ROOT-CAUSE ANALYSIS OF RSAF MAINTENANCE-RELATED FLIGHT SAFETY MISHAPS

THESIS

Heaf Alqahtani, Major, RSAF

AFIT-ENV-MS-22-S-072

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT-ENV-MS-22-S-072

ROOT-CAUSE ANALYSIS OF RSAF MAINTENANCE-RELATED FLIGHT SAFETY MISHAPS

THESIS

Presented to the Faculty

Department of Systems Engineering and Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Engineering Management

Heaf H. Alqahtani, BS

Major, Royal Saudi Air Force (RSAF)

September 2022

AFIT-ENV-MS-22-S-072

ROOT-CAUSE ANALYSIS OF RSAF MAINTENANCE-RELATED FLIGHT SAFETY MISHAPS

Heaf H. Alqahtani, BS

Major, Royal Saudi Air Force (RSAF)

Committee Membership:

Alfred E. Thal, Jr., PhD
(Chair)

John J. Elshaw, PhD
(Member)

Brent T. Langhals, PhD
(Member)

AFIT-ENV-MS-22-S-072

Abstract

Flight safety depends on maintenance; however, poor maintenance is a major factor in many aviation mishaps. This is due to the fact that some maintenance activities are carried out improperly or are overlooked as a result of human error. Although maintenance staff are accountable and responsible for their actions, it is important to acknowledge that maintenance mistakes are a visible sign of deeper organizational issues. Therefore, adequate solutions to maintenance issues must consider organizational influences. Despite efforts reduce the accident rate within Royal Saudi Air Force (RSAF), the RSAF suffers from an increasing trend in mishaps attributed to maintenance. Safety data was subsequently analyzed to gain an understanding of the problem nature and to discover trends within the data. Additionally, the Human Factors Analysis and Classification System (HFACS) was used to investigate previous accidents reports in an attempt to discover the root causes behind the accidents. HFACS was applied to 16 maintenance-related accidents to capture the nature of and connections among latent conditions and active failures, as well as uncover the underlying causes to the accidents. Twelve-hour shifts, fatigue, shift handover documentation & recordkeeping, and management response to maintenance issues were among the underlying causes discovered in this research.

Acknowledgements

I want to express my appreciation to Dr. Alfred Thal, my thesis and academic adviser, for his guidance and mentorship throughout this research and my academic career. Additionally, I want to thank Dr. John Elshaw and Dr. Brent Langhals from my thesis committee, whose suggestions and insights made this study feasible. I want to express my gratitude to my wife and daughters for their support and patience throughout this endeavor.

Table of Contents

List of Figures

Page

List of Tables

Page

Definition of Terms

RSAF	Royal Saudi Air Force
MSC	Maintenance Squadron Commander
LWC	Logistics Wing Commander
SAFO	Safety and Foreign Objects
IM	Intermediate maintenance
OM	Organization Maintenance
FWC	Flying Wing Commander
FSC	Flying Squadron Commander
SWC	Safety Wing Commander
BSO	Base Safety Office
KKTC	King Khalid Training Center
MSO	Maintenance Safety Officer
CPL	Commander Policy Letter
QVI	Quality verification Inspection
MRL	Master Reference library
AQL	Accepted Quality Level
MTC	Maintenance Training Center
KKAB	King Khalid Air Base
FS-005	Flight Safety Incident Report
MDS	Maintenance Data Analysis
QIS	Quality Information System

I. Introduction

Military aviation accidents are considered very costly accidents, not only in terms of loss of lives and property, but they may also cause the nation to lose a unique defense weapon that may threaten its military capability and weaken its political position. From this point of view, the Royal Saudi Air Force (RSAF) lost two pilots and five fighter aircraft in 2021. The deceased are irreplaceable, and lost aircraft could be irreplaceable for the RSAF as well. Therefore, this research attempts to shed light on the reasons that led to the current aviation safety situation within the RSAF.

Background and Significance of Study

According to the International Civil Aviation Organization (2022), safety is defined as "the condition in which, through a continuous process of hazard identification and risk management, the risk of harm to persons or of property damage is reduced to, and maintained at or below, an acceptable level." The field of aviation is a field full of hazards; whether these hazards affect humans or equipment, they are mostly serious in nature and expensive in dollar value. That is the reason why attention to safety within the aviation industry must be a concern for everyone involved (Winter, 2001).

In the last 50 years, the safety of air travel has dramatically increased in the United States. Aircraft are more dependable, navigation systems are upgraded, and flights operate with more detailed and up-to-date weather reports thanks to the collaborative efforts of manufacturers, air carriers, government agencies, and many others. Pilots are also highly trained with the assistance of incredibly advanced flight simulators (Wells, 2006).

Ancel et al. (2014) discussed how learning from past accidents is the fundamental strategy for enhancing safety and preventing new accidents. In Cincinnati for instance, an Air Canada DC-9 disaster led to the installation of smoke alarms and floor-level lights. Lessons from a Delta L-1011 tragedy in Dallas led to modifications in pilot training and flying protocols meant to prevent wind shear. Lessons acquired from a US Air Fokker 28 disaster in New York led to changes in deicing and anti-icing methods for aircraft. Because of the lessons acquired from the Aloha B-737 tragedy in Hawaii, testing and inspection methods for structural fatigue and corrosion were modified (Ancel et al., 2014).

It is not as easy as it would seem to investigate the reasons behind accidents. Accidents are usually the result of a series of events some of which may be regarded as causes (Reason, 2000). The possible safety issues that are highlighted might vary depending on how these multi-cause events are perceived. Imagine a scenario where an aircraft loses one of its two hydraulic reservoirs just as it is about to take off. The crew must accurately diagnose the issue and respond swiftly and precisely in order to prevent an accident, even though modern passenger aircraft are built to experience hydraulic failure and still actually fly for a limited period of time. A crash might occur if the crew pauses or makes even a little error. If the aircraft did crash, the pilot's fault is likely to be the cause. However, it might also be attributable to system failures, as the pilot would not have been put in such a challenging scenario if the system had not failed.

Traditional safety programs concentrate on the final moment at which an accident may have been prevented in an effort to learn from safety issues that have previously contributed to fatal crashes and major mishaps. Such a strategy always highlights the pilot or the maintainer. It is a legitimate strategy that might help advance pilot training and maintenance programs. However, there is another, equally legitimate method that emphasizes the question of what set off the chain of events that led to the disaster. Aviation safety professionals must consider both strategies to stop the series of events from beginning and ways to stop a sequence that has already started from ending in an accident (Wiegmann & Shappell, 2000).

Aviation safety is a topic that has received a great deal of attention on a global level, and this is evident in the noticeable decrease in the number of annual global aviation accidents, as shown in Figure 1. However, contrary to the global trend, Figure 2 shows that the number of aviation accidents appears to be increasing in Saudi Arabia. There were six accidents in 2021, while there were four accidents in 2019 and one accident in 2013 (International Civil Aviation Organization, 2022).

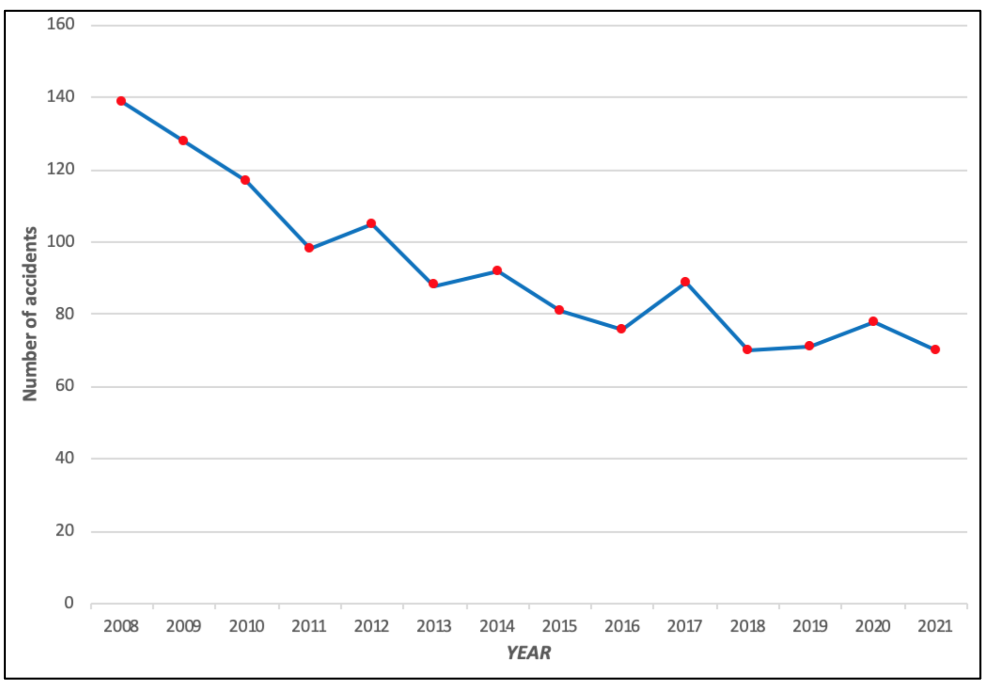

Figure 1. Global Number of Accidents per Year (ICAO, 2022)

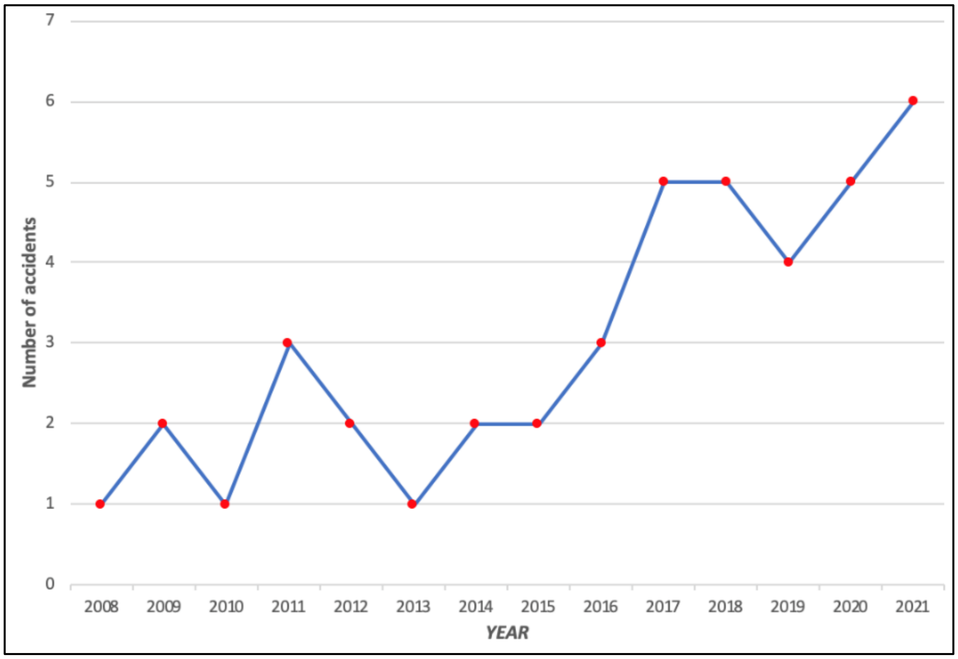

Figure 2. Saudi Arabia Civil Aviation Accidents per Year (ICAO, 2022)

Looking into military aviation, the U.S. Air Force accident rate witnessed a noticeable improvement over the years since the 1950s where the rate of accidents dropped dramatically, as shown in Figure 3. This may be seen from the fact that, on average, there were 32.6 mishaps throughout the 1950s (excluding mishaps in battle). During the 1970s, that rate was 6.8 mishaps for every 100,000 flights, and between 2010 and 2018, it was less than two mishaps (Light, Hamilton & Pfeifer, 2019).

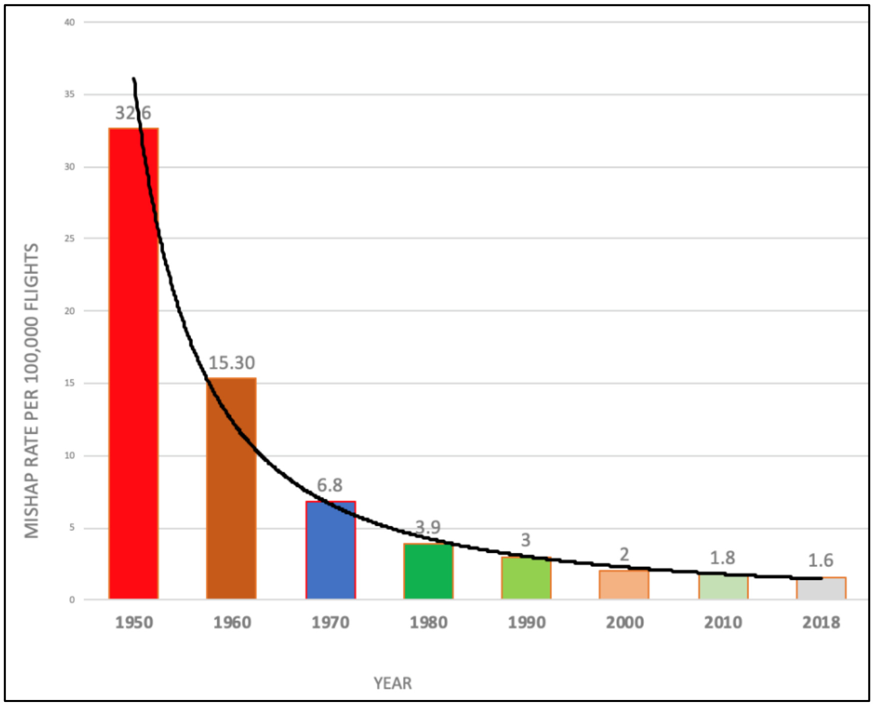

Figure 3. U.S. Air Force Fighter Aircraft Accident Rate (Light & Pfeifer, 2019)

In the RSAF, data for the year 2021 indicated a 13.1% increase in the rate of aviation accidents from the year 2020 (RSAF, 2021). There were 52 flight mishaps in 2021 (RSAF Safety Directorate, 2021). According to the annual RSAF Aviation Safety Bulletin, this is an alarming indicator (RSAF, 2021). As previously stated, the RSAF has lost two pilots and five fighter aircraft due to these flight mishaps. As seen in Figure 4, the concluded accident causes were attributed to many factors for example, maintenance error, material failure, aircrew error, and undetermined/miscellaneous. After investigations, it was found that maintenance is responsible for 61% of the total accidents. This is a serious percentage; however, it can be seen as an opportunity for improvement and development since any success towards improving maintenance safety will likely result in a considerable change to the overall accident rate.

