5 the airworthiness is 4.2.



Figure E-9: Surface plot - 1 month for risk matrix 2

E.4.2 Three months

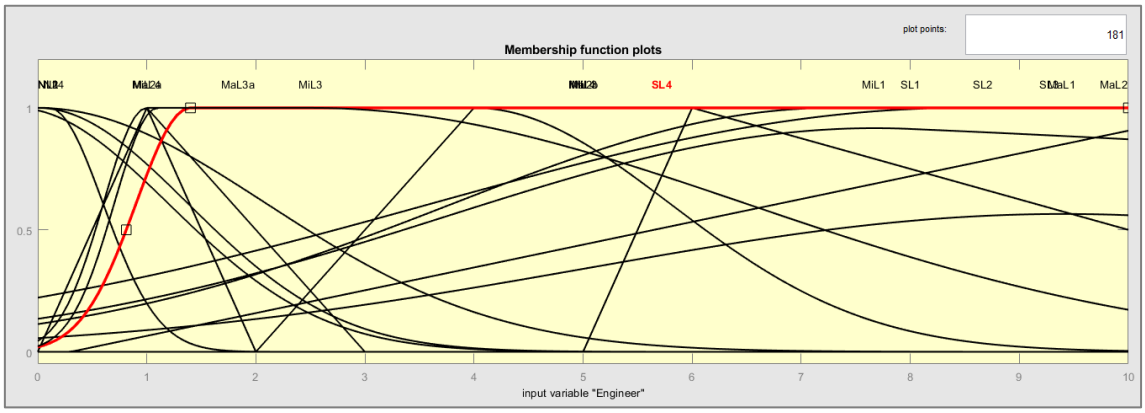


Figure E-10: Engineers' membership function plots - 3 months for risk matrix 1 and 2

- Risk matrix 1

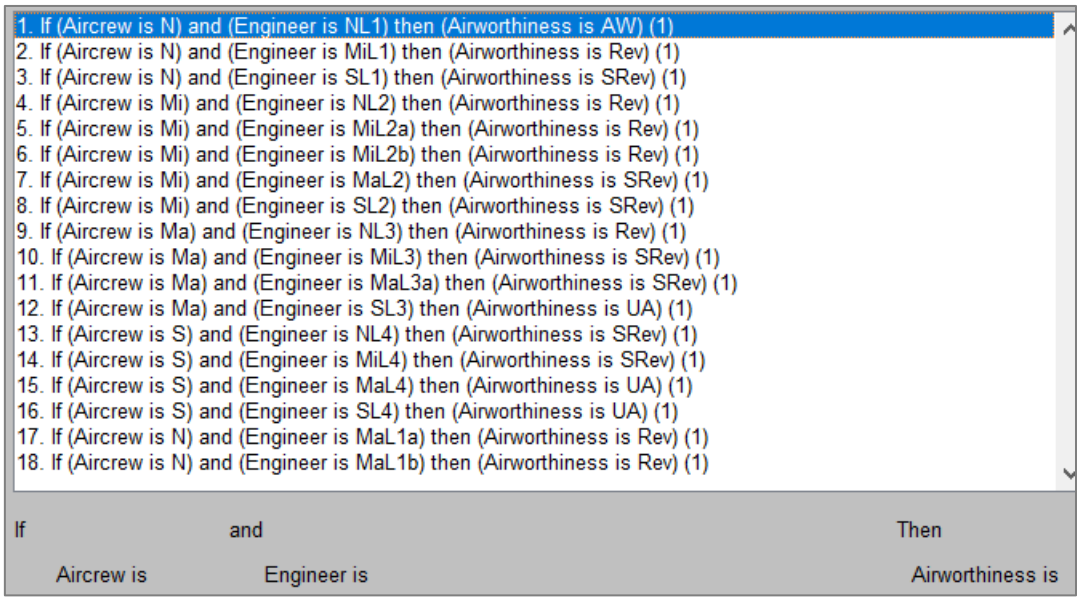


Figure E-11: Rules - 3 months for risk matrix 1

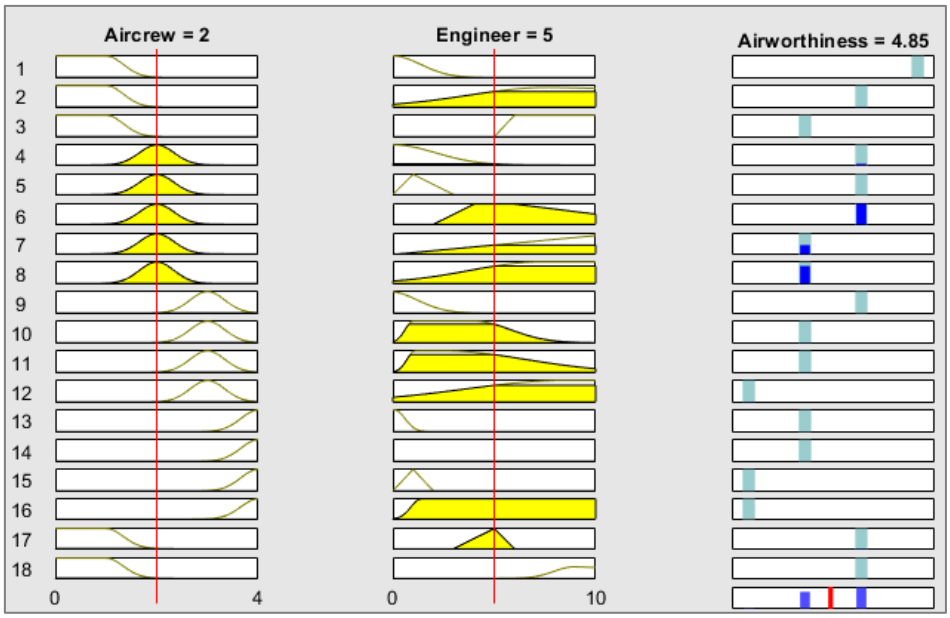


Figure E-12: Rule plots for 3 months for risk matrix 1 aircrew level 2 and engineer level 5

For aircrew level 2 – Engineer – 5 the airworthiness is 4.9.

