APPLYING HUMAN FACTORS AND ERGONOMICS SYSTEM ANALYSIS METHODS TO THE V5-NRS CESSNA 441 CONQUEST II AVIATION ACCIDENT

JORDAN DAENA FISCHER

https://orcid.org/0000-0003-3671-741X

MASTER OF SCIENCE DISSERTATION

Submitted in fulfillment of the requirements for the Master of Science Degree

Department of Human Kinetics and Ergonomics

Rhodes University, 2023

Makhanda, South Africa

ABSTRACT

Intro: Accidents are complex in nature with multiple contributing factors. The way in which accidents are investigated is important and using system-based analysis tools assists in understanding and mapping these contributing factors to learn from them. There has been an increase in the number of accidents that have occurred within the general aviation industry in South Africa and while accident investigations have been undertaken, these have not included the application of system-based analysis tools. This led to a collaboration between Rhodes University and the Accident and Incident Investigations Division (AIID) of the South African Civil Aviation Authority where it was agreed that two systems-based analysis tools will be applied to a previously investigated accident that occurred in 2015. **Aims:** The first aim of this thesis was to identify if, through the implementation of these systems-based tools, the systemic contributory factors could be determined using the existing report by the AIID. The second aim of this thesis was to identify if, using the two systems-based tools, the actors and levels involved in the accident could be identified and the third aim was to identify if the implementation of these tools generates the same or different recommendations to that of the AIID. **Methods:** The two systems-based analysis tools applied were AcciMap and Causal Analysis using Systems Theory (CAST). These tools were applied to the V5-NRS Cessna 441 Conquest II accident report which captured the details of how the aircraft flew into the Tygerberg mountain on its descent into the Cape Town International Airport in August 2015. **Results:** Through the application of these two systems-based analysis tools the major contributing factors elucidated throughout this analysis were: visual and lighting conditions, pilot experience, training, lack of terrain warning equipment, fatigue, inadequate oversight, and inadequate risk management. In line with these findings, the analysis revealed various actors across various levels (the crew; South African Air Traffic Control, the SACAA, WestAir (the operator) and the Namibian Civil Aviation Authority Through the elucidation of these factors at various levels, 14 to 15 different recommendations were generated which was more than the one recommendation that was generated by the AIID. **Discussion:** Even when applied to an existing report, both the CAST and Accimap tools were able to bring to light the systemic contributing factors to this accident and importantly, highlight the role that various actors and levels within the system had in this unfortunate event. Consistent with previous literature, most of the

contributing factors were found at the lowest level (the crew in this case) and fewer, but key factors were identified at higher levels (management and regulator level). Importantly, the application of the systems tools facilitated a systematic and systemic analysis of this accident, which allowed for the generation of recommendations at all levels, not just at the operator level. **Conclusion:** This study demonstrates the benefits and importance behind implementing a systems-based analysis method to an accident as these tools generate more useful recommendations which allows for important lessons to be learned following accidents, with the intention of re-designing systems to prevent them from happening again.

ACKNOWLEDGEMENTS

I would like to take this opportunity to extend my appreciation and acknowledgement to the many individuals who have supported me both personally and professionally throughout this journey.

To my supervisor: Dr. Jonathan Davy. Words cannot express how grateful I am for what you have provided me through this journey. Thank you for believing in me and constantly pushing me to do my absolute best. Considering all that you have on your plate, your dedication and commitment to your students are admirable and inspiring.

To my mentor: Mr. David Doull. Thank you for being so willing to help me through this process. Your guidance, encouragement and time is much appreciated and without these I would have not been able to research and learn about a topic I am truly passionate about.

To my co-supervisor: Mr. Andrew Todd. Thank you for all the conversations and chats about my thesis. Your passion for Human Factors and Ergonomics is amazing and rubbed off on me.

This work is based on the research supported wholly in part by the National Research Foundation. It must be acknowledged that opinions or conclusions that have been expressed in this study are mine and must not be seen to represent the views, opinions, or conclusions of the National Research Foundation.

To my family: Mom, Dad and Keags. I love you all so much and will forever be truly grateful for all the support, love, and encouragement that you have given me. You all inspire me in different ways and that is what has kept me going through this all.

To my uncle: Uncle Sean, thank you so much for financially supporting me through my honour's year and believing in me through this master's Journey. Without you I would not have made it to this stage of my academic career.