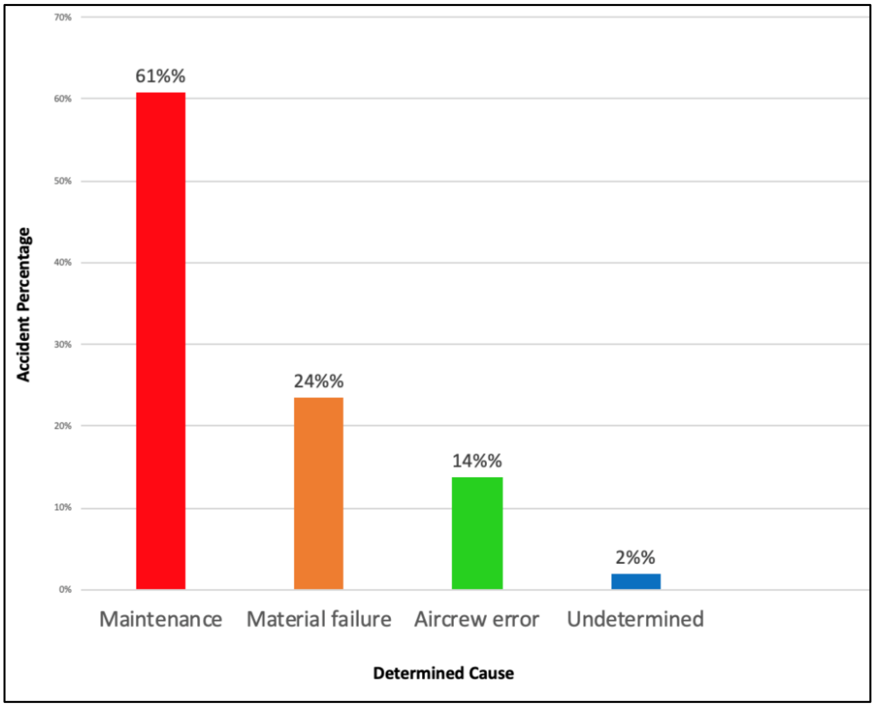

Figure 4. RSAF Accident Causes (RSAF Safety Directorate, 2021)

Flight safety mishaps are still among the current problems that the RSAF continues to encounter. The RSAF safety directorate is making considerable educational efforts to raise the level of safety in flying squadrons, as well as aircraft maintenance squadrons. These efforts take the form of periodic lectures, notice boards for flyers, and holding workshops during which the importance and danger of this field are clarified. However, each base implements its safety program, called The Safety and Foreign Object (SAFO) Program, which is defined and authorized by the safety directorate. However, although military aviation safety is a topic that has been extensively researched in the literature, each organization has special circumstances that do not necessarily apply to others. Based on this fact, no research or scientific publication has been found that specifically explores the causes of aviation accidents in the RSAF and the reason why the accident rate is increasing.

It is worth noting that the RSAF accidents were classified as serious accidents (CAT 3 and 4) that led to loss of life or property or both. Looking at the data and global safety indicators, it becomes clear that the high rate of flying accidents in the RSAF is an issue that calls for immediate action to determine the root causes and take the appropriate action to sustain safe operation environments (Light, Hamilton & Pfeifer, 2020).

The Royal Saudi Air Force possesses the necessary infrastructure to implement effective safety programs, including training programs, capabilities, and the necessary manpower to implement these programs. However, implementing an effective safety program requires starting with knowing the roots of the problem that needs to be solved, and from there solutions are developed that address the roots of the problem and make sure that they do not occur in the future (Batalov, 2021).

Problem Statement

Despite the efforts made by the Royal Saudi Air Force to improve flight safety and reduce the occurrence of accidents, the number is increasing annually. Based on data published by the Air Force Safety Directorate, there were 46 flight accidents in 2020, including two fatal accidents. This number continued to climb, reaching 52 accidents in 2021. Since 2017, the number of accidents is gradually increasing, as shown in Figure 5, and that could be attributed to many factors which will be addressed individually in the analysis portion of this thesis. This research effort will study, analyze, and investigate why, despite all RSAF safety efforts, we continue to have an increasing rate of accidents.

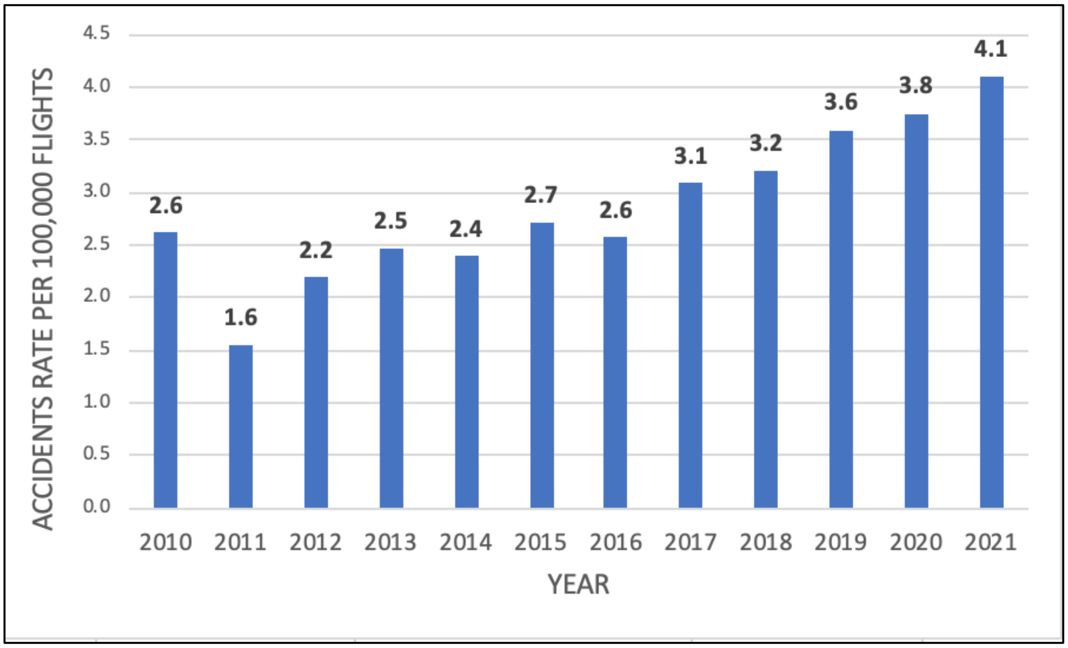

Figure 5. RSAF F-15 Accidents rate per Year

Research and Investigative Questions

The question this research is trying to answer is: What are the root causes behind the increasing number of maintenance-related accidents in the F-15 fleet within the RSAF? To address this question, this research will attempt to answer the following investigative questions.

1. What do maintenance-related accidents in the RSAF have in common?
2. What factors that led to the increasing violations and the unsafe maintainer act?
3. Is maintenance the only cause for maintenance-related accidents?

Methodology

This research is based on an analysis of archival data received from the Maintenance Data Analysis at the F-15 Maintenance Squadron at King Khalid Air Base and data from the Safety Directorate at the Royal Saudi Air Force Command. The data was extracted from the reports of the accident investigation committees to represent a dataset that can be better analyzed. An Exploratory Data Analysis was performed to show any trends and build a general understanding of the data. Additionally, the incidents were studied by applying the Human Factors Analysis and Classification System (HFACS) framework to each maintenance-related accident.

Assumptions and Limitations

The analysis in this research is based on data collected from the RSAF HQ Safety Directorate records. It is assumed that the data is generated accurately and the conclusions of investigation committees were correct. After reviewing the causes of accidents attributed to aircrews, training was not a factor and since access to aircrew training records was not possible, it is assumed that all aircrews received the appropriate level of training.

Thesis Organization

To illustrate the gap in knowledge, more in-depth literature review of related fields such as Human Factors in aviation, HFACS framework, Organizational Culture, and the process of accident investigations in aviation will be reviewed in Chapter II. Chapter III discusses the methodology of the research and introduces the chosen tools and analysis methods. Findings and results will be discussed in Chapter IV, which is followed by a general discussion of the findings and improvement proposals for related maintenance processes in Chapter V.

II. Literature Review

This chapter reviews literature related to the research question, with emphasis on four topics. The first topic reviewed is the Human Factors and Classification System (HFACS) to show how it was developed and how it works. The second topic discusses the organizational culture and how it could be a factor affecting the research question. Moving on, the third topic is human error in aviation and how it impacts aircraft maintenance workers. In this topic, some human factors theories are discussed to better understand this field and formulate a plan to approach the research question. Finally, Managing the Risk of Maintenance Error will be reviewed to illustrate the knowledge gap between what is in the literature and what is being followed in the Royal Saudi Air Force (RSAF).

Human Factors Analysis and Classification System (HFACS)

Accidents in complex systems happen as a result of the buildup of several conditions and failures. According to the renowned model shown in Figure 6, which was created by Reason (2009) using the Swiss cheese analogy, several contributors must line up for any undesirable outcomes to happen. Humans are prone to make errors by their very nature. This is represented in the holes in the cheese slices. The cheese slices represent the imperfect system barriers which are supposed to stop errors that cause the undesirable outcomes (Reason, 2009). The Swiss cheese model is one way to look at how human error begins. It explains how an accident could happen and how accidents are often not coincidental or the result of an error committed by the last worker, but rather are the result of malfunctions in different levels of the system (Reason, 2009).

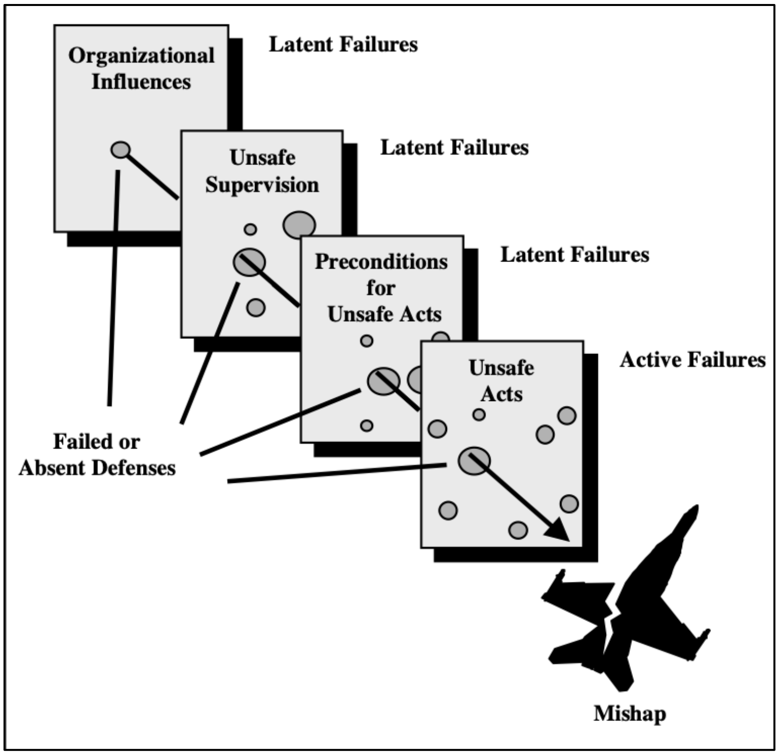

Figure 6. Reason's Swiss Cheese Model (Reason, 2009)

In 70-80% percent of all civilian and military aircraft accidents, human error was a contributor. However, the majority of accident reporting processes are not created using a theoretical model of human error. Because of this, it is difficult to identify intervention techniques because the majority of accident records are not suitable for a conventional human error examination. A generic framework for human error is needed so that new investigation techniques may be developed and accident datasets can be reorganized. In reality, a thorough system for Human Factors Analysis and Classification System (HFACS) has been created to address these requirements (Wiegmann & Shappell, 2000).

Wiegmann and Shappell (2000) were the first to employ HFACS based on Reason's Swiss Cheese model for the study of aircraft accidents. A hierarchical structure may be used to investigate accident occurrences using this broad human error analysis approach. This approach makes it feasible to detail the key active and latent failures as well as investigate the influence of human factors on accidents. The most significant characteristic that sets HFACS apart from previous accident analysis techniques is its thorough taxonomy for the investigation of organizational and human components. In difficult situations like accidents, this taxonomy makes it simple and precise to separate organizational and human factors. Following are the main components and causal categories for the HFACS framework.

Unsafe Acts

According to the HFACS, the unsafe acts of operators/workers can be divided into the two categories shown in Figure 7. An unsafe act can be simply an error or an honest mistake which we are subjected to at all times or it could be a violation which is a willful disregard for rules and regulations which operators/workers willingly sometimes do. However, separating mistakes from violations does not offer the degree of detail needed for the majority of accident investigations. As in other places (Reason, 1990; Rasmussen, 1982), the categories of errors and violations were broadened to cover three fundamental error kinds (decision-based, skill-based, and perceptual) and two types of violations (routine and exceptional).