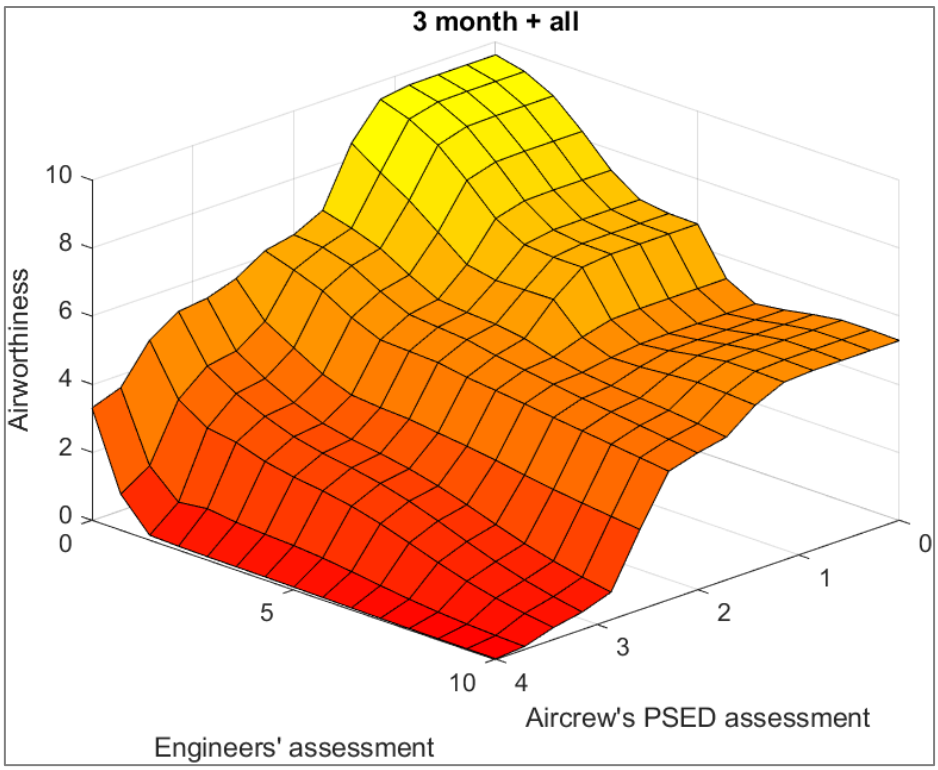


Figure E-13: Surface plot - 3 months for risk matrix 1

- Risk matrix 2

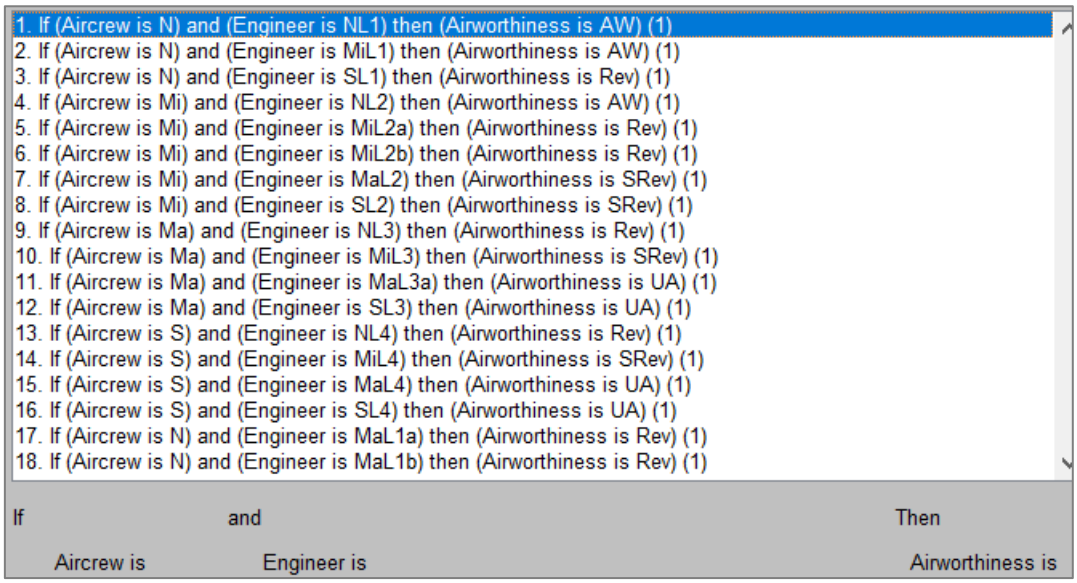


Figure E-14: Rules - 3 months for risk matrix 2

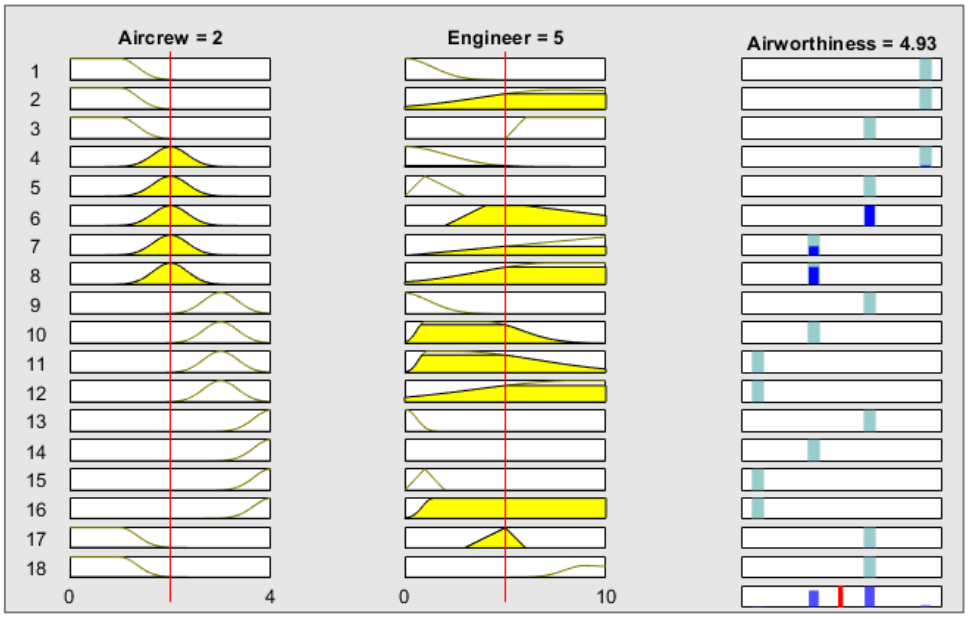


Figure E-15: Rule plots for 3 month for risk matrix 2 aircrew level 2 and engineer level 2

For aircrew level 2 – Engineer – 5 the airworthiness is 4.93.



Figure E-16: Surface plot - 3 months for risk matrix 2

E.4.3 Six months

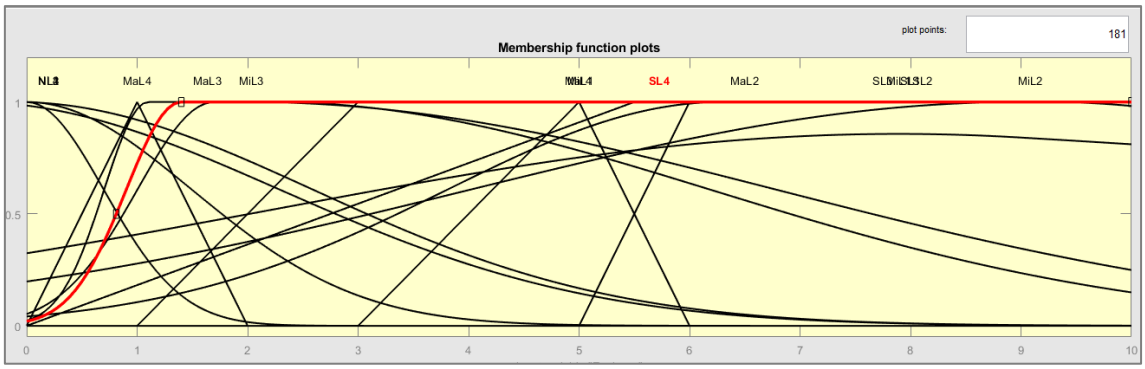


Figure E-17: Engineers' membership function plots - 6 months for risk matrix 1 and 2