To my grandparents: Ma and Gramps. Thank you for being my pillars of strength and for always making me know that you believe in me and are so proud for how far I have come. I love you two so much.

To my Partner: Terri Harris. You have no idea how much you have assisted me through this whole process. Thanks for all the love, support, snacks, and positivity. I appreciate it more than you know, and I am sure you are glad that you no longer must hear about this thesis.

To my pets: Bailey, Zack, Balto and Angel. Thank you for being my emotional support animals who have helped brighten me up on the days that I have struggled the most.

TABLE OF CONTENTS

ABSTRACT ii
ACKNOWLEDGEMENTS iv
LIST OF TABLES viii
LIST OF FIGURES x
1 CHAPTER 1: INTRODUCTION 11
1.1 BACKGROUND TO THIS STUDY 11
2 CHAPTER 2: REVIEW OF LITERATURE 13
2.1 OVERVIEW OF THE GLOBAL AVIATION INDUSTRY 13
2.1.1 Trends in the global aviation industry 14
2.2 ACCIDENTS WITHIN THE SOUTH AFRICAN AVIATION INDUSTRY 15
2.3 WHY DO ACCIDENTS HAPPEN? 16
2.3.1 Loss of Control-in Flight (LOC-I) 17
2.3.2 Runway Safety 18
2.3.3 Controlled Flight into Terrain (CFIT) 18
2.4 HUMAN FACTORS AND ERGONOMICS 19
2.4.1 Human Factors and Ergonomics takes a system approach 19
2.4.2 Human Factors and Ergonomics is design-driven and seeks to improve performance and well-being 20
2.4.3 Human Factors and Ergonomics in the aviation industry 20
2.4.4 Human Factors and Ergonomics in Accident/Incident Investigation 21
2.4.5 Human Factors and Ergonomics Models to understand accidents 21
2.5 THE EVOLUTION OF ACCIDENT INVESTIGATION 23
2.5.1 Sequential Accident Models 24
2.5.2 Epidemiological Accident Models 25
2.5.3 Systemic Accident Models 26
2.6 RASMUSSEN'S RISK MANAGEMENT FRAMEWORK AND ACCIMAP 29
2.7 STAMP-CAST 33
2.7.1 Casual Analysis Using Systems Theory (CAST) 36

2.8 COMPARISON OF ACCIMAP AND CAUSAL ANALYSIS USING SYSTEMS THEORY 39
2.9 RELIABILITY AND VALIDITY OF ACCIMAP AND CAST 41
2.10 SUMMARY AND RATIONALE OF THE THESIS 42
3 CHAPTER 3: METHODOLOGY 44
3.1 INTRODUCTION 44
3.2 OVERVIEW OF THE V5-NRS CESSNA CONQUEST 441 ACCIDENT 44
3.3 OVERALL APPROACH TO THE ANALYSIS 45
3.4 ANALYSIS METHODS 45
3.4.1 Causal Analysis Using Systems Theory (CAST) 45
3.5 ACCIMAP 50
3.6 REFLEXIVITY ON THE ROLE OF THE RESEARCHER IN THE PROCESS 55
3.6.1 Reflexivity on the use of one method before the other 55
4 CHAPTER 4: RESULTS OF ANALYSIS 57
4.1 CAUSAL ANALYSIS USING SYSTEMS THEORY REPORT 57
4.1.1 Basic Information 57
4.1.2 Safety Control Structure 62
4.1.3 Analysis of Components: 64
4.1.4 Control Structure Flaws 77
4.1.5 Recommendations 79
4.2 ACCIMAP ANALYSIS REPORT 79
4.2.1 Accimap for the V5-NRS Cessna Conquest 441 Accident 79
4.2.2 The Accimap Framework of the V5-NRS Aviation Accident 81
4.2.3 Recommendations 86
5 CHAPTER 5: DISCUSSION 92
5.1 CONTRIBUTORY FACTORS OF THE V5-NRS CESSNA 441 CONQUEST II ACCIDENT AND THE RELEVANT RECOMMENDATIONS 93
5.2 COMPARISON OF CONTRIBUTORY FACTORS FROM THE V5-NRS CESSNA 441 CONQUEST II TO THAT OF OTHER STUDIES 96
5.3 A SUMMARY OF THE SYSTEMIC NATURE OF THE V5-NRS CESSNA 441 CONQUEST II ACCIDENT 98
5.4 LIMITATIONS RELATED TO THIS INVESTIGATION OF THE V5-NRS ACCIDENT 99
5.5 REFLECTIONS 100
6 CHAPTER 6: CONCLUSION 102
7 BIBLIOGRAPHY 103