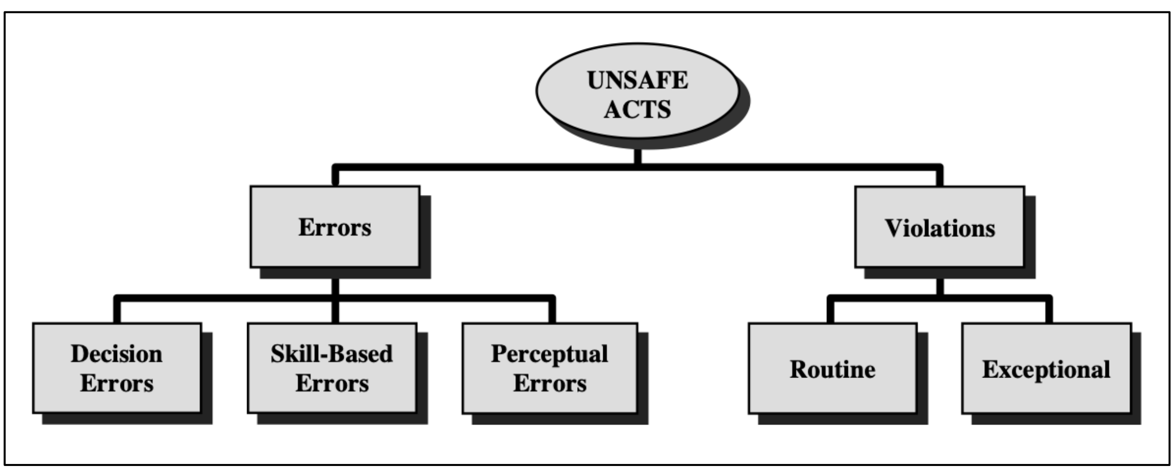

Figure 7. Categories of Unsafe Acts (Wiegmann & Shappell, 2000)

Errors are those actions committed by humans not knowing they are committing an error at that time. These types of errors are further divided into three categories. They can be decision error, skill-based error, or a perceptual error. However, these errors share a very important aspect which is that these errors were committed with the best intentions in mind. It could also be either the direct cause of an accident or a contributing factor to a cause of an accident (Wiegmann & Shappell, 2000). The following paragraph describes each error and how it came to existence.

Decision errors are the first type of errors; they involve the intentional action that goes as planned but the strategy turns out to be insufficient or improper for the circumstance. Although having "the best intentions," these unsafe actions are the result of people who either lacked the necessary information or made poor decisions. Skill-based behaviors are especially prone to cognition and memory failures. The breakdown of visual scan patterns, task fixation, accidentally activating controls, and the improper sequencing of stages in a method are just a few examples of the many skill-based mistakes that attention lapses have been connected to (Wiegmann & Shappell, 2000). Perceptual errors are those errors connected to our human senses. For example, visual illusions and spatial disorientation are examples of perceptual errors. Additionally, perceptual errors can arise when pilots incorrectly estimate the aircraft's position, orientation, or velocity.

Violations signify a deliberate disobedience for the laws and guidelines governing safe flight. Fortunately, because they typically result in fatalities, they happen far less frequently (Shappell et al., 1999b). The first type of violation, known as the “common violation,” is typically overlooked by the government (Reason, 1990). Consider someone who often exceeds the posted speed limit by 7 to 12 mph. Although the driver is undoubtedly in violation of the laws, many other people also act in this way. Furthermore, those who go 66 mph in a zone designated for 55 mph usually do so. In other words, they "regularly" go over the speed limit. If a regular violation is discovered, the investigator must go higher up the managerial hierarchy to find the people in positions of power who are not upholding the law (Reason, 2000).

Next are the exceptional violations, which can be defined as a clear departure from authority; they represent clearly breaking the norm which is not accepted in the public opinion or the government and is not categorized as being within the usual limits (Reason, 1990). An example of the exceptional violation is going 120 mph in a 55 mph highway. These violations are particularly difficult to deal with because they are unpredictable and do not represent the individual's typical behavior. In addition, people often have nothing to say when questioned to defend their reckless behavior when faced with the facts (Wiegmann & Shappell, 2000).

<u>Preconditions for Unsafe Acts</u>

The unsafe acts of workers account for more than 80% of all accident causes in aviation (Reason, 2000). Understanding why and who caused the accident is essential but it is not what an accident investigator should only be looking for. Instead, an organization should identify the systemic or underlying reasons of an occurrence, as opposed to the obvious or immediate ones, by doing a root cause analysis. An issue's symptom may be eliminated by addressing merely its immediate source, but the problem is not resolved. Dealing with only what caused the accident is similar to taking fever medication without knowing and treating what caused that fever in the first place. Some organizations do not investigate the root causes of accidents. The preconditions of unsafe acts are divided into the two main categories shown in Figure 8.

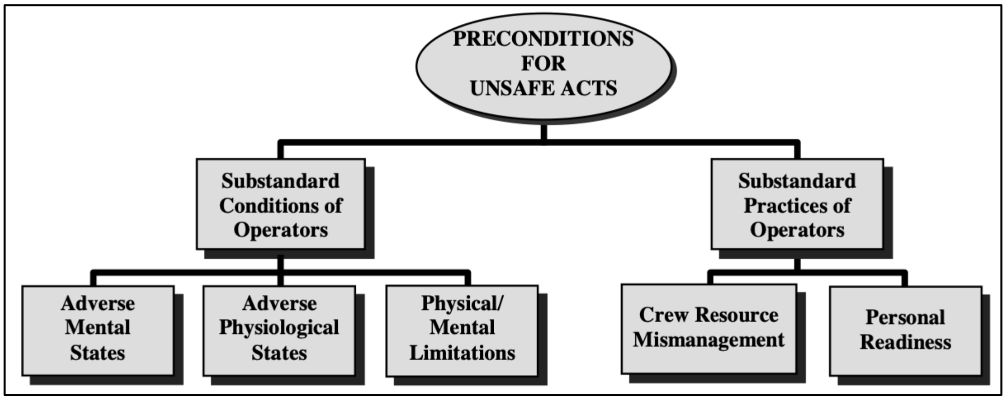

Figure 8. Pre-conditions for Unsafe Acts (Wiegmann & Shappell, 2000)

Being psychologically prepared is important in almost any activity, but perhaps more so in aviation. Situational awareness loss, task obsession, interruption, and mental exhaustion brought on by lack of sleep or other pressures are among the key examples. Personality characteristics and harmful attitudes like arrogance, complacency, and improper motivation can be included in this class. Understandably, the risk that an error will be committed increases if a person is mentally exhausted for any reason. Similar to this, ego and other harmful traits like arrogance and recklessness will affect the probability that a mistake will be committed.
The presence of negative mental states earlier in the causal chain of events must thus be considered in any framework of human error analysis (Wiegmann & Shappell, 2000).

Adverse physiological states refer to any physical or medical issues that make it difficult to perform an operation safely. Visual limitations, physical exhaustion spatial disorientation, physical exhaustion, and the wide range of pharmacological and medical disorders that are known to impair performance are all of particular importance to aviation.

Physical/Mental limitations specifically covers situations where the task requirements are more than what the person in charge is capable of. Examples include a maintenance worker replacing a heavy part without the necessary tools or a pilot who does not have the physical capacity to operate during a high G maneuver. Pushing the limits on the physical and mental limits of individuals is more likely to result in an error (Reason, 2000).

For instances of ineffective staff coordination, the category of crew resource mismanagement was introduced. This refers to coordination between and among aircraft, air traffic control and maintenance in the aviation domain. It is simple to picture a situation in which a lack of crew cooperation resulted in uncertainty and faulty decision-making in the cockpit which then resulted in a disaster. In practice, there are several instances of ineffective crew communication in aviation disaster records (Reason, 2009).

Unsafe Supervision

As shown in Figure 9, inadequate supervision, planned inappropriate operations, failed to correct problem, and supervisory violations are the four forms of unsafe supervision that was discussed in the HFACS framework (Wiegmann & Shappell, 2000). The supervisor is responsible for providing direction, opportunity for training, mentoring, and motivation, as well as serving as a good example. However, it does not always happen. Any successful company requires dependable expert monitoring and leadership

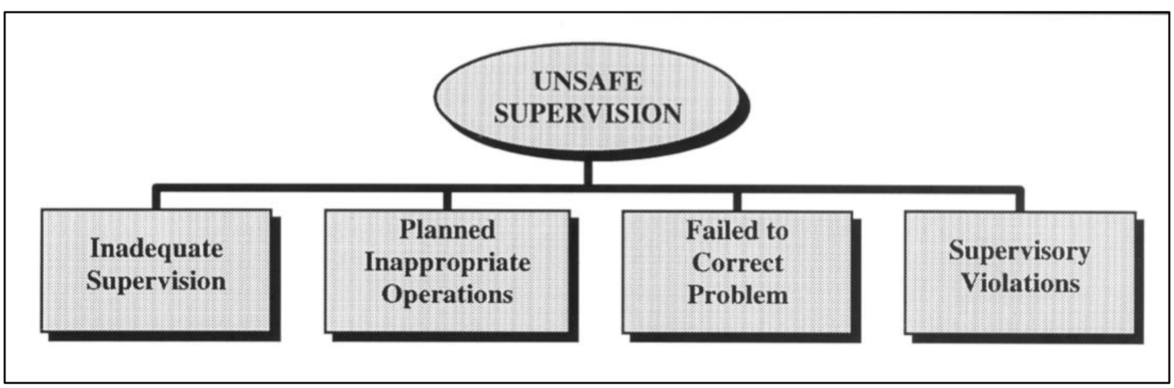

Figure 9. Unsafe Supervision (Wiegmann & Shappell, 2000)

While giving people the freedom to make decisions and work independently is unquestionably important, it does not absolve the manager of responsibility. Many of the errors that have snuck into the cockpit were found to be caused by a lack of supervision and direction (Reason, 2000). As a result, the role supervision plays in the development of human mistakes must be considered in any complete analysis of accident-causing elements.

Occasionally, the operating pace and/or the management of aircrew puts people in an intolerable danger, jeopardizes crew rest, and eventually has a negative impact on performance. During exceptional circumstances, leadership might be forced to enforce some decisions which normally will not be enforced. For example, during an emergency, leadership might order an aircrew to fly during their crew rest time.

Failing to Correct Problem refers to situations in which supervision is "aware" of problems with employees, training, equipment, or other associated safety areas, yet the problems are nonetheless allowed to continue unchecked and the problem is left uncorrected. However, unsafe environments and rule-breaking results when inappropriate behavior is not constantly corrected or penalized.

Supervisory violations refer to situations where supervisors willfully violate existing rules and procedures. Supervisors have been seen to go against the rules when managing their assets; however, this is debatably rare. For instance, there have been instances where people have been given permission to carry out a duty without the necessary training or authorization. It is also possible to argue that disregarding existing laws and regulations or abusing power are violations at the supervisory level.

Organizational Influences

Upper-level management's poor judgments have a direct impact on supervision procedures, worker conditions, and behaviors. Consequently, safety experts frequently miss these organizational mistakes since there is not a defined foundation from which to look into them. The most unknown underlying failures typically include problems that relate to resource management, organizational climate, and operational processes as shown in Figure 10 (Wiegmann & Shappell, 2000). However, to make it easier for committees to investigate organizational influences, the committees should be formed to have independent, expert, and unbiased members.

Figure 10. Organizational Influences (Wiegmann & Shappell, 2000)

Resource Management covers the area of corporate-level decision-making with relation to the distribution and upkeep of organizational assets including manpower, financial assets, machinery and buildings. Serious cost-cutting may also restrict financing for new equipment purchases or result in the purchase of equipment that is not optimum or properly built for the desired operations. Poorly maintained workplaces and equipment, as well as the neglect of current equipment's recognized design problems, are further consequences that cascade down.

As a result, untrained, less-skilled workers are forced to service outdated, subpar aircraft under less than ideal circumstances and time constraints.

Organizational Climate alludes to the environment at work within the company. The organizational structure is represented in the chain of command, the division of labor, the communication patterns, and the legal accountability for actions. Within an organization, coordination and communication are essential. Organizational safety definitely suffers and accidents occur when leaders and staff are not in communication or when no one is sure who is in control (Muchinsky & Howes, 1997). An example of the influence of the organization climate over the performance of workers is whenever it tolerates bad work behaviors, good workers, for many reasons, are likely to stop being good and follow the footsteps of everyone else.

Operational processes refer to the organization's rules and regulations that control day-to-day operations inside an organization. Time pressure, formal means of communication between employees and management, shift patterns, and reward systems are some of the examples that fall under this category.

Organizational Culture

What is an organization's culture? Intuitively, one might assume the term is referring to the set of values and behaviors that members of an organization have normalized and which have become the norms. "It is how we do things around here" regardless of whether it is the wrong or the right thing to do. Culture is both an ever-present dynamic phenomena that is continually generated by our interactions with others and molded by leadership conduct, as well as a collection of routines, structures, rules, and standards that direct and control behavior (Smith, 2003). Organizational culture is a term that refers to the prevailing and recognized atmosphere among the employees of the organization, and it is one of the characteristics that distinguish organizations from each other (Light, Hamilton & Pfeifer, 2019). An interesting feature of culture as a concept is how it alerts us to things that are profound in their effects, yet unseen. We can observe the resulting behavior, but frequently we are unable to observe the underlying causes that give rise to certain patterns of behavior. Just as our personality and character shape and limit our conduct though, so too can common norms held by members of a group shape and limit the behavior of those members.

Managers strive to influence the behavior of their employees, but they frequently run across an employee’s reaction that seems like a fear of change which is often irrational. It is common to see organizations with several departments that appear more concerned with arguing with each other than getting the work done. It can be observed that there are issues with group members' interactions and conflicts which should not exist between logical people. Understanding the complexity of culture will allow us to understand why individuals or organizations can be so different, as well as why it can be difficult to change them. We should be less confused, annoyed, and worried when we encounter unusual and somewhat irrational conduct among employees and management. Even more crucially, a deeper understanding of culture will help us better comprehend who we are as individuals, the factors that shape who we are, the groups with which we identify, and the groups to which we want to belong (Smith, 2003).

When existing beliefs and norms might contribute to organizational failure, change is essential for an organization's existence (Karube, Numagami & Kato, 2009). Organizational transformation is the practice of implementing behavioral science-based tactics to adjust at work and increase performance via changing employee behavior (Bale, 2008). Piderit (2000) developed the force-field theory by advancing Lewin's concept of resistance as "a restraining force acting in the direction of sustaining the status quo" (Lewin, 1947). Employee attitudes, cognitive and emotional processes, and managerial behavior are all blamed for resistance (Smollan 2009). According to Piderit (2000), resistance might take the form of deliberate actions of disobedience, a certain sort of inactivity, or even a readiness to lie to officials. Since meaning for people exists at the subjective level, it is necessary to develop communication tactics at that level (Mouton, Just & Gabrielsen, 2012).