- Risk matrix 1

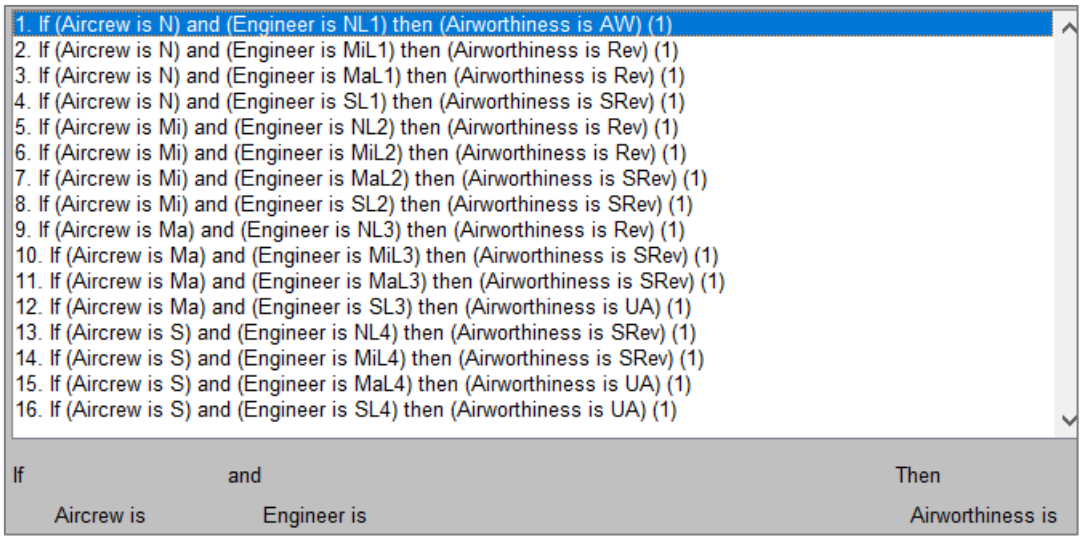


Figure E-18: Rules - 6 months for risk matrix 1

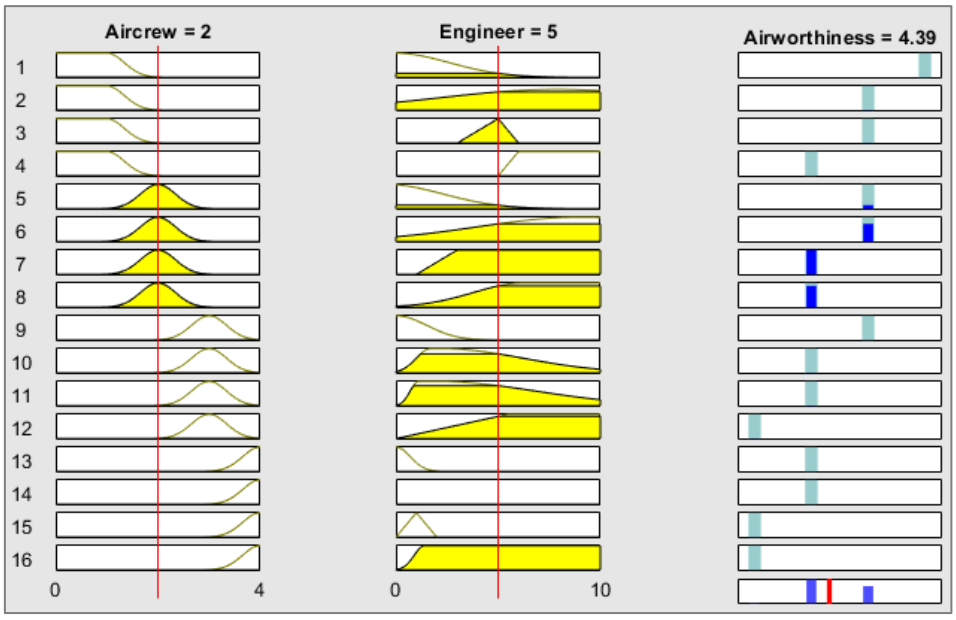


Figure E-19: Rule plots for 6 months for risk matrix 1 aircrew level 2 and engineer level 5

For aircrew level 2 – Engineer – 5 the airworthiness is 4.4.