LIST OF TABLES

Table I: Statistics of commercial aviation accident statistics reported on by the South African Civil Aviation Authority in Annual Reports. _____ 15

Table II: Statistics of general aviation accident statistics reported on by the South African Civil Aviation Authority in Annual Reports. _____ 16

Table III: AcciMap applied in different industries and findings on contributing factors _____ 35

Table IV: CAST applied in different industries and what these authors said about the tool. _____ 40

Table V: Questions Raised from the Proximal Events in the above figure 7. _____ 60

Table VI: Flaws in the mental/process models of the pilots in terms of contributing actions._____ 64

Table VII: Contextual Factors that explain the actions, decisions, and process model flaws of the Pilots. _____ 65

Table VIII: Flaws in the mental/process models of the Air Traffic Navigation Services in terms of contributing actions. _____ 68

Table IX: Contextual Factors that explain the actions, decisions, and process model flaws of the Air Traffic Navigation Services. _____ 69

Table X: Flaws in the mental/process models of the Technical, operational, and safety management of the Operator in terms of contributing actions._____ 70

Table XI: Contextual Factors that explain the actions, decisions, and process model flaws of the Technical, operational, and safety management of the Operator.____ 71

Table XII: Flaws in the mental/process models of Senior Management at WestAir in terms of contributing actions. _____ 72

Table XIII: Contextual Factors that explain the actions, decisions, and process model flaws of the Senior Management at WestAir. _____ 73

Table XIV Flaws in the mental/process models of the Namibian Civil Aviation Authority in terms of contributing actions. _____ 75

Table XV: Contextual Factors that explain the actions, decisions, and process model flaws of the Namibian Civil Aviation Authority. _____ 75

Table XVI Flaws in the mental/process models of the South African Civil Aviation Authority in terms of contributing actions._____ 76

Table XVII: Contextual Factors that explain the actions, decisions, and process model flaws of the South African Civil Aviation Authority. _____ 77

Table XVIII: Summary of Recommendations generated by the Causal Analysis using Systems Theory on the V5-NRS Cessna 441 Conquest II accident. _____ 88

Table XIX: Summary of Recommendations generated by the AcciMap on the V5-NRS Cessna 441 Conquest II accident. _____ 90

LIST OF FIGURES

Figure 1: Rasmussen's Dynamic Safety Model (Rydenfalt et al., 2013). _____ 22

Figure 2: Rasmussen's AcciMap Method (Left) and the Risk Management Framework (Right) (taken from Svedung & Rasmussen, 2002). _____ 31

Figure 3: The five components to a CAST analysis (CAST Handbook, Leveson 2004). _____ 46

Figure 4: A Simple Feedback Control Loop (Leveson, 2019). _____ 48

Figure 5: This is a part of the Safety Control Structure of the V5-NRS CAST report, the Safety Control Structure can be seen in its entirety in the results section. ____ 48

Figure 6: A Standardised AcciMap Format (Igene et al., 2021). _____ 51

Figure 7: Proximal Events of the V5-NRS Cessna Conquest 441. _____ 59

Figure 8: Safety Control Structure that prevents an aircraft from having an accident/incident. _____ 63

Figure 9: AcciMap of the V5-NRS Cessna Conquest 441 accident _____ 80

Figure 10: An extract of the contributory factors at the level of the Regulatory bodies and Association. _____ 81

Figure 11: An extract of the contributory factors at the level of Company Management and Planning & Budgeting. _____ 82

Figure 12: An extract of the contributory factors at the level of Technical and Operational Management of WestAir. _____ 83

Figure 13: An extract of the contributory factors at the level of Physical Processes and Actor Activities. _____ 85

Figure 14: Cape Town International Airport Runway 19 Final Approach Chart (AIID final report of the V5-NRS Cessna 441 Conquest II accident). _____ 87