Lean and Action Research are two examples of significant context-driven actions that may help persuade the more hesitant workers to adopt change and willingly correct their own behavior. Only when dissonance is clearly understood and handled can the fight for consistency between declared and practiced values be won. Otherwise, the organization would experience the negative impacts of its unconscious behaviors and unintentionally degrade. What is important to realize is that previous behaviors of individuals and groups can subtly undermine an organization's viability and that better approaches can be found in the study of topics like psychology, lean manufacturing, action research, and resistance to change (Danese, Manfè & Romano, 2017).

In conclusion, culture may be thought of as the collective knowledge that members of a group have acquired over time. This knowledge includes mental, affective, and behavioral aspects of the group members' overall psychological functioning. In order for this type of shared learning to take place, there must be a record of prior shared experiences, which entails some degree of membership stability. With this stability and a common past, the numerous shared parts will ultimately coalesce into patterns that may be referred to as a culture as a result of human desire for consistency, stability, and meaning.

Human Factors

Human error is subjective to every human. However, the negative consequences of human failure or human error tend to be common. Human error builds on one's weaknesses and cognitive disabilities, which leads to an adverse reaction or outcome. In the case of aircraft, human error may be the most significant factor when it comes to aircraft accidents, aircraft breakdowns, aircraft dysfunctionalities, etc. "Reason's use of learning and performance mechanisms to explain errors is an exciting demonstration of the power of cognitive theory. It is true to his thesis that errors arise out of normally adaptive psychological processes" (Kirschenbaum, 1990). Kirschenbaum (1990) describes the mechanisms and backing of human cognitive behavior that lead to making errors. Kirschenbaum (1990) highlights that the performance mechanisms have a strong bearing on the magnitude of the error; therefore, it will not be an exaggeration to say that performance mechanisms and human error have a direct relationship.

In terms of the aircraft industry, human error has a more specified definition. "According to the definition, the human factor is an unintentional error in the work which results in immediate damage of the system or it may be a hidden error which represents a potential danger for the technical airworthiness of the aircraft" (Virovac, 2017). Here, Virovac (2017) provides an immaculate description of the word 'human error' with respect to aircraft maintenance. Virovac (2017) simply builds on the relationship of human error being a large reason enough to cause potential danger to the technicality and functionality of the aircraft. "The modern era of aviation has witnessed an ironic reversal of sorts. It now appears to some that the aircrew themselves are deadlier than the aircraft they fly" (Mason, 1993; cited in Murray, 1997). In fact, estimates in the literature indicate that "between 70 and 80 percent of aviation accidents can be attributed, at least in part, to human error" (Shappel, 2000).

Now that we have established the true meaning of the word human error, we can study in-depth the human errors in aircraft maintenance. For starters, we will talk about the different types of accidents that occur due to human error. At times, the aircraft is flown towards the ground without any explainable or traceable reasons. This circumstance tends to create a huge safety hazard and a cause of concern for all the people directly involved. For instance, Shappell (2001) states, "Most agree that Controlled Flight into Terrain CFIT is an unintentional collision with terrain occurs when an airworthy aircraft, under the control of a pilot, is flown into terrain (water or obstacles) with inadequate awareness on the part of the pilot of the impending disaster." Here, Shappell (2001) highlights that such accidents are usually attributed to the lack of awareness on the part of the pilot. At times, these attributes or lack of awareness could be attached to personal mental or phycological disorders. Shappell (2001) states that a stressful and dysfunctional mind is more likely to either zone out or make a mistake due to the inability to focus.

Adding to the causes, we can also shed light on unsafe procedures and faulty process lines. Even though organizations have large and efficient inspection teams, there is still a chance that some errors or faults could have been ignored or overlooked before final execution. Anu (2016) sheds light on it by exclaiming, "Traditional fault-based requirements inspection techniques (like Fault Checklist inspection) focus inspectors' attention on a different type of faults (e.g., incorrect or incomplete or ambiguous requirements). Even a faithful application of validated fault-based techniques does not help inspectors in finding all faults." Anu (2016) highlights how much of a deterrent it is to the safety of all stakeholders regardless of how many inspection units are set up. Adding to this, Anu (2016) also highlights that since many of the faults are not identified earlier, they pose greater costs when they are discovered later. Anu (2016) asserts that most of the budget and time of the organization and the members of the organization respectively is spent on fixing the failures that could have been prevented in the first place.

Another underlying reason for increased human errors is frequent maintenance. The aviation and aircraft industry call for drastic and frequent maintenance. If, however, the maintenance is influenced by commercial backings, it is more likely to have a detrimental effect on the smooth and efficient operations of the organization. Commercially backed maintenance requires certain aircraft equipment to stay out of use, which ultimately results in lower productivity and efficiency. This tends to cause delays in operations which serve as an obstacle to the reduction in human error (Pennie, 2007).

In another instance, Hobbs (2008) initially presented the notion of how maintenance tends to give rise to human failure and human error. This is mainly attributable to the state where the machinery or equipment cannot be used due to them undergoing the maintenance process. In such situations, due to lack of time and poor productivity, there is a greater chance of a human error occurring. However, Hobbs (2008) later builds on the idea of power outages and maintenance quality as the major contributing factors. Hobbs (2008) builds on his argument, "Maintenance errors not only pose a threat to flight safety, but can also impose significant financial costs through delays, cancellations, diversions, and other schedule disruptions."

Human Error Reduction in The Aviation Industry. Moving further, now we will attempt to deeply look for and analyze reasons that result in a greater chance of a human error occurring in the aircraft industry and maintenance; we can propose a series of solutions that have proved to be effective in the past to help resolve the issue. For example, Cacciabue (2004) states, “When performing a process of design or assessment of a Human Machine System HMS, it is essential that the specific area of application of the system under study is well delineated. This differs from the point of view on identification of the goals of the system of thought; there are strong links between these two standpoints. In practice, four areas of application must be considered, namely, Design, Training, Safety Assessment, and Accident Investigation.” Cacciabue (2004) here highlights a four-factor framework that could be put into effect as a promising solution to the problem at hand. The first step includes the assurance of an accurate design for aircraft equipment and materials. The design and structure of the aircraft equipment should be as such that it ensures smooth and perfect running without limited risks of breaking down. The second step includes proactive training. Training is integral to smooth operations in such a setting. Training allows workers to thoroughly know and understand how to operate aircraft equipment and tools. If a worker fails to properly operate aircraft equipment, there could be a greater risk of associated human error, which may eventually lead to adverse consequences.

The third most important level from the four-factor framework is the safety assessment. The safety assessment includes conducting dry runs, quality assurance, keeping a check and balance on every step, and ensuring that every tool and equipment is used correctly in a safe manner. Safety assessments allow management to discover any risks associated with aircraft equipment or tools before final execution and use of the product. This helps the managers provide solutions to it beforehand without running large risks. Lastly, another very essential factor is the accident investigation. Human error might definitely lead to accidents, although the magnitude of the accidents may differ. Therefore, to prevent such mistakes in the future and to assess the core reason for the cause of the accident, an effective and thorough investigation becomes a requirement.

In addition to this, restricting the aviation environment coupled with thorough and systematic inspection is another approach suggested by researchers to reduce errors associated with accidents. Latorella (2000) highlights, "Aviation maintenance and inspection tasks occur within the larger context of organizational and physical environmental factors. A system model of aviation maintenance and inspection defines four interacting components in this system (operators, equipment, documentation, and task) and suggests that these components interact over time as well as within both physical and social, or organizational, environments." Latorella (2000) here highlights that to reduce human error significantly and permanently, it is necessary to restructure the organization to complement a more efficient task force system. As Latorella (2000) has stated already, an effective workplace includes four components: operators, equipment, documentation, and task.

These four factors combine to form the baseline for the aircraft industry. Efficiently executing each of the four components will help achieve a vivid reduction in accidents caused by human errors. Again, operators include all the processes that involve the usage and execution of aircraft equipment and tools. The equipment factor includes the design, processing, and functionality of each aircraft. This ensures that the equipment works properly and fulfills its desired purposes and tasks. The third and fourth factors are interlinked with each other. Documentation and tasks include efficient and effective recording and assigning of tasks, primarily to keep a check and balance on each staff member, pilot, worker, etc. The last and most important factor is inspection. The author states that inspection is very important since it has characteristics that are synonymous with the theory of total quality assurance and management. Quality assurance techniques ensure every individual in the organization takes inspection and effective functionality as their primary responsibility.

In another instance, the European aircraft maintenance organization has managed to establish a safety program to create a more cohesive environment in an attempt to reduce human error and the intense consequences of it. This safety program is called the maintenance action safety program. There are a variety of underlying principles backing the solutions it has proposed. Not only does the safety action program suggest a range of solutions, but it also questions and attempts to break the shackles of rigid organizational structures and policies. For instance, Virovac (2017) states the following:

> Maintenance Safety Action Program has been developed as tools for the prevention and reduction of errors in aircraft maintenance caused by an unintentional error of technical personnel. The program proposes the participation of all the immediate stakeholders included in the process of aircraft operation and maintenance.
>
> The basic characteristics of the program include technical personnel must continuously work on the improvement of the quality of work, the culture of reporting errors without punishing the personnel has been developed; when people are punished, the errors are kept hidden, reporting in case that employees have any recommendation for improvement of the work process in the way to prevent possible future error, introduction of the program into an organization for aircraft maintenance means fewer errors in maintenance, which results in an increase of safety and reduction of costs.

The maintenance safety action program is a multi-dimensional program since it includes possibly all the members and stakeholders of the aircraft maintenance industry. The first factor, where the program states that every individual must work on the improvement of their work, is simply the role every member of the staff must play when a quality control and quality assurance department is setup. Every individual must view reducing human error and quality as their primary responsibility through every task. The second factor attempts to question the rigidity in our conventional organizational structures. Usually, when a worker accidentally makes an error, the staff member is punished. Therefore, in such circumstances, it is unlikely that a staff member will report any operational or technical issue. Once this perception is changed into managers being more cohesive and worker-friendly, it is more likely that workers will report significant issues; this reduces the chance of intense adverse consequences of human error as it gives room to managers to improve or prevent such a situation from occurring.

Additionally, the third factor also attempts to question the otherwise autocratic nature of the aviation industry. A worker-friendly environment is more likely to welcome innovative solutions to reduce human error. Therefore, the idea behind this is to perpetuate a more democratic approach towards employees, thereby reducing the power distance between managers and employees. Lastly, the maintenance action safety program also brings in the need for training and development for safety measures, precautionary measures, etc., all with respect to the aviation industry.

Managing the Risk of Maintenance Error

How to motivate the reporting of maintenance issues that could otherwise go unreported to management is a key challenge for maintenance organizations. Quick access recorders, cockpit voice recorders, and flight data recorders, in addition to passengers and the general public, can be used to constantly monitor the operations of pilots. However, despite the significant paperwork that goes along with maintenance, the day-to-day activities of technicians may be less noticeable to management than the activity of pilots.

Error Management refers to the process of analyzing all available data to identify the root causes of errors and then taking the necessary steps, such as altering rules, regulations, and training, to both prevent errors from happening in the first place and to decrease the impact of those that happen (Andrei, 2011). The phrase quality management system (QMS) first originated in the airlines industry in the 1960s, laying the groundwork for occupational health and Safety Management Systems SMS (Stolzer, Goglia, and Stolzer, 2015).

The SMS is a performance-based approach to safety which delivers benefits because it puts more emphasis on obtaining the intended result than it does on whether or not an entity is in compliance. It is crucial to remember, however, that the application of a safety performance strategy is participatory because it calls for aviation industry to make a concerted effort to design appropriate methods to accomplish the desired objectives and, with regard to entities, to analyze almost every approach (ICAO, 2018).

Implementing safety management has several advantages, some of which are as follows: improved safety culture; a documented, methodical procedure to guarantee safety; a better comprehension of the links and interactions linked to safety; improved early warning of safety risks; and cost reduction (ICAO, 2018).

III. Methodology

This chapter explains the methodology and the tools used for the analysis. The goal is to answer the research question through exploring and visually representing the data and the application of the Human Factors Analysis and Classification System (HFACS). This chapter will also show the method used for applying the HFACS to the accidents' reports. However, there were some potential accidents causal investigations frameworks to consider: Accimap, STAMP, and HFACS. Despite the fact that Accimap and STAMP are probably more thorough in terms of the contributing factors they discover, the HFACS framework is more reliable since it is taxonomic and is more effective in analyzing various case study scenarios (Salmon, Cornelissen & Trotter, 2012).

The Data

Two sources of archival data were used in this research. Firstly, data was obtained from the Maintenance Data Analysis department of the F-15 Maintenance Squadron at King Khalid Air Base. Secondly, data was obtained from the Safety Directorate at the Royal Saudi Air Force Command. The data contains records for 52 aircraft accidents reports which contains aircraft type, aircraft total hours, system failure, prior system failure, pilot rank, technician level, and the main cause of the accident.

Exploratory Data Analysis (EDA)

The data was received in the form of reports of the accident investigation committees, as well as in the form of incidents safety reports. Work has been done to extract the data from the reports so the data can be analyzed. The data was cleaned after the extraction process during which the data source was contacted to clarify or provide more data whenever necessary. Accidents reports that had missing data were excluded from the analysis and 52 accident reports were analyzed. The software used was JMP® Pro 15.0.0 and Microsoft Excel for the purpose of EDA. JMP® Pro 15.0.0 and Microsoft Excel were used simultaneously to visually represent the data in a graphical representations to better understand, identify patterns, and discover trends within the data.

HFACS Application

The application of HFACS requires thorough investigation of the accidents reports to identify the potential errors that might have caused or contributed to the cause of the accident. This requires access to detailed information surrounding the accident. The 16 maintenance-related accidents produced 33 causes for additional analyses. Each of these causes was then coded individually using the HFACS framework. The causes acknowledged by the accident committees were considered. However, no new causes were formed during the coding process. The next step in the HFACS application is to code/categorize the errors to fall into one or more levels of the framework shown in Table 1. Table 3 shows the HFACS coding method. Each accident cause was given a code across the different levels of HFACS: management influences (M), Maintainer Conditions (T), Working Conditions (W), and Maintainer Acts and Violations (V). However, the HFACS framework is flexible on how many levels are needed to address the organization's individual needs and the codes can be changed as long as they follow the general frameworks methodology.