Figure E-20: Surface plot - 6 months for risk matrix 1

- Risk matrix 2

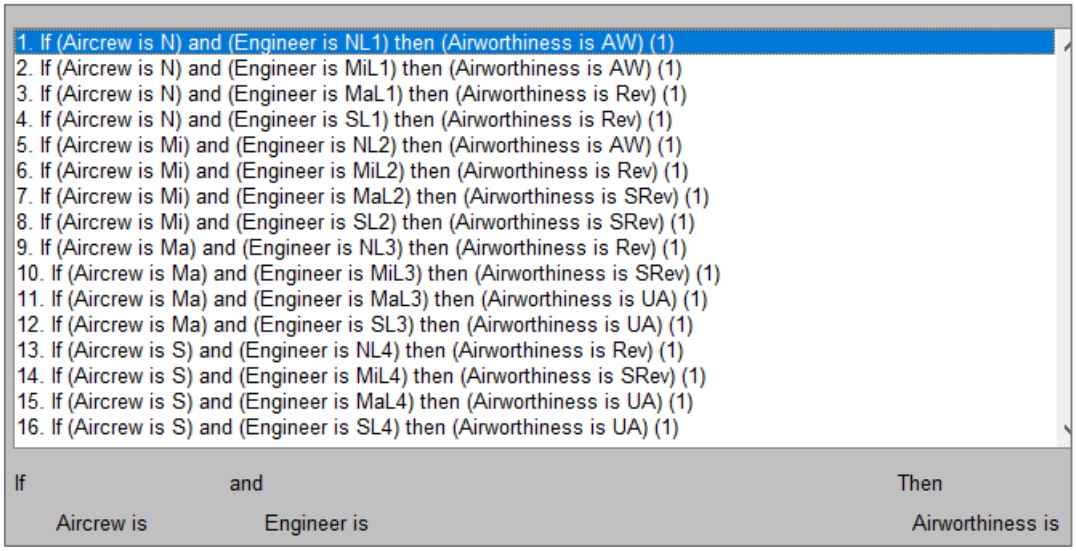


Figure E-21: Rules - 6 months for risk matrix 2

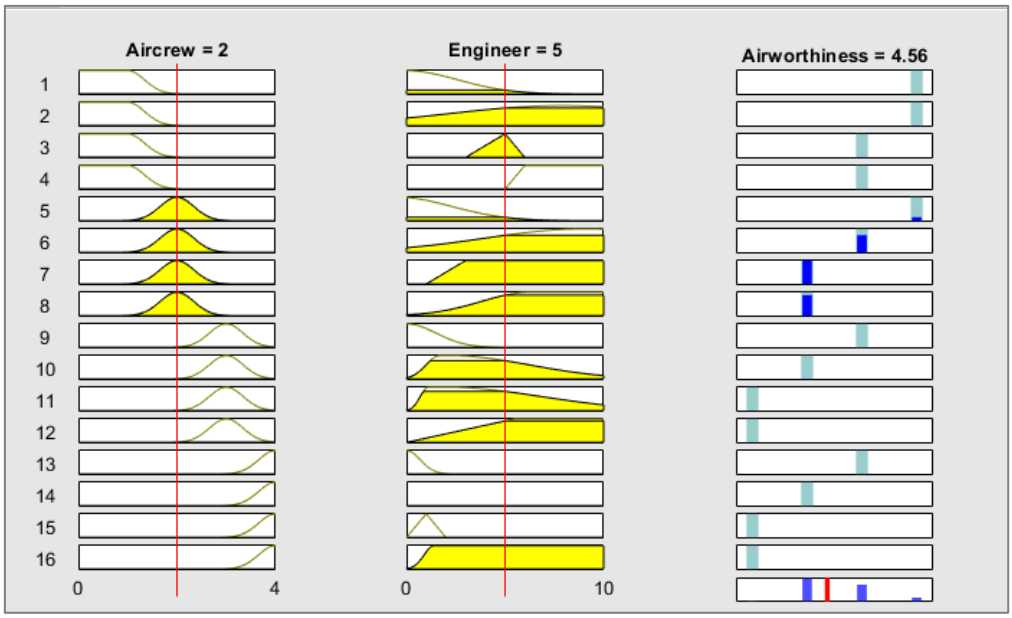


Figure E-22: Rule plots for 6 months for risk matrix 2 aircrew level 2 and engineer level 5

For aircrew level 2 – Engineer – 5 the airworthiness is 4.6.