Figure 15: Adapted version of Rasmussen's Structural Hierarchy of Risk management and the Dynamic Safety Model. _____ 99

1 CHAPTER 1: INTRODUCTION

1.1 BACKGROUND TO THIS STUDY

The aviation industry is complex and includes many interacting components such as various personnel and complicated technologies that interact in an open and sometimes unpredictable environment, under varying regulatory frameworks (Cook et al., 2005; Griffin et al., 2015; Yastrub et al., 2020). While considered to be an ultrasafe industry (Čokorilo, 2020; Glogovac & Čokorilo, 2018; Lykou et al., 2019; Papatheodorou & Liasidou, 2016) the interactions between these components can and have resulted in unexpected emergent challenges to safety (Griffin et al., 2015; Yastrub et al., 2020), which include accidents and incidents (Čokorilo, 2020; Glogovac & Čokorilo, 2018; Lykou et al., 2019; Papatheodorou & Liasidou, 2016). While the prevalence of commercial (large operator) accidents has been low in South Africa, the general aviation industry has seen an increase in accidents and incidents over the last five years which highlights the need to understand what may be contributing to this trend. To learn from and prevent future accidents and incidents, a thorough investigation of the contributory factors is critical. However, the theoretical models that underpin and frame the way in which these investigations occur have and continue to influence the quality of these approaches.

Over time there have been multiple models developed to explain accident causation, which represent an evolution of perspective of accident causation (Salmon et al., 2011). Historically, accident causation was attributed to equipment failures (Leplat, 1978). Over time, this view has changed and accidents were attributed to unsafe acts or human error that occurs at the ‘sharp end’ (where humans do the work) (Anderson, 1987; Rasmussen, 1990). Theorists such as James Reason, who introduced models such as the Swiss Cheese Model (Reason et al., 2006), further shifted the view that accidents result from a combination of both latent failures (found within the work system of an organisation) and active failures (Reason et al., 2006), which, in essence, posited that accidents are often caused by poorly designed systems, rather than just human error. Jens Rasmussen built on this idea by positing that accidents and incidents need to be understood through a systems approach (Hollnagel and Goteman, 2004; Dekker, 2011). This major shift in thinking came about due to large scale accidents for example the Challenger Space Shuttle Disaster (Leveson, 2004) and the Herald of Free Enterprise sinking (Reason, 1990), both of which are complex systems, which resulted in significant damage and loss

of many lives (Dallat et al., 2019). These large accidents shifted thinking around how such accidents occur and simultaneously how these accidents need to be investigated to ensure that learning is occurring which assists to prevent them from reoccurring (Dallat et al., 2019). It is well accepted now that systems thinking, and systems models and methods are critical to fully understand the complexity of modern sociotechnical systems and the many factors that can and do interact to cause accidents (Hulme et al., 2019). Human Factors and Ergonomics (HFE) is a systems discipline that has and continues to be well positioned to apply these methods in accident investigations in various contexts. These have included outdoor led activities (Salmon et al., 2014), disease outbreaks (Carayon et al., 2021) and transport industry accidents (Gertman et al., 2015), including those in aviation.

In South Africa, the Accident and Incident Investigation Department (AIID), which is part of the South African Civil Aviation Authority (SACAA), are currently mandated to undertake investigations related to aviation incidents and accidents. The investigations use the International Civil Aviation Organisation (ICAO) Annex 13 guidance document as a framework but, to date, investigators in the AIID have not been trained in and therefore have not used HFE systems methods in their investigations. Considering this, the researchers involved in this thesis, in collaboration with the AIID, agreed to apply two HFE systems methods to map the contributory factors to and recommendations around the V5-NRS Cessna 441 Conquest II accident that occurred in August 2015. Briefly, the accident involved a plane with five occupants crashing into the Tygerberg mountain during its approach to Cape Town International airport. A report was published on the accident and in collaboration with the AIID, it was agreed that the existing report would be analysed using two systems-based tools.

Therefore, the first aim of this thesis was to identify if, through the implementation of HFE systems tools, systemic contributory factors could be determined by using the existing AIID report. The second aim of this thesis was to identify if, using the two systems-based tools, the various actors and system levels involved in the accident could be identified. Lastly, the study aimed to identify if the implementation of these tools generates the same or different recommendations to that of the AIID.