Table 1. HFACS Coding Process

			HFACS code			
	Aircraft Number	Main Cause	M	T	W	V
1	611	HYDRULICS	M5	T2		
2	612	HYDRULICS	M4		W5	
3	613	ENGINE	M7			V8
4	620	FUEL	M8	T5		
5	622	APG	M5			V7
6	624	ELECTRICS	M1			V6
7	5502	APG	M5	T5		
8	5506	HPO	M5			V7
9	5509	FLIGHT CONTROL	M5		W4	
10	5509	ENGINE	M4	T3		
11	5511	FUEL	M6		W2	
12	5515	ELECTRICS	M7	T4		
13	9202	APG	M5			V1,V8
14	9211	FLIGHT CONTROL	M1			V7
15	3413	HYDRULICS	M8	T2		
16	3405	APG	M7			V5

Each accident report was reviewed to gather the necessary information to select the appropriate level of HFACS which had an input on the overall accident cause. According to HFACS, it is possible to have more than one contributing cause or, on ratre occasions, just the main cause. For example, accident report number 13 was coded for two violation codes (V1 and V8). The reason for this coding is that the maintainer relied on experience (Attention/Memory V1) and knowingly serviced tires with the wrong pressure gauge (Flagrant V8), which resulted in a mishap during take-off.

Table 2. HFACS Application to Accidents Reports

First Order	Second Order	Third Order	Example	Code
		Inappropriate Processes	A publication skips a step	M1
		Inadequate Documentation	A manual does not state torque limits	M2
	Organizational	Inadequate Design	A poor component layout	M3
Management Conditions		Inadequate Resources	A shortage of tools	M4
	Supervisory	Inadequate Supervision	A commander does not ensure the use of PPE	M5
		Inappropriate Operations	An engine change is performed in high wind	M6
		Uncorrected Problem	A supervisor does not correct cutting corners	M7
		Supervisory Misconduct	Assigning untrained technicians to a task	M8
		Adverse Mental State	A maintainer who has marital problems	T1
		Adverse Physical State	A maintainer who worked for 20 hours straight	T2
	Medical	Physical/Mental Limitation	A short maintainer cannot inspect a component	T3
		Inadequate Communication	Poor hand signals led to an incident	T4
Maintainer Conditions	Crew Coordination	Inadequate Assertiveness	Signing off an inspection due to perceived pressure	T5
		Inadequate Adapt/Flexibility	Downgrading a discrepancy to meet schedule	T6
	Readiness	Training/Preparation	Skipping the requisite OJT evaluation	T7
		Certification/Qualification	Engaging in a procedure while not qualified	T8
		Infringement	A maintainer who is intoxicated on the job	T9
		Inadequate Lighting/Light	A maintainer who is working at night does not see	W1
		Unsafe Weather/Exposure	Securing an aircraft in a rainY weather	W2
	Environment	Unsafe Environmental Hazards	Falling from a ladder	W3
		Damaged/Unserviced	Using a defective test set	W4
Working Conditions	Equipment	Unavailable/Inappropriate	Working on landing gear without a jack	W5
		Dated/Uncertified	Using an old manual	W6
	Workspace	Confining	Unable to position a maintenance stand	W7
		Obstructed	Spotting an aircraft with his view obscured	W8
		Inaccessible	unable to have access to perform a an inspection	W9
		Attention/Memory	Reversing steps in a sequence	V1
	Error	Knowledge/Rule Based	Inflates an aircraft tire to a the wrong pressure	V2
		Skill/Technique Based	Roughly handling a delicate engine valve	V3
Maintainer Acts		Judgment/Decision-making	Misjudges the distance b/w tractor and an aircraft	V4
		Routine	Engaging in rule bending	V5
	Violation	Infraction	straying from accepted procedures	V6
		Exceptional	Omitting an inspection and signing it off	V7
		Flagrant	willfully breaking standing rules	V8

The Accidents Investigation Committee report shown in Table 2 was randomly selected from the available data. Based on the available information within the report and looking at the details that led to the accident, we can apply the HFACS framework in order to know what caused the accident (Unsafe Act) and what other factors led to this event (preconditions to the unsafe act, unsafe supervision and organizational influence), not just the main cause. A total of 16 maintenance related accident reports were analyzed following a similar process. Subsequently, we can answer the research question: What are the root causes behind the increasing number of maintenance-related accidents in the F-15 fleet within the RSAF?

Table 3. Summary of Key Results in an Accident Investigation Committee Report

Sequence of Event	- 84 seconds after takeoff of F-15 S, tail number: 613 from Runway 14 at King Khalid Air Base, Right Engine Fire caution light was illuminated. The pilot then declared an emergency landing and returned to base. Emergency procedures were followed until the aircraft landed safely after engaging the arresting hook and sustaining major damages to the landing gears. Upon landing, it was then when pilots realized that both engines caught fire
Main Cause	- Sergeant A did not follow the correct procedures when replacing the Main Fuel Pump Filter Bowl, the day before the accident. - Master Sergeant B did not sign off the Inspected by block in the work order.
Recommendations	- Adhering to technical manuals when replacing parts. - Providing aircrew lectures and scheduling them on flight simulator for training on emergency procedures.

IV. Results and Findings

This chapter presents two types of analysis techniques, Exploratory Data Analysis (EDA) of the data discussed in Chapter III and an application of the Human Factors Analysis and Classification System (HFACS) which is an accident casual investigation framework. The analysis will only be presented with no attempt to make impressions of these analyses. The inferences portion is reserved for Chapter V.

Data Analysis

After the data has been cleaned, rearranged and analyzed, the results of the analysis are presented in this section.

<u>Prior System Failure</u>

It is clear from this analysis that one of the causes of accidents is improper maintenance as more than a third of the accidents were related to previous failures that could have been properly repaired but for some reason were not. Figure 12 shows that 38% of the accidents, a total of 19 accidents, had a malfunction in the same system that caused the accident on recent flights. However, it is possible that the prior failure is not directly related to what actually caused the accident. In other words, if maintenance had performed the right maintenance, a third of the RSAF F-15 fleet maintenance-related mishaps could have more likely been avoided.

Similarly, 4 of the 19 accidents which had a prior failure were attributed to material failure and maintenance should have captured and dealt with these errors right from the first occurrence.

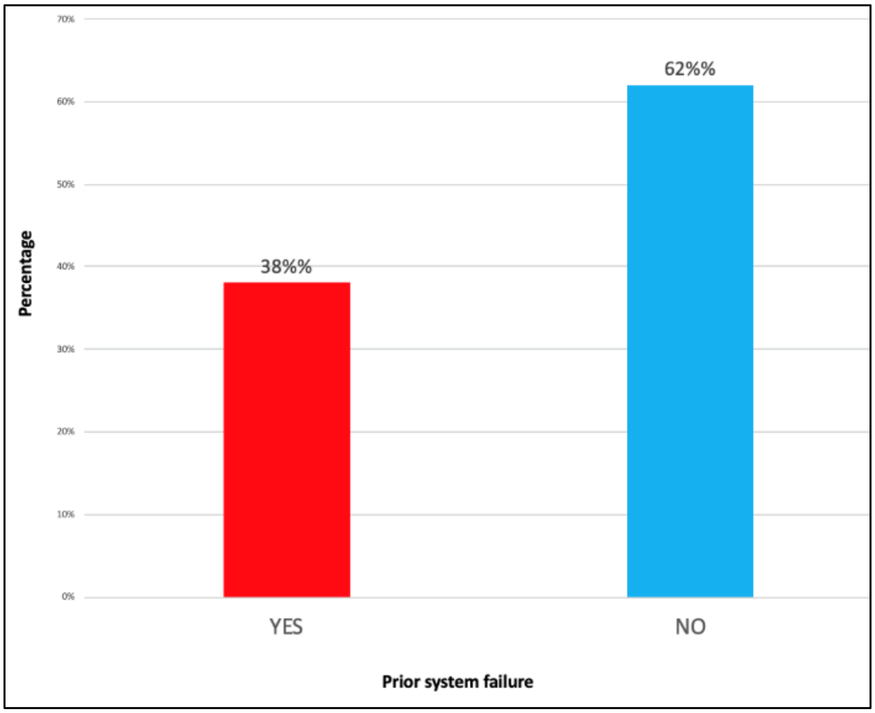

Figure 11. Prior System Failure

Total Aircrew-Related Accidents vs. Pilot Rank

It was noted from the data that the rank of 2nd Lieutenant was the rank that had the most accidents classified as an air crew error. In second place is the rank of captain, and then the rank of major. It should be noted that the rank of 1st lieutenant has encountered fewer accidents than the rank of officers with more experience and seniority. However, the Lieutenant colonel was attributed to 10% of the aircrew-related accidents, as shown in Figure 13.

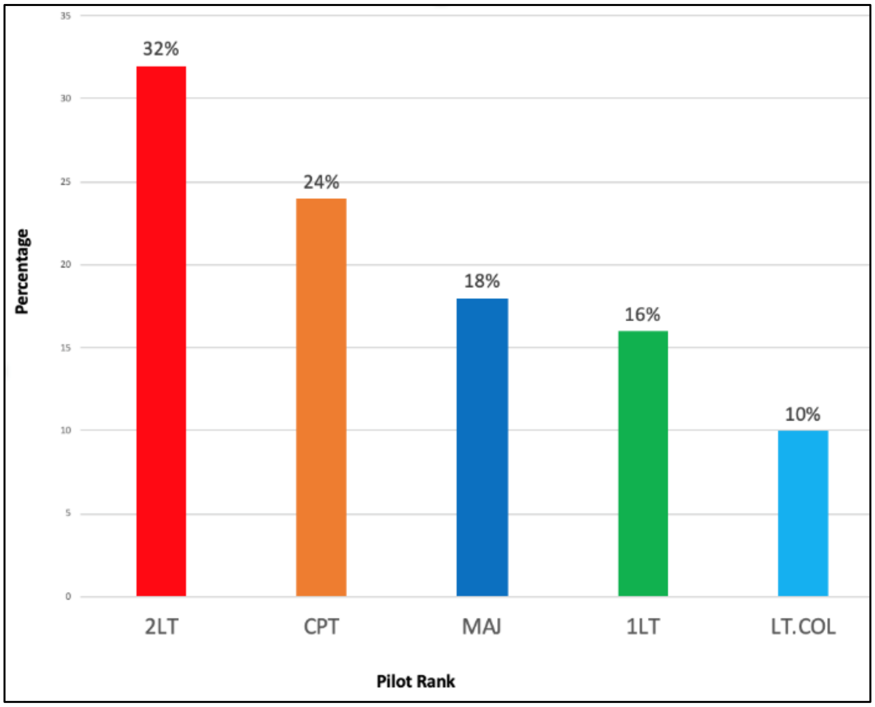

Figure 12. Total Aircrew-Related Accidents vs. Pilot Rank

Intuitively, the more experience the pilot has, the less errors he/she might commit. However, with limited understanding of how aircrew training works, there are some points worth mentioning. In the RSAF, the rank of 2nd Lieutenant (equivalent to 1st Lieutenant in the USAF) is the rank where pilots are allowed to fly without an instructor pilot. When pilots pass a course known as Fighter Pilot training-003 course, they are allowed to lead a mission. 1st Lieutenant (equivalent to 2nd Lieutenant in the USAF) is generally not yet allowed to lead the mission and must fly with an instructor pilot. The rank of Captain and Major are considered experienced pilots and most missions are carried out by these two ranks. However, this research did not look into the flying hours for the pilots and the level of training they received due to the data collection limitations mentioned in Chapter I. It is recommended to further investigate this area to determine if there is any association between the pilot’s rank and the rate of accidents.

Accident Cause and Technicians Level

Maintenance is determined to have contributed/caused 31 accidents out of 50. Technician level is shown to have some association with accidents. Figure 14 shows that out of 31 accidents attributed to maintenance, level 5 technicians were attributed to have caused 22 accidents which accounts for 71% of total maintenance-related accidents.

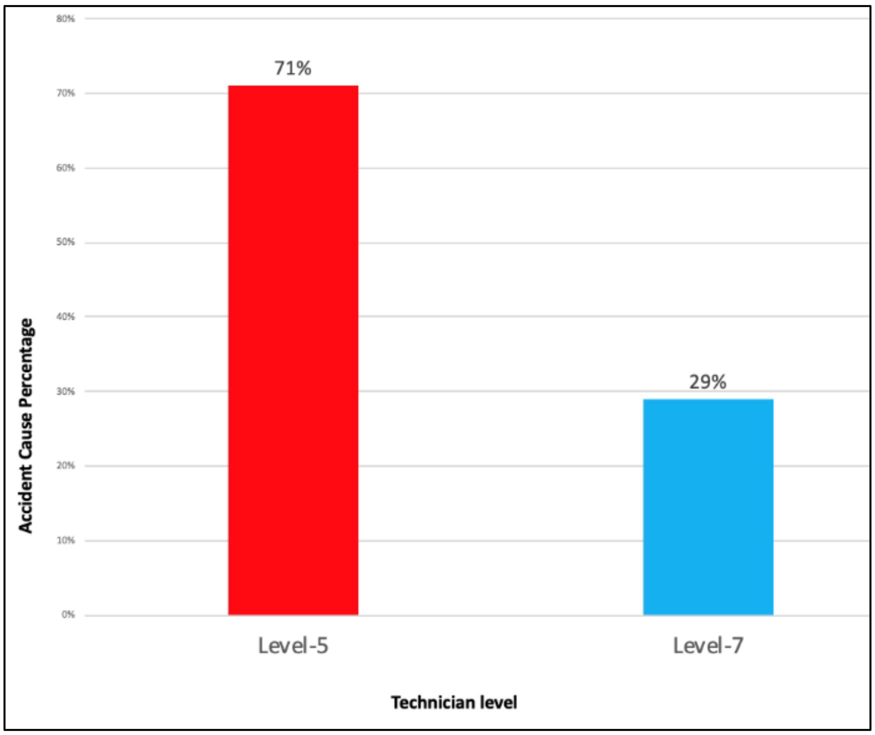

Figure 13. Accidents and Technician Level

Technical Orders (TOs) specifically prohibit level-5 technicians from working on or signing off any task without supervision from a senior technician. However, accident reports clearly show that level-5 technicians are actively taking part in maintenance without the requirement of the presence of a supervisor. Moreover, the TOs make it unquestionably clear that each level-5 technician should be considered a trainee and must always be assigned to work with a supervisor to follow up and monitor his training. This is clearly a violation of the RSAF rules by the management, trainer, and the trainee as well.