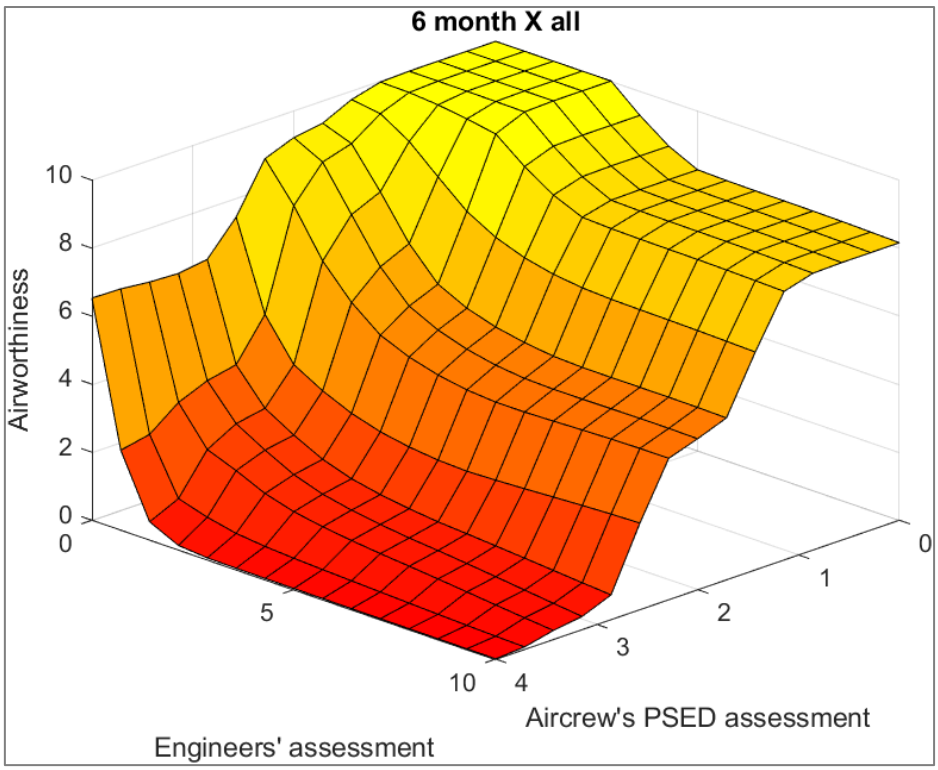


Figure E-23: Surface plot - 6 months for risk matrix 2

E.4.4 12 months

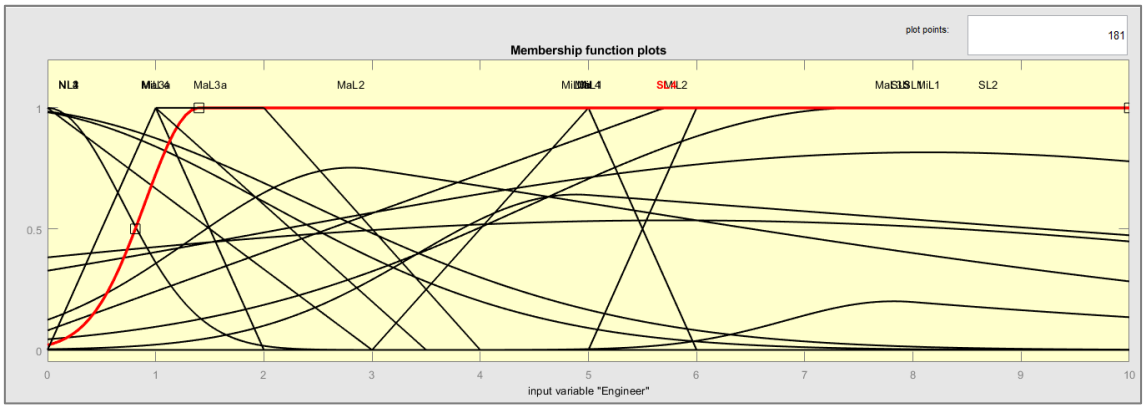


Figure E-24: Engineers' membership function plots - 12 months for risk matrix 1 and 2