2 CHAPTER 2: REVIEW OF LITERATURE

2.1 OVERVIEW OF THE GLOBAL AVIATION INDUSTRY

The aviation industry provides various transport services and is divided into commercial, general, and military aviation (Bergantino et al., 2020; Environment Branch of ICAO (ICAO), 2010). Commercial aviation consists of aircraft operating for hire to passengers or cargo and focuses on transporting passengers and cargo worldwide (Bergantino et al., 2020; Environment Branch of the International Civil Aviation Organisation (ICAO), 2010). Three principal actors in the commercial industries are airlines, airports, and Air Navigational Services. Airlines provide the aircraft that carry out transport services, airports offer the ground infrastructure that handles aircraft movement, where maintenance and safety checks can be performed and Air Navigational Services has control over air traffic and navigation of the airspace (Bergantino et al., 2020; Environment Branch of the International Civil Aviation Organisation (ICAO), 2010). Scheduled flights are flights that most travelers buy tickets for (Abdelghany et al., 2017). These flights run according to schedules and are fixed in terms of departure times and routing, whereas non-scheduled flights do not have a fixed schedule and can fly at any stage (Gebel, 2004; Abdelghany et al., 2017; Kucko, 2018).

General Aviation refers to all nonscheduled, nonmilitary civilian flight operations. These flights do not use airline company aircraft or military aircraft. Some examples of general aviation are aerial firefighting, search and rescue, agricultural aviation, medical transport, overnight delivery, and business and personal travel (Boyd, 2017; Goblet et al., 2015). Lastly, military aviation uses aircraft and other technologies such as drones to assist in any military missions (Gebel, 2004; Verhoeff et al., 2015). Within the commercial and general aviation sectors, there are two categories of flights: scheduled and non-scheduled (Gebel, 2004).

The aviation industry is constantly changing, and it is seen as one of the safest among the four major transport sectors which are rail, maritime, road and air (Čokorilo, 2020; Glogovac & Čokorilo, 2018; Lykou et al., 2019; Papatheodorou & Liasidou, 2016). This is due to the decades of safety engineering that have focused on improving

interactions between technology and people in the system (The Human Dimension in Tomorrow's Safe Aviation System, 2021). The progression in markets, technology, and new business models are just a few examples of the constant moving development in the industry (Wittmer et al., 2011). Although the aviation industry is considered ultra-safe, the complexity of the industry sometimes results in accidents or incidents occurring. To address this, the trends of the industry in terms of accidents and incidents will be addressed in the following section.

2.1.1 Trends in the global aviation industry

The number of commercial flights every year has been growing continuously, however, the number of accidents and incidents have been decreasing each decade (Janic., 2000; Shappell et al., 2007). This shows that industry is still working to maintain a high level of safety. Although looking at accidents per year is important, it is more beneficial to look at accident rates (yearly number of flights vs yearly number of accidents) as this allows trends to be identified. In 1960 there were far fewer flights, but the accident rates were high, and the major contributing factor was the lack of sophisticated technology (Douglas et al., 2017). The number of flights has increased over the decades but advances in technology have helped reduce the number of accidents each decade (Douglas et al., 2017).

The general aviation industry accident statistics are substantially higher in comparison to the commercial aviation industry (Boyd, 2017) with 78% of all aviation accidents and incidents occurring within the general aviation sector (Boyd, 2017). The reason as to why this may be higher is that there are many more general aviation flights occurring daily than commercial flights. There are also different certifications and standards for general aviation aircraft and there is less oversight in general aviation than there is in commercial aviation (Boyd et al., 2021).

The above overview describes the global aviation industry however, it is important to characterise the general aviation sector within South Africa as the accident investigated in this thesis occurred in South Africa. The next section will discuss the South African Aviation Industry.

2.2 ACCIDENTS WITHIN THE SOUTH AFRICAN AVIATION INDUSTRY

The South African Civil Aviation Authority (SACAA) is the regulatory body responsible for the safe operation and oversight within the SA aviation industry, with the Accident and Incident Investigation Division being specifically responsible for investigating and reporting on accidents and incidents (Wildenboer, 2006). To better understand the safety level within the South African aviation industry, Table I highlights South African accident statistics for commercial aviation aircraft that weigh more than 5.7 tons (5700kgs). These statistics are from Annual Reports provided by the South Africa Civil Aviation Authority. Table I shows that the commercial aviation accident rates in South Africa are relatively low. However, as safe as the aviation industry is made out to be, the number of accidents/incidents over the past year (2021-2022) in the general aviation sector (includes all civil aviation aircraft operations, however, excludes commercial airlines and transport) has increased by between 70-73% while the number of accidents in commercial aviation flights have decreased (Khosa, 2021).