Accidents and Failure System

Representing more than 52% of the total accidents causes, Aircraft Electrical and Avionics systems were shown to be the top contributors to all maintenance-related accidents, as shown in Figure 15. The third category is labeled MISC; it includes causes that are not related to a particular aircraft system, for example, aircrew procedure errors, bird strikes, etc. These causes accounted for 24% of the total accidents. Engines, Hydraulics, and Air Plane General were the cause for 24% of the total accidents. It is worth mentioning that although many sub-systems fall under these systems, only the main system was selected to facilitate data analysis. However, each accident was examined separately to ensure that there was no ambiguity in determining the main cause of the accident, and thus the reliance on this data would be more appropriate.

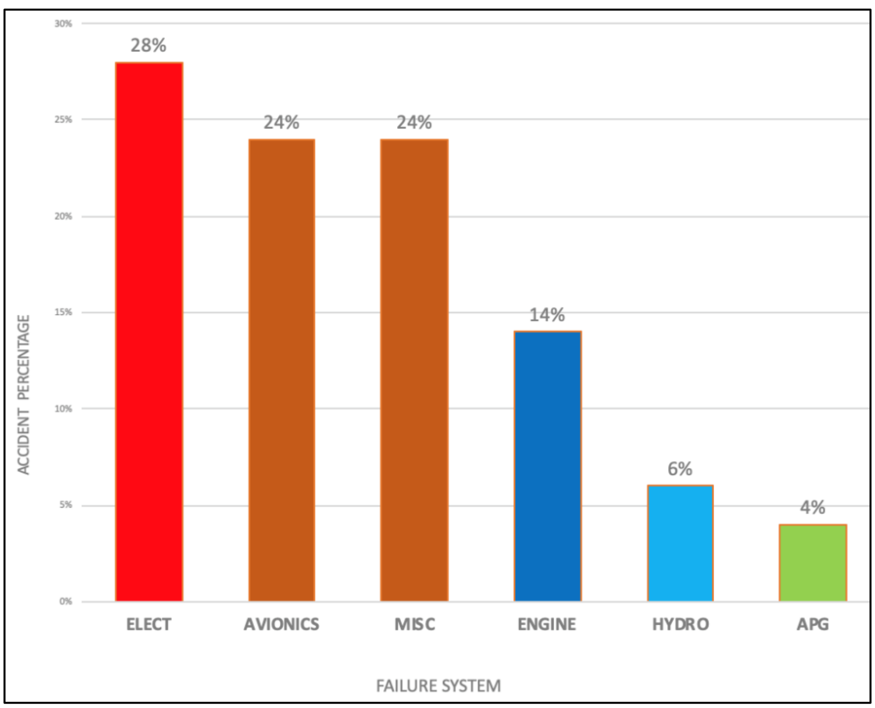

Figure 14. Accident and Failure System

HFACS Application to Maintenance-Related Accidents

The HFACS results in Figure 16 show management and supervisory influence to be a contributing factor in all accidents. Maintainer acts are linked to 44% of the total accident, maintainer conditions were attributed to 38%, and working conditions were responsible for 19% of the total accidents.

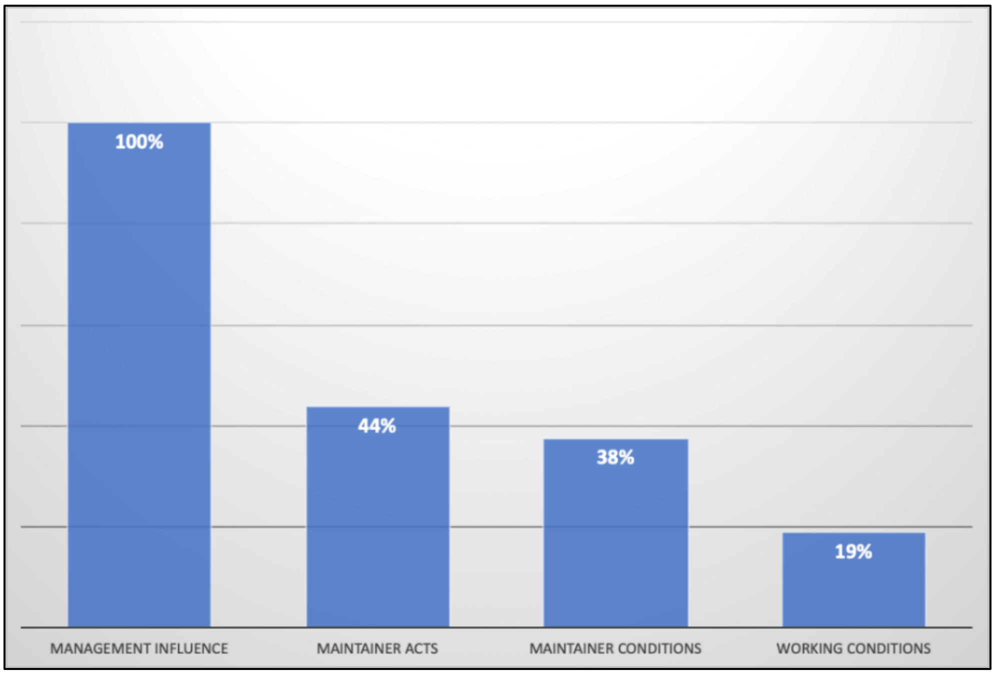

Figure 15. HFACS Results

Management Influence

Looking at the management and supervisory influence and how the HFACS addresses this level, HFACS showed inadequate supervision and uncorrected problems to be the top contributors to this level (50%), as shown in Figure 17.

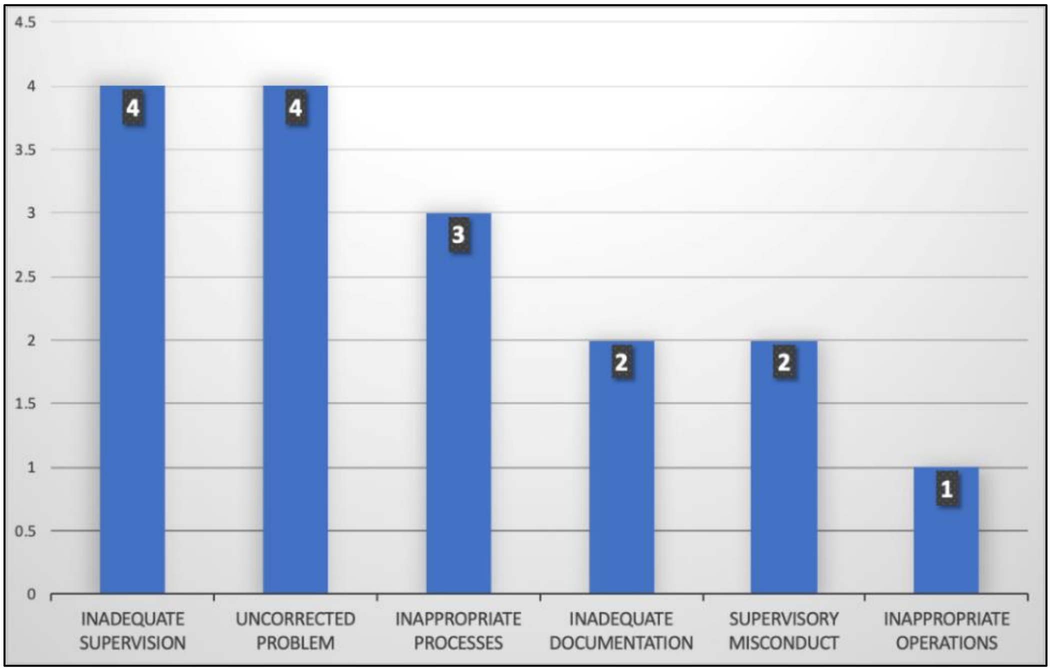

Figure 16. Management Influence

Unsafe Maintainer Acts

Errors and violations were the cause for 50% of the total accidents, as shown in Figure 18. Exceptional and Flagrant violations are said to be the cause for 31% of total accidents. It is worth mentioning that with every violation and error, management is also held responsible under the HFACS framework since management is expected to anticipate, prepare for, and react to violations prior to their occurrences.

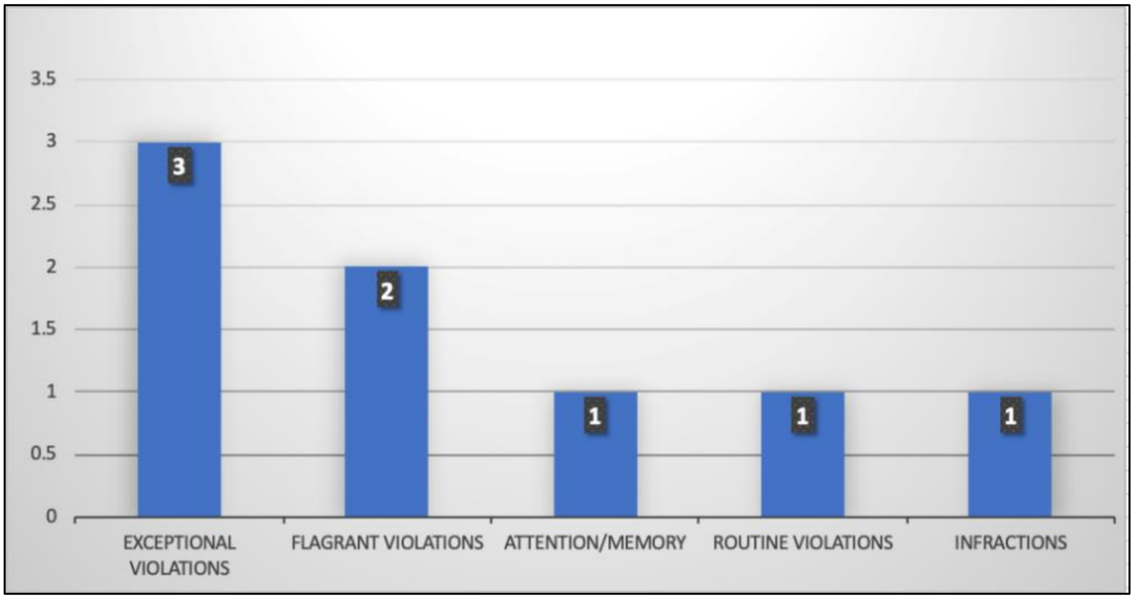

Figure 17. Errors and Violations (Unsafe Maintainer Acts)

<u>Maintainer Conditions</u>

Maintainer conditions were linked to a total of 6 accidents (37.5%) Figure 19. Inadequate assertiveness and adverse physical states were the top two contributors to this level. An example for inadequate assertiveness is when a technician signs off a discrepancy to meet the schedule, and an adverse physical state condition is when a technician commits an error because he/she was overworked.

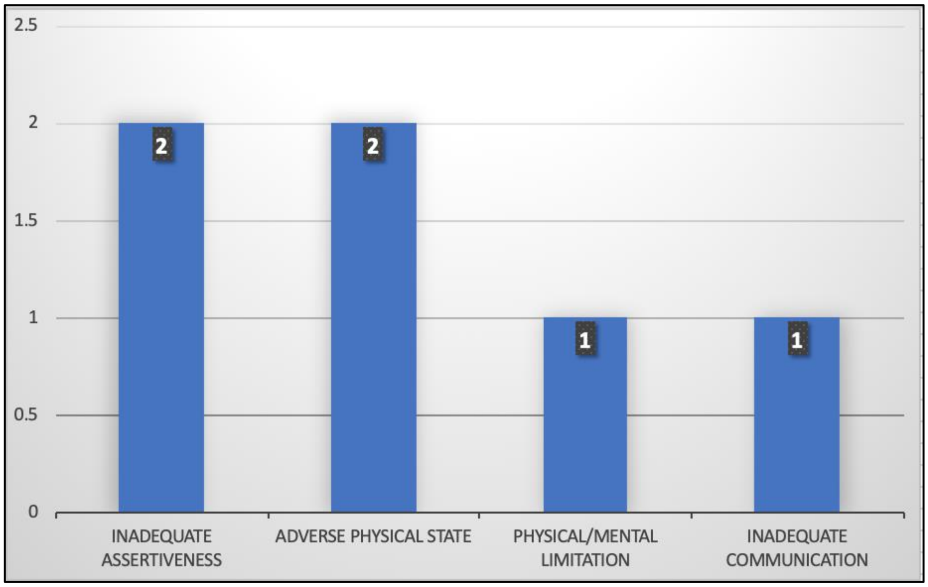

Figure 18. Maintainer Conditions

<u>Working Conditions</u>

Working Conditions were linked to three accidents (19%), as shown in Figure 20. All three events are linked to management for failure to either enforce the rules or make resources available.

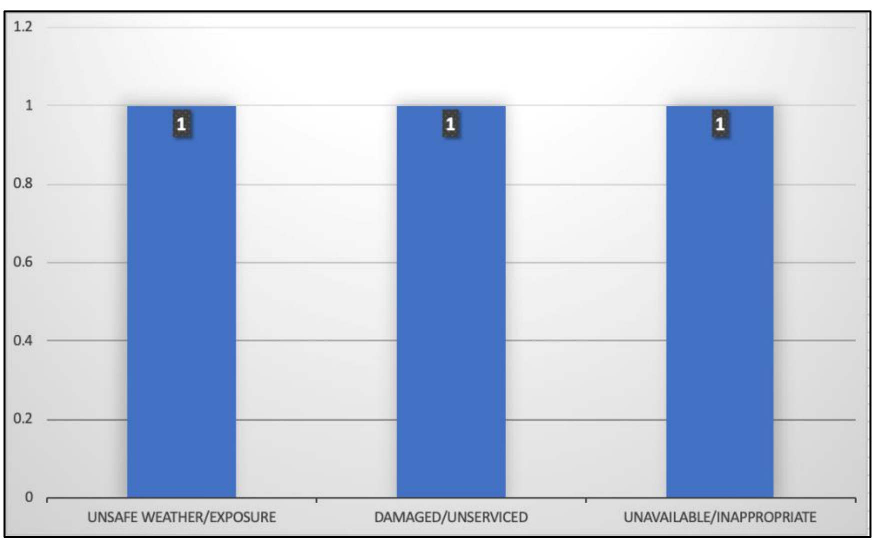

Figure 19. Working Conditions

Discussion

Utilizing a structured and methodical error investigation system like HFACS has two major benefits. First, it increased the efficacy of investigations. Structured systems act as prompts or checklists to help the investigator find pertinent concerns when they are being investigated. Second, when the system has been in operation for some time, a bank of incident data in a format appropriate for statistical analysis becomes accessible. Applying HFACS to accidents related to maintenance has clearly shown that management contributed to all accidents in different ways. However, maintenance squadrons must be reassessed in terms of management and supervision.