- Risk matrix 1

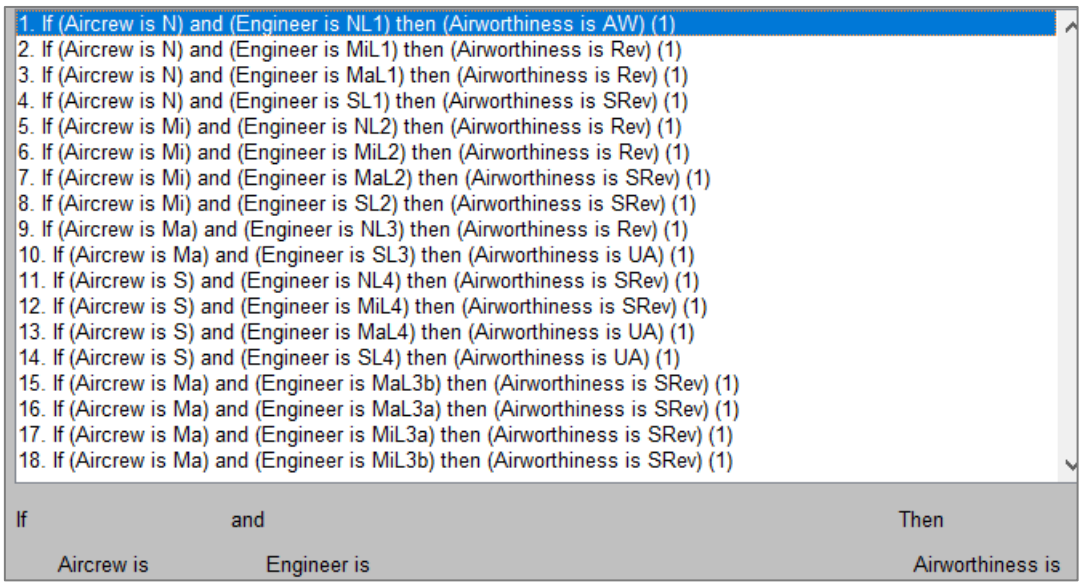


Figure E-25: Rules - 12 months for risk matrix 1

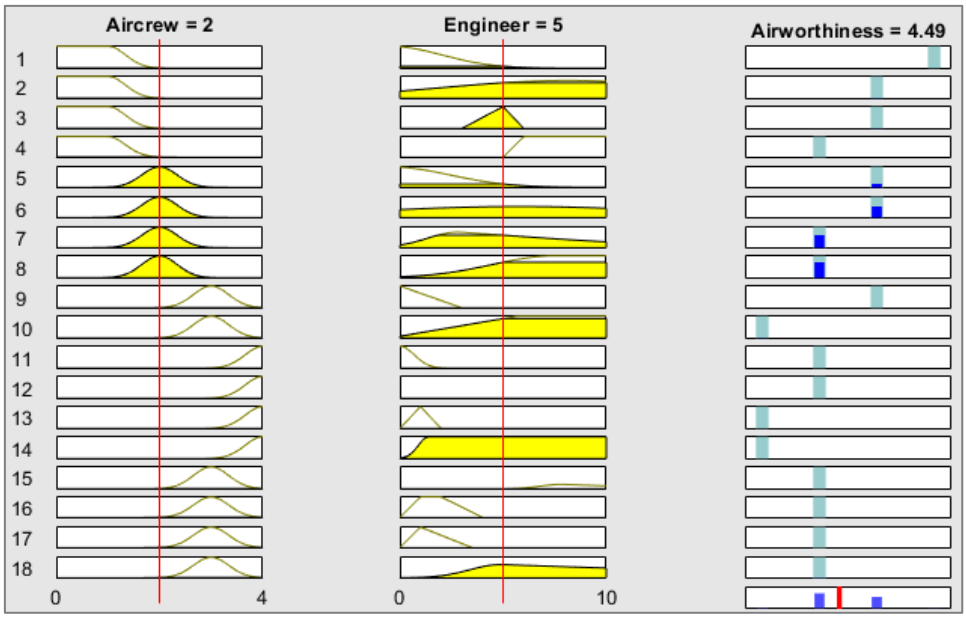


Figure E-26: Rule plots for 12 months for risk matrix 1 aircrew level 2 and engineer level 5