Table II below highlights the accident statistics for the general aviation industry in South Africa. These data demonstrate that within general aviation in South Africa, the number of accidents has been increasing over the last five years and the number of accidents overall are far greater than that of the commercial aviation industry.

Table I: Statistics of commercial aviation accident statistics reported on by the South African Civil Aviation Authority in Annual Reports.

South African Civil Aviation Authority Commercial Aviation accident statistics	
Year	**Number of overall accidents**
2015/2016	0
2016/2017	0
2017/2018	0
2018/2019	3
2019/2020	1
2020/2021	0
2021/2022	1

Table II: Statistics of general aviation accident statistics reported on by the South African Civil Aviation Authority in Annual Reports.

South African Civil Aviation Authority general aviation accident statistics		
Year	**Number of fatal accidents**	**Number of overall accidents**
2015/2016	16	120
2016/2017	23	110
2017/2018	18	72
2018/2019	15	83
2019/2020	14	97
2020/2021	16	96
2021/2022	20	147

As seen in the above tables, there have been, particularly over the last three years, an increase in the number of accidents and associated fatalities in the South African general aviation industry. In trying to reduce the number of accidents or Incidents there needs to be an understanding of why these complex accidents or incidents are occurring. To understand the complexity, investigators need to ensure that these incidents are being investigated using the latest approaches, with the aim of trying to fully understand the complex interactions that lead to these adverse events, while simultaneously trying to generate meaningful recommendations to improve safety within the industry. The next section discusses why accidents occur in the Aviation Industry.

2.3 WHY DO ACCIDENTS HAPPEN?

According to Leveson (2019, p. 9), “an accident is considered an undesirable and unplanned event that results in a loss of property damage, human life or injury, and environmental pollution”. An incident on the other hand can be defined as an undesirable and unplanned event that does not result in a significant loss, damage, or injury (Wienen et al., 2017). A near miss is an unplanned event that could have resulted in an accident but does not (Oster et al., 2013, Kelly & Efthymiou, 2019). There are many contributory factors to accidents and incidents however historically humans have received a great share of blame for aviation accidents (Hollnagel & Speziali, 2008; Salmon et al., 2012; Dallat et al., 2019; Kelly & Efthymiou, 2019; Stanton et al., 2019). Pilot error has been and continues to be cited as the main cause

of many aviation accidents, with values such as 75% of the accidents being caused by pilot error (Oster et al., 2013, Kelly & Efthymiou, 2019). Alongside human error, bad weather is also commonly cited in most fatal accidents however as time has passed and systems have increased in complexity it has become evident that accidents emerge as a result of a combination of systemic factors interacting with one another (Dallat et al., 2019; Oster et al., 2013; Salmon et al., 2012; Zarei et al., 2022). These include, but are not limited to fatigue, maintenance failures, air traffic density, Air Traffic Controller error, design and manufacturer defects, distraction and lack of proper training or procedures, a combination of these factors may lead to an accident which is considered a loss event (Griffin et al., 2015; Keebler et al., 2023; Oster et al., 2013). A loss event may include the loss of human life or injury, equipment, damage to property, environmental pollution, mission loss, or negative impact on a business (Kenneth & Gould, 2020).

To prevent these losses from occurring risks and hazards need to be identified (Kenneth & Gould, 2020). A hazard is something that is harmless when by itself but depending on one's interaction with it can lead to an accident, incident or near miss (Xue & Fu, 2018). Examples of hazards in the aviation context include a mountain that can be crashed into or terrain that can interfere with flight or ground operations, lack of communication, employee turnover, work-related stressors and incorrect procedures that could lead to several dangerous situations (Xue & Fu, 2018). A risk is a dangerous situation that arises from a hazard (Xue & Fu, 2018). To demonstrate the difference, below are examples of operational risks that are considered high risk categories of occurrence which emanate from hazards. The categories are Loss of Control in Flight (LOC-I), Runway Safety and Controlled Flight into Terrain (CFIT). These are considered the top three categories of operational risks.