HFACS was able to link all accidents back to management (100% of the time) whether it was uncorrected problems, shortage of appropriate tools, or reluctance to enforce the RSAF rules. The number of violations within maintenance squadrons that have caused these accidents seem to suggest that it became a culture to cut corners and bend the rules; additionally, it was noted on one instance that a supervisor allowed it to happen.

HFACS has a unique ability to capture the root causes of an accident and not just the unsafe act that caused it. The RSAF accidents, as well as the connections between underlying conditions and active errors, were successfully captured by the HFACS framework. The obtained insights offer a sound framework for the creation of viable intervention solutions. The majority of the detected human error causal factors include aspects of insufficient supervision, procedures, and training; communication issues on process modifications; inspection and errors omission; and procedural breaches. These conclusions allow for the prioritization and subsequent identification of the main failure sources.

Some areas within the maintenance squadrons are clearly in need of a system-level intervention. For example, record keeping, overworked technicians, resources allocations, shift handovers, 12-hours shifts, manpower, quality control, and other areas are briefly discussed in the next section.

Working Conditions

Reading through the investigation committees reports showed that maintainers who were involved had complained about certain issues with the working conditions and might have contributed to the cause of the accident. These issues are as follows.

<u>Documentation & Recordkeeping</u>

Documented procedures are crucial for aircraft maintenance. The FAA estimates that between 25% and 40% of the time spent by aircraft maintenance staff is spent on maintenance reporting ("Documentation & Recordkeeping," 2019). One of the major reasons for maintenance issues is improper documentation. A variety of problems, including memory lapses, technical ambiguities, and regulation breaches, can result from poor maintenance documentation management. The major issue is not typically inaccurate information or technical mistakes when it comes to the content of maintenance manuals, structural repair manuals, and other documents like the minimum equipment list. Few, if any, mistakes were discovered in maintenance manuals. However, there were other issues with the methods that were written down.

The aircraft file is mostly the only form of communication between aircrew and maintenance technicians. In the accident reports discussed in the results chapter of this research, maintenance technicians reported that aircrew write-ups of faults were frequently insufficient in pinpointing the issue. However, pilots admitted that they did not really document the issue but instead noted discrepancies on scraps of paper or verbally informed maintenance staff.

Investigations of the accident reports revealed organizational-level issues, often including training and certification processes, budget allocation, and widespread culture, even though maintenance incidents typically entail mistakes committed by workers. For instance, a maintenance infraction, like using the wrong tool, may have happened since the right tool was not supplied, which may have been caused by equipment purchase restrictions or financial limitations. Time constraints are among the most frequently cited justifications for maintenance infractions, and this is itself a sign of organizational issues like budgeting, workforce shortages, or task management. But even though technicians' activities normally uncover human factors vulnerabilities in maintenance, these issues are typically solved at the organizational level.

Shift Handover

Numerous maintenance jobs, especially those involving heavy maintenance, cannot be finished in a single shift. Workers who maintain aircraft regularly have to accept work-in-progress from coworkers and transfer incomplete work to a new shift. One of the most important aspects of maintenance work is the requirement to communicate information properly and effectively, sometimes without direct interaction. However, handovers are also a chance to monitor work progress, discover faults, and remedy them. Shift handovers are frequently focused on the transmission of information from the departing shift to the incoming shift. It is advised that face-to-face handovers be done by the technicians themselves.

Fatigue

There are two primary causes of fatigue. The first is lack of sleep, and the second is how human performance is impacted by 24-hour cycles. According to recent studies (FAA, 2016), shift workers who undergo moderate sleep loss might have symptoms that are strikingly comparable to those brought on by alcohol. The ability to execute numerous jobs mentally and physically is compromised after 18 hours of awake time. The consequences of weariness are especially noticeable during boring duties that call for the detection of a rare issue, such as some inspection assignments. The likelihood of maintenance mistakes seems to be higher during night shifts. According to accident reports, maintenance personnel are more likely to make mistakes regarding failures to carry out intentions, such as forgetfulness and perceptual mistakes, when they are feeling sleepy.

Twelve-Hour Shifts

Maintenance shifts of 12 hours are becoming more typical. Sometimes, rather than being forced by management, a corporation chooses to implement 12-hour shifts. When compared to 8-hour hours, 12-hour shifts have several benefits, including the ability to finish more work during each shift and fewer job handovers between shifts. They also allow additional days off. Workers occasionally report fewer health issues and better sleep while on a 12-hour shift pattern than when on an 8-hour pattern, despite the fact that they are often more exhausted at the conclusion of a 12-hour shift than at the end of an 8-hour shift (Pollock, 1988). The likelihood of accidents or injuries will not necessarily rise if shift lengths are increased from 8 to 12 hours, according to current studies. However, 12-hour shifts might not always be the best option. It is crucial to assess the impact of any move to 12-hour shifts on the productivity and well-being of employees.

Responding to Maintenance Issues

There are two ways that an organization might respond to a maintenance issue. First, error-producing situations inside the organization can be identified and addressed in order to reduce the likelihood of maintenance error. This often entails paying attention to fatigue management, providing proper tooling and equipment, training on human factors, and taking additional measures aimed at the human aspects connected to maintenance mistakes. Second, it is important to recognize that a maintenance mistake is a risk that can be diminished but never completely removed. The RSAF may learn to control the unavoidable risk of a maintenance error in the same manner that they control other natural risks like weather.

V. Conclusion

This chapter's goal is to use the information from the preceding chapters to address the research questions which were asked in the first chapter. After finishing the process and reviewing the research's findings, the investigative questions were addressed. The three questions and their answers are presented below. A conclusion and recommendation for further research are also included.

Answers to the Investigative Questions

This section addresses the three investigative questions. The first investigative question was, “What do maintenance-related accidents in the RSAF have in common?” The second investigative question was, “What factors that led to the increasing violations and the unsafe maintainer acts?” The third investigative question was, “What factors that led to the increasing violations and the unsafe maintainer acts?” The answers to these questions act as the foundation for exploring the root causes for the maintenance-related accidents.

1. What do maintenance-related accidents in the RSAF have in common? The research shows that the root cause of all maintenance-related accidents is linked back to management in different ways. This link is in the form of something management did or should have done.
2. What factors that led to the increasing violations and the unsafe maintainer acts? By not enforcing the RSAF laws and regulations, and since this is linked to all unsafe maintainer acts, management is the main factor. Maintainer conditions, organizational culture, training, and supervision are also important factors that contributed to the increasing maintainer violations and the unsafe acts.

3. Is maintenance the only cause for maintenance-related accidents? No. Applying HFACS to all accidents showed that there is system level malfunction beyond maintenance level.

The maintenance workforce is essential to the operation of aviation; however, maintenance errors pose a serious and ongoing danger to aviation safety. Management used to respond to maintenance faults with punishment or dismissal since they believed them to be nothing more than people failing to do their given jobs. Nowadays, it is well acknowledged that maintenance slip-ups reflect the interaction of organizational, workplace, and human elements. Managing the risk of maintenance missteps necessitates a system-level reaction, even if maintenance specialists must still accept responsibility for their activities.

The majority of the time, a mishap's immediate conditions are signs of more serious, underlying issues. Rarely will treating a problem's symptoms result in acceptable remedies, and it might even make matters worse. For instance, mandating compliance with a habitually disregarded process could be counterproductive if it is unsuitable or badly designed. We must locate and address the underlying basic reasons, also known as root causes, of accidents if we are to achieve long-lasting changes. We must continuously question "Why?" (as in “Why did the behavior occur?”) to get to the organizational underlying causes of a mistake impacting human performance. What caused risk controls to fail? Why did the underlying causes exist? "Why?" ultimately brings us to organizational details that have significant and far-reaching effects on safety and quality.

Further Research Recommendation

The quality control flight (QCF) is responsible for managing quality within the F-15 maintenance squadron. That includes ensuring maintenance works, related facilities, equipment, training, and technicians are in accordance with all procedures outlined in Royal Saudi Air Force technical orders and procedures. For future research, it is suggested to study the feasibility of merging the QCF with the Logistics Performance Evaluation Squadron (LPES) to eliminate the management influence of the QCF. As a supporting argument for the future research, some of the interesting facts and information about the current quality program at the Maintenance Squadron at King Khalid Air Base process will be discussed in the next few sections.

Quality Control Flight

As shown in Figure 21, the QCF Commander reports directly to the Maintenance Squadron Commander (MSC) and has horizontal association with other flight commanders and section chiefs.

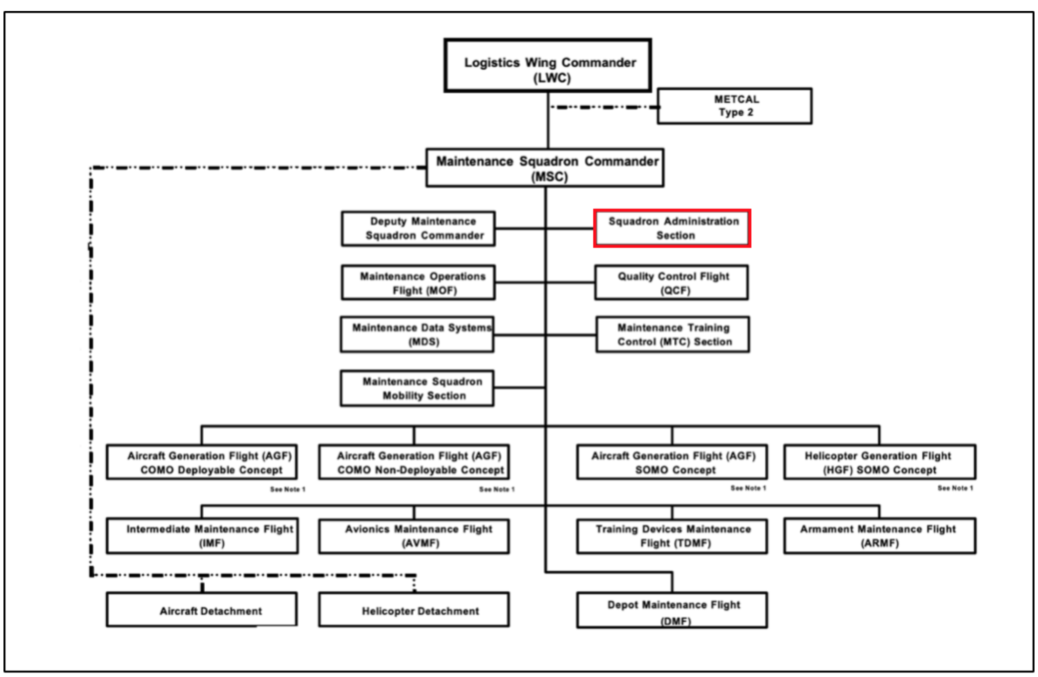

Figure 20. Maintenance Squadron Structure (RSAF Quality Management, 1998)

For the Quality Control Flight to fulfill its responsibility, it is required to perform certain inspections some of which are random inspections and some are planned in coordination with each flight or section. Table 4 shows the number of required inspections in the second half of 2021 and how many were achieved.

Table 4. Required vs. Achieved Baseline Inspections

Inspection type	Required	Achieved	percentage
Quality verification inspection (QVI)	300	122	41%
Quality Management Assessment (QMA)	15	8	53%
Individual or Team Evaluation (ITE)	200	99	50%
Overall Total	515	229	47%

Although the facilities and tools to perform these inspections are available, for example, management, computers, office spaces and transportation, the quality control flight is struggling to achieve its minimum requirement (75%). This minimum requirement is just an indicator that shows whether quality control is putting in enough effort to match the amount of maintenance work performed or not, and in this case, it is not. Since 2009, QC never fell this short of the baseline and as can be seen in Figure 23; it appears to be something that has been accumulating overtime which causes this down slope.

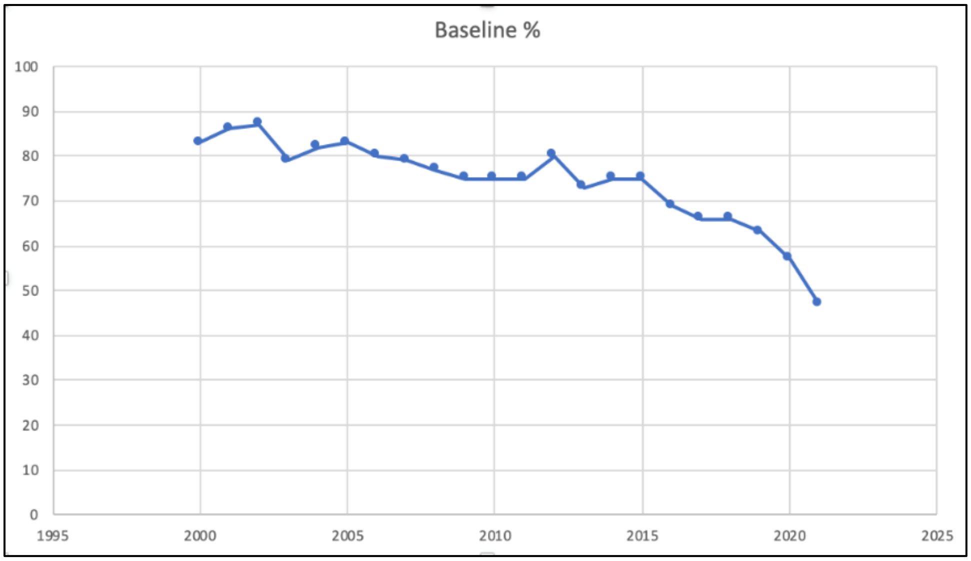

Figure 21. Baseline Percentage per Year

To understand the issues that QCF is struggling with from a worker point of view, a quick overview of survey results by the Logistic Performance and Evaluation Squadron showed that outside intervention with QC decisions accounted for 40% of the issues, as shown in Figure 24, A new issue came to light which was not expected – manpower. It seems like manpower is now a strong driver behind the issue (33%). Workload (11%), training (8%), and supporting tools (8%) are also contributing factors.