For aircrew level 2 – Engineer – 5 the airworthiness is 4.5



Figure E-27: Surface plot - 12 months for risk matrix 1

- Risk matrix 2

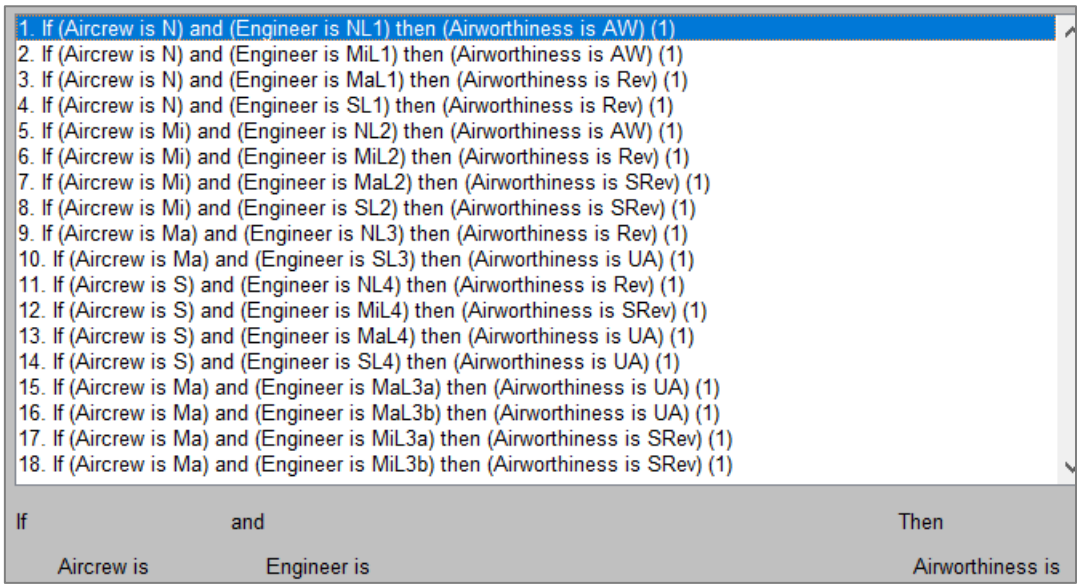


Figure E-28: Rules - 12 months for risk matrix 2

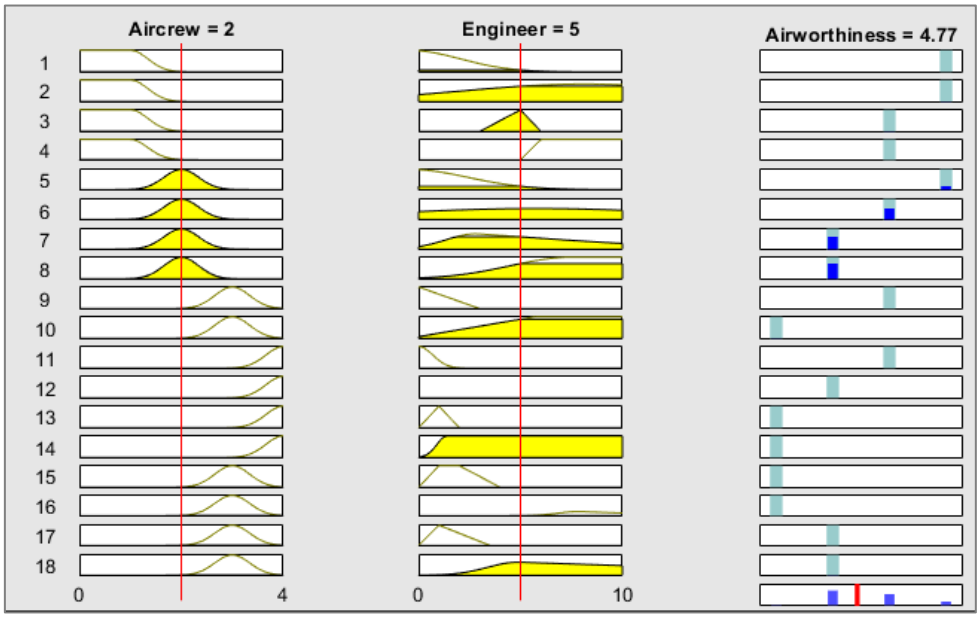


Figure E-29: Rule plots for 12 months for risk matrix 2 aircrew level 2 and engineer level 5

For aircrew level 2 – Engineer – 5 the airworthiness is 4.77.

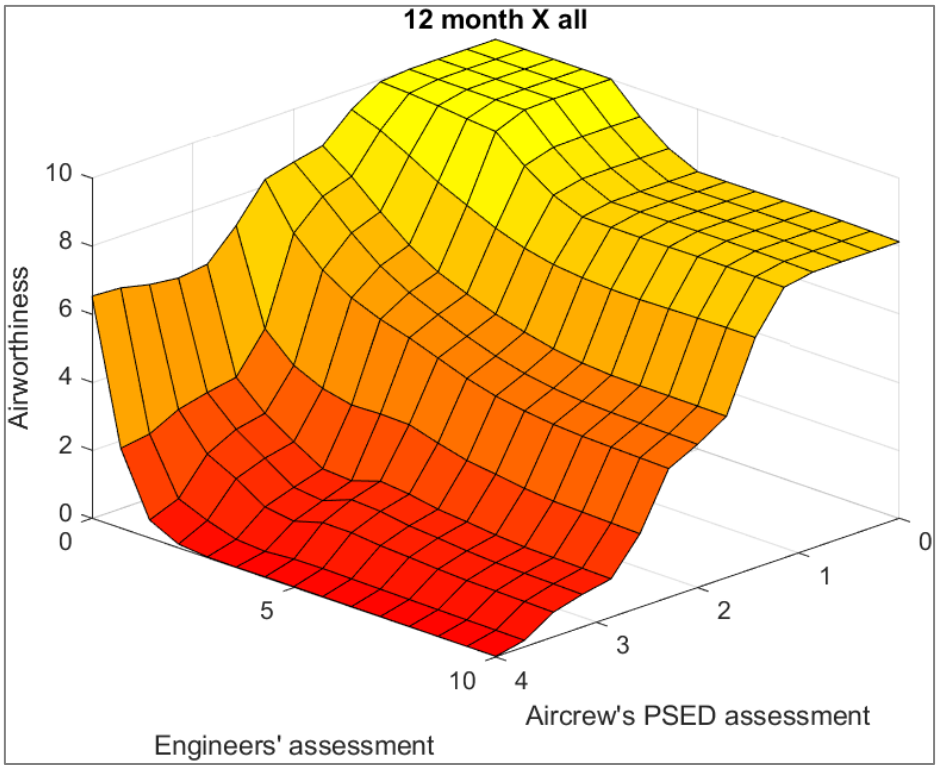


Figure E-30: Surface plot - 12 months for risk matrix 2

Appendix F - Flow chart - Aircrew and engineer – experience and knowledge assessment tool

F.1 Engineer

Knowledge

Yes / No	Level	Code
None	0	Red
Q course	1	Amber

Experience

Amount	Level	Code
None	0	Red
0 to 1 year	1	Amber 1
1 to 2 year	2	Amber 2
2 to 3 year	3	Amber 3
3 to 4 year	4	Green 1
4 to 5 year	5	Green 2

Combined knowledge and experience

	Knowledge	Level 0		Level 1	
Experience	None	0	Red	0	Red
	0 to 1 year	1	Red	1	Amber 1
	1 to 2 year	2	Red	2	Amber 2
	2 to 3 year	3	Red	3	Amber 3
	3 to 4 year	4	Red	4	Green 1
	4 to 5 year	5	Red	5	Green 2

F.2 Aircrew

Knowledge

Yes / No	Level	Code
None	0	Red
Q course	1	Amber

Experience

Amount	Level	Code
None	0	Red
0 to 1 year	1	Amber 1
1 to 2 year	2	Amber 2
2 to 3 year	3	Amber 3
3 to 4 year	4	Green 1
4 to 5 year	5	Green 2

This would have to be experience of PSED with another air system

Combined knowledge and experience

	Knowledge	Level 0 and Code		Level 1 and Code	
Experience	None	0	Red	0	Red
	0 to 1 year	0	Red	1	Amber 1
	1 to 2 year	0	Red	2	Amber 2
	2 to 3 year	0	Red	3	Amber 3
	3 to 4 year	0	Red	4	Green 1
	4 to 5 year	0	Red	5	Green 2