2.3.1 Loss of Control-in Flight (LOC-I)

Loss of Control-In flight (LOC-I) is recognised as a major contributing factor to fatal aviation accidents worldwide (Bromfield & Landry, 2019). LOC-I is a contributory factor to accidents where the flight crew is unable to keep control of the aircraft during flight, which results in an irrecoverable shift from the intended flight path (Bromfield & Landry, 2019). LOC-I can be caused by a range of factors such as stalls, engine failures, or

icing (Bromfield & Landry, 2019). LOC-I is considered one of the most complex accident categories, as there are many contributing factors that act in isolation, or, more often, act in combination (Bromfield & Landry, 2019). In this case, a hazard would be meteorological conditions such as extreme weather conditions that increases the risk of engine failure, icing or stalls that contribute to the LOC-I (Bromfield & Landry, 2019).

2.3.2 Runway Safety

Runway Safety Incidents include runway incursions and excursions, overshoots/undershoots, hard landings and tail strikes (Kirwan et al., 2017). These incidents or accidents occur while an aircraft is either taking off or landing and can be caused by multiple factors such as unstable approaches, failure to ground, inappropriate aircraft handling technique, aircraft weight exceeding maximum, prevailing conditions, aircraft system malfunction, wind velocity, loss of directional control as well as the condition of the runway (Kirwan et al., 2017).

2.3.3 Controlled Flight into Terrain (CFIT)

Controlled Flight into Terrain (CFIT) occurs when an aircraft that is airworthy and under complete control of the pilot is inadvertently flown into terrain, water, or any obstacle (Kelly & Efthymiou, 2019). CFIT is the second most common category of fatal accidents with LOC-I being the most common category (Kelly & Efthymiou, 2019). CFIT has been identified as a catastrophic event with the majority of accidents involving fatalities (Kelly & Efthymiou, 2019). There are many contributing factors to CFIT accidents which include, but are not limited to; lack of situation awareness; non-compliance with the established Standard Operating Procedures; inadequate flight path management; lack of vertical and/or horizontal position awareness; un-stabilised approaches; failure to initiate a go-around when required; operations in weather conditions that are poor; incorrect response by flight crew; failure in Crew Resource Management such as cross-checking; communications; coordination; and leadership (Kelly & Efthymiou, 2019; Tian et al., 2022). The causes of CFIT are multi-faceted and complex in nature and are usually the result of a poor interaction between humans and the broader systems. To understand and unpack this complexity, a systems approach is necessary. Human Factors and Ergonomics is a systems discipline that

focuses on understanding the human and system interaction with the intention of optimising this interaction.

2.4 HUMAN FACTORS AND ERGONOMICS

Human Factors and Ergonomics (HFE) is the scientific discipline that aims to understand interacting components among humans and other elements of a system so that human well-being and the overall performance of the system is optimised (IEA, 2019). It focuses on systems where humans interact with the environment that they are in (Bridger, 2017; Dul et al., 2012; Mohammed Elmardi Suleiman Khayal, 2019; Salvendy & Karwowski, 2019). The system can be classified in different ways. In a work system, the individual is a worker, and the environment is the work environment. In a product/service system, the human receives a product or service and the environment, they are within, is where the product or service is being received (Moray 2000; Wilson, 2000; Carayon, 2006). HFE focuses on trying to improve human performance and well-being by designing and integrating the human into the system (Dul et al., 2012). This is achieved by HFE adopting a systems approach, and being design driven (Dul et al., 2012).

2.4.1 Human Factors and Ergonomics takes a system approach

HFE focuses on characterising and understanding the interactions between humans and other components of the systems they form part of, which may be understood at different levels (Bridger, 2017; Dul et al., 2012; Mohammed Elmardi Suleiman Khayal, 2019). These levels range from the micro level which includes humans using tools for a single task; the meso level where humans form part of technical processes or teams for example and at a macro level where humans form part of networks within organisations, regions, countries, or the globe (Bridger, 2017). An HFE approach defines system boundaries so the focus can be on specific people, aspects of environment, at a specific level, while acknowledging the impact of the broader context (Dul et al., 2012). This approach to understanding the functioning of systems is called the systems approach which is design driven and aims to improve human performance and human well-being (Dul et al., 2012).