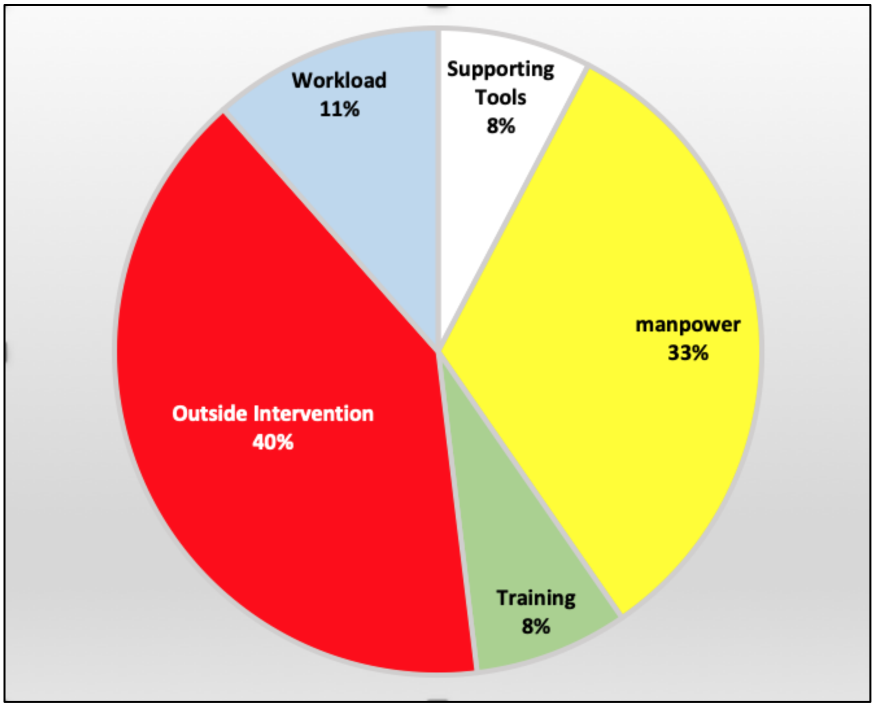

Figure 22. QC Issues Restricting Performance (RSAF Safety Directorate, 2019)

Outside Interventions

When an individual is a quality inspector and has made the right decision that might affect the running of operations in the maintenance squadron, the individual should be commended for the work that may have spared the squadron heavy losses. However, apparently that is not the case; the odds are that the individual will be called to the MSC's office or the Maintenance Operations Control Flight (MOCF) and ordered to reverse their decision. In a military environment, no is not an answer.

Current QCF Manpower Status

According to RSAF Instruction 4-7166-1-3-1, only those technicians who have spent 5 years working in their Air Force Air Force Specialty Code (AFSC) after they have finished their training will qualify to be selected as a QC inspector. However, their assignment to QC is not permanent and it is under the MSC discretion to move them again as he/she sees appropriate. There are currently 39 workers (inspectors, support staff, and admin) assigned to QCF, which is almost half the number it was last year. The reason that the number dropped is because 30 inspectors were assigned back to their original sections and given an additional duty as a QC point of contact. However, the authorized manpower for QCF is based on the number of aircraft in the squadron, and in the case of the KKAB F-15 maintenance squadron, the Unit Manning Document states that the authorized manning for QCF is 94.

F-15 Maintenance Culture

In the survey, it was discovered that 66% of QC personnel prefer to go back to work at their previous sections (their original AFSCs). When queried further using the "Five Whys" technique, they feel their job is harder than their previous job and they are not being appreciated or compensated for that. Another reason is that they feel outcasted by the maintenance community and looked at as a source of problems.

When a QC inspector decides to write-up a technician for some unsafe act or unlawful maintenance procedure, it is almost guaranteed that the MSC will step in and overrule the inspector's decision. The MSC is not violating any rules here, he/she is just practicing his/her lawful authority. Most MSCs have an operationally oriented way of looking at their squadrons. Their primary aim is to not miss a scheduled flight to prevent the readiness status from dropping below the lower control with little to no considerations to quality. All these reasons do not justify the decline in the level of quality, but it is a good starting point for understanding how we reached this level and how we can recover and avoid this in the future.

Training

Newly assigned technicians to QC must start with Cross-Utilization Training (CUT), which is a type of training that qualifies a person to accomplish a task unassisted outside of their specialty but within a related field. According to RSAF Instruction 4-7166-1-3-1, CUT should be accomplished within 180 days of the assignment to QC. The survey shows only 1 out of 7 technicians who were recently assigned to QC have completed their CUT in time. There are several courses to augment in-house training. Course availability, content, length, location, and schedule should be known by MTC. The capability of QC personnel can be improved by scheduling them for the available quality training courses during their period of assignment to QC.

Future State

The goal is to design a quality program that ensures the following:

1. Maintenance tasks are performed in accordance with quality control standards.
2. No outside interventions/influence can happen.
3. Guarantees the smooth flow of the quality control processes.
4. Restores customer satisfaction.

The level of quality should be expected to increase within aircraft maintenance squadrons which can only lead to better performance, safer work environments, fewer maintenance-related accidents, fewer human errors, and higher aircraft readiness. The benefits of designing such a process will not just be for the maintenance squadrons but for the entire Royal Saudi Air Force and the country.

References

Accident Statistics. (2022). Retrieved 18 July 2022, from https://www.icao.int/safety/iStars/Pages/Accident-Statistics.aspx

Ancel, E., Shih, A., Jones, S., Reveley, M., Luxhøj, J., & Evans, J. (2014). Predictive safety analytics: inferring aviation accident shaping factors and causation. Journal Of Risk Research, 18(4), 428-451. doi: 10.1080/13669877.2014.896402

Bale, Jo. (2008). Understanding the Influences on Employee Motivation for Lean (Ph.D.). Cardiff University.

Cacciabue, P. (2004). Human error risk management for engineering systems: a methodology for design, safety assessment, accident investigation and training. Reliability Engineering and System Safety, 229–240.

Danese, P., Manfè, V., & Romano, P. (2017). A Systematic Literature Review on Recent Lean Research: State-of-the-art and Future Directions. International Journal Of Management Reviews, 20(2), 579-605. doi: 10.1111/ijmr.12156

D. J. Pennie, N. B.-C. (2007). HUMAN FACTORS GUIDANCE FOR MAINTENANCE. Human Factors in Ship Design, Safety and Operation, London, UK.

D. Virovac, A. D. (2017). THE INFLUENCE OF HUMAN FACTOR IN AIRCRAFT MAINTENANCE. The Influence of Human Factor in Aircraft Maintenance.

Documentation & Recordkeeping. (2019). Retrieved 21 April 2019, from https://www.faa.gov/hazmat/air_carriers/compliance_enforcement/documentation_recordkeeping

Douglas A. Weigmann, S. A. (2001). A Human error analysis of commercial aviation accidents using the human factors and classifications system (HFACS). office of aviation medicine.

Heinrich, Herbert William. 1931. Industrial accident prevention: A scientific approach. New York. McGraw-Hill.

Hobbs, A. (2008). An Overview of Human Factors in Aviation Maintenance. ATSB TRANSPORT SAFETY REPORT.

International Civil Aviation Organization. (2022). Retrieved 23 July 2022, from https://www.icao.int/Pages/default.aspx

Jr., Clinton V. Oster, C. Kurt Zorn, and John S. Strong. "Improving Air Safety: Long-Term Challenges." Issues in Science and Technology 17, no. 2

Kara A. Latorella, P. V. (2000). A review of human error in aviation maintenance. International Journal of Industrial Ergonomics, 133-161.

Kark Smollan, R. (2014). Control and the emotional rollercoaster of organizational change. International Journal Of Organizational Analysis, 22(3), 399-419. doi: 10.1108/ijoa-08-2012-0609

Karube, M., Numagami, T., & Kato, T. (2009). Exploring Organizational Deterioration: 'Organizational Deadweight' as a Cause of Malfunction of Strategic Initiatives in Japanese Firms. Long Range Planning, 42(4), 518-544. doi: 10.1016/j.lrp.2009.06.005

Lewin, K. (1947). Frontiers in Group Dynamics. Human Relations, 1(1), 5-41. doi: 10.1177/001872674700100103

Light, T., Hamilton, T., & Pfeifer, S. (2022). Trends in U.S. Air Force Aircraft Mishap Rates (1950–2018). Retrieved 8 July 2022, from https://www.rand.org/pubs/research_reports/RRA257-1.html

MacKay, R., & Steiner, S. (1997). STRATEGIES FOR VARIABILITY REDUCTION. Quality Engineering, 10(1), 125-136. doi: 10.1080/08982119708919115

Mouton, N., Just, S., & Gabrielsen, J. (2012). Creating organizational cultures. Journal of Organizational Change Management, 25(2), 315-331. doi: 10.1108/09534811211213973

Muchinsky, P., & Howes, S. (1997). Psychology applied to work.

Oreg, S. (2003). Resistance to change: Developing an individual differences measure. Journal Of Applied Psychology, 88(4), 680-693. doi: 10.1037/0021-9010.88.4.680

Pollock, C. (1988). The use of human error data as indicators of changes in work performance. In A. Feyer & A. Williamson (Eds.) Occupational Injury. Risk, prevention and intervention (pp. 59-71). London: Taylor andFrancis.

Reason, J. (1990). Human error. Cambridge: Cambridge Univ. Pr.

Royal Saudi Air Force. RSAF Quality Management (1998). Riyadh.

RSAF Safety Directorate. (2019). *2019 Quality Audit*.

RSAF. (2021). *RSAF Annual Safety Bulletin*. Riyadh: RSAF Safety Directorate.

Salmon, P., Cornelissen, M., & Trotter, M. (2012). Systems-based accident analysis methods: A comparison of Accimap, HFACS, and STAMP. Safety Science, 50(4), 1158-1170. doi: 10.1016/j.ssci.2011.11.009

Scott A. Shappel, D. A. (2000). The Human Factors Analysis and Classification System–HFACS. Office of Aviation Medicine.

Scott A. Shappell, D. A. (2001). UNRAVELING THE MYSTERY OF GENERAL AVIATION CONTROLLED FLIGHT INTO TERRAIN ACCIDENTS USING HFACS. International Symposium on Aviation Psychology.

Smith, M. (2003). Changing an organization’s culture: correlates of success and failure. Leadership &Amp; Organization Development Journal, 24(5), 249-261. doi: 10.1108/01437730310485752

Stolzer, A. J., Goglia, J. J., & Stolzer, P. A. J. (2015). Chapter 1: Introduction to SMS. In Taylor and Francis (Ed.). Safety management systems in aviation: Taylor and Francis, NY: USA. doi: http://ebookcentral.proquest.com

Susan S. Kirschenbaum, W. D. (1990). Review of Human Error. International Journal of Man-Machine Studies, 302.

TAPPING, D. (2018). VALUE STREAM MANAGEMENT. CRC Press.

T. Wells, A. (2006). Commercial aviation safety team identifies safety enhancements. Aircraft Engineering and Aerospace Technology, 78(6). doi: 10.1108/aeat.2006.12778fab.015

Trochim, W., & Donnelly, J. (2008). Research methods knowledge base. Mason, OH: Thomson Custom Pub.

Tukey, J. Exploratory data analysis.

U.S. Department of Transportation Federal Aviation Administration. (2016). *Maintainer Fatigue Risk Management*. Advisory Circular

Vaibhav Anu, G. W. (2016). Usefulness of a Human Error Identification Tool for Requirements Inspection: An Experience Report. Software Engineering and Knowledge Engineering.

Wiegmann, D., & Shappell, S. A Human Error Approach to Aviation Accident Analysis.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
09/15/2022	Master's Thesis	Jan 2021-Sep 2022

4. TITLE AND SUBTITLE

ROOT-CAUSE ANALYSIS OF RSAF MAINTENANCE-RELATED FLIGHT SAFETY MISHAPS

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Alqahtani, Heaf H., Major, RSAF

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
2950 Hobson Way
Wright-Patterson AFB OH 45433-77765

8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT-ENV-MS-22-S-072

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Royal Saudi Air Force
1495 Al sulimaniyah, Riyadh, Saudi Arabia, 22463
Telephone number: +96611476977 x4222

10. SPONSOR/MONITOR'S ACRONYM(S)

RSAF

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES

This work is a declared work of the U.S. Government and is not subject to copyright protection in the United States.

14. ABSTRACT

Poor maintenance is a major factor in many aviation mishaps. This is due to the fact that some maintenance activities are carried out improperly or overlooked as a result of human error. It is important to acknowledge that maintenance mistakes are a visible sign of deeper organizational issues. Therefore, adequate solutions to maintenance issues must consider organizational influences. Despite efforts to reduce the accident rate within the Royal Saudi Air Force (RSAF), the RSAF suffers from an increasing trend in mishaps attributed to maintenance. Therefore, safety data was analyzed to examine trends. Additionally, the Human Factors Analysis and Classification System (HFACS) was used to investigate accident reports in an attempt to discover the root causes of the accidents. HFACS was applied to 16 maintenance-related accidents to capture the nature of and connections among latent conditions and active failures, as well as uncover the underlying causes to the accidents. Twelve-hour shifts, fatigue, shift handover documentation & record-keeping, and management response to maintenance issues were among the underlying causes discovered in this research.

15. SUBJECT TERMS

Aviation Safety, HFACS, Accidents Investigations, Human Errors in Aviation.

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Alfred E. Thal, Jr., PhD
					19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	72	(312) 785-3636 x7401