F.3 Aircrew and engineer combined

	Aircrew	Engineer	Effect
Level	Level	Level	Code
0	Amber 1	Red	Red
1	Amber 1	Amber 1	Amber 1
2	Amber 1	Amber 2	Amber 2
3	Amber 1	Amber 3	Green 1
4	Amber 1	Green 1	Green 1
5	Amber 1	Green 2	Green 2

	Aircrew	Engineer	Effect
Level	Level	Level	Code
0	Amber 2	Red	Red
1	Amber 2	Amber 1	Amber 2
2	Amber 2	Amber 2	Green 1
3	Amber 2	Amber 3	Green 1
4	Amber 2	Green 1	Green 2
5	Amber 2	Green 2	Green 2

	Aircrew	Engineer	Effect
Level	Level	Level	Code
0	Amber 3	Red	Red
1	Amber 3	Amber 1	Green 1
2	Amber 3	Amber 2	Green 1
3	Amber 3	Amber 3	Green 2
4	Amber 3	Green 1	Green 2
5	Amber 3	Green 2	Green 3

	Aircrew	Engineer	Effect
Level	Level	Level	Equals
0	Red	Red	Red
1	Red	Amber 1	Red
2	Red	Amber 2	Red
3	Red	Amber 3	Red
4	Red	Green 1	Red
5	Red	Green 2	Red

	Aircrew	Engineer	Effect
Level	Level	Level	Equals
0	Green 1	Red	Red
1	Green 1	Amber 1	Green 1
2	Green 1	Amber 2	Green 2
3	Green 1	Amber 3	Green 2
4	Green 1	Green 1	Green 3
5	Green 1	Green 2	Green 3

	Aircrew	Engineer	Effect
Level	Level	Level	Equals
0	Green 2	Red	Red
1	Green 2	Amber 1	Green 1
2	Green 2	Amber 2	Green 2
3	Green 2	Amber 3	Green 3
4	Green 2	Green 1	Green 3
5	Green 2	Green 2	Green 4

Engineer	Amount	Knowledge		Experience						Knowledge and Experience					
		Engineer Level													
Aircrew		L0	L1	L0	L1	L2	L3	L4	L5	L0	L1	L2	L3	L4	L5
Knowledge	Level 0	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red
	Level 1	Red	Amber 1	Red	Amber 1	Amber 2	Green 1	Green 1	Green 2	Red	Amber 1	Amber 2	Green 1	Green 1	Green 2
Experience	Level 0	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red
	Level 1	Red	Amber 1	Red	Amber 1	Amber 2	Green 1	Green 1	Green 1	Red	Amber 1	Amber 2	Green 1	Green 1	Green 2
	Level 2	Red	Amber 2	Red	Amber 2	Green 1	Green 1	Green 2	Green 2	Red	Amber 2	Green 1	Green 1	Green 2	Green 2
	Level 3	Red	Amber 3	Red	Green 1	Green 1	Green 2	Green 2	Green 3	Red	Green 1	Green 1	Green 2	Green 2	Green 3
	Level 4	Red	Green 1	Red	Green 1	Green 2	Green 2	Green 3	Green 3	Red	Green 1	Green 2	Green 2	Green 3	Green 3
	Level 5	Red	Green 2	Red	Green 2	Green 2	Green 3	Green 3	Green 4	Red	Green 2	Green 2	Green 3	Green 3	Green 4
Knowledge and Experience	Level 0	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red
	Level 1	Red	Amber 1	Red	Amber 1	Amber 2	Green 1	Green 1	Green 2	Red	Amber 2	Green 1	Green 1	Green 1	Green 2
	Level 2	Red	Amber 2	Red	Amber 2	Green 1	Green 1	Green 2	Green 2	Red	Green 1	Green 1	Green 2	Green 2	Green 3
	Level 3	Red	Green 1	Red	Green 1	Green 1	Green 2	Green 2	Green 3	Red	Green 1	Green 2	Green 2	Green 3	Green 3
	Level 4	Red	Green 1	Red	Green 1	Green 2	Green 2	Green 3	Green 3	Red	Green 2	Green 2	Green 3	Green 3	Green 4
	Level 5	Red	Green 2	Red	Green 2	Green 2	Green 3	Green 3	Green 4	Red	Green 2	Green 3	Green 3	Green 4	Green 4

Appendix G - Flow Chart – PSED Airworthiness levels

DEFINITION: “Airworthiness is the ability of an aircraft or other airborne equipment or system to be operated in flight and on the ground without significant hazard to aircrew, ground crew, passengers or to third parties; it is a technical attribute of materiel throughout its lifecycle;” it is to be undertaken by competent and authorized individuals, according to approved procedures and instructions.

Level 1	Description – Was the airworthiness level of the aircraft impacted? Level 1 - Negligible to none. Minimal to no impact on the sortie. Mission was completed successfully. No reversion to backup modes.
Level 2	Description - Was the airworthiness level of the aircraft impacted? Level 2 - Minor Sortie/Mission completed successfully but had to engage aircraft backup system(s). Took slightly more risk. Had to revert to ‘old school’ flying skills.
Level 3	Description - Was the airworthiness level of the aircraft impacted? Level 3 - Major Sortie outcome only partially effective despite the engagement of reversionary (backup) systems. Partially completed the sortie objectives. Scope of mission plan had to be altered.
Level 4	Description - Was the airworthiness level of the aircraft impacted? Level 4 - Severely Mission not completed, even with reversionary modes engaged. Stopped trying to achieve mission objectives. Focus reverted to surviving flight and landing the aircraft.