2.4.2 Human Factors and Ergonomics is design driven and seeks to improve performance and well-being

HFE seeks to ensure the improvement of performance and well-being through improving the interactions between humans and the broader systems (Bridger, 2017; Dul et al., 2012; Mohammed Elmardi Suleiman Khayal, 2019; Salvendy & Karwowski, 2019). This is achieved by the application of various methods that can be used to analyse and act on situations, allow for the assessment of and subsequent design of technical and organisational environments, allow for the redesigning and constant improving of system designs to allow for increased performance such as productivity, efficiency and safety as well as well-being (Woods and Dekker 2000; Dul et al., 2012). Such approaches have been and continue to be applied in the aviation industry, particularly when trying to understand why errors, incidents or accidents occur.

2.4.3 Human Factors and Ergonomics in the aviation industry

Historically, errors and system failures were poorly understood in the aviation industry (Keebler & Fausett, 2023). The technology in the industry has and continues to rapidly change, which has required designers and operators to understand the performance of the aircraft, but also, why they fail (Keebler & Fausett, 2023). The introduction of HFE allowed for the understanding of how pilots and any human operators interact within the system and how the design of the aircraft, surrounding systems and the controls reduce the risk of errors and promote safety (Arcúrio et al., 2018; Salvendy & Karwowski, 2019; Keebler & Fausett, 2023). The understanding gained from looking at all interacting parts was then used in the design, training, policies, or procedures to assist with increasing human performance and overall system performance (Arcúrio et al., 2018; Salvendy & Karwowski, 2019; Keebler & Fausett, 2023).

HFE historically only focused on the design of the flight deck however there has been a shift to a broader range of contributing factors such as psychology, human performance, physiology, visual perception, and human-computer interface design in aviation research (Arcúrio et al., 2018; Salvendy & Karwowski, 2019; Keebler & Fausett, 2023). This broader range of factors allows for the better design of systems to help humans perform to the best of their ability while being aware of their limitations (Arcúrio et al., 2018; Salvendy & Karwowski, 2019; Keebler & Fausett, 2023).

Designing systems to optimise human-system interaction, as mentioned before, has contributed to a reduction in aviation accident rates. However, when accidents do occur, the application of HFE methods has been recognised as critical to help in understanding the factors that contribute to the accidents and incidents (Arcúrio et al., 2018; Salvendy & Karwowski, 2019; Keebler & Fausett, 2023).

2.4.4 Human Factors and Ergonomics in Accident/Incident Investigation

Accidents are complex and often arise as the result of poor system design or inadequate training. Accidents arise from the interactions among many factors and components rather than individual factors or component failures (Qureshi, 2009; Bridger, 2017; Wilson, 2014). Considering this, HFE, as a systems discipline is uniquely placed and may aid to elucidate the problematic interactions and recommend design interventions to limit accident and incidents from occurring again (Bridger, 2017; Hancock, 2022; Hulme et al., 2022). HFE takes into consideration the human as well as the individual characteristics as these factors influence behaviour at work which may ultimately affect health and safety (Bridger, 2017; Hancock, 2022; Hulme et al., 2022). HFE goes beyond looking at the sharp end worker behaviour and looks at the system that failed to support safe performance in the first place (Qureshi, 2009; Bridger, 2017; Wilson, 2014). There are models and tools that have been developed to systemically (and systematically) understand how adverse events occur and these models will be discussed in the next section.

2.4.5 Human Factors and Ergonomics Models to understand accidents

HFE has multiple methods that are aimed at analysing systems to better understand complex sociotechnical systems such as those in aviation (Scribante et al., 2019; Thatcher et al., 2019). Rasmussen (1997) developed models that have been widely used within the Human Factors and Ergonomics field and more broadly in Safety Science. A model that was developed is the Dynamic Safety Model (Figure 1). The Dynamic Safety Model describes a dynamic system inside a performance envelope (Cook & Rasmussen, 2005; Chen et al., 2022). It includes a boundary of acceptable performance and parallel error margin boundary which is the point where errors in performance may occur (Cook & Rasmussen, 2005; Chen et al., 2022). The model shows how workload pressures and economic considerations act on a system, which can shift the system away from a safe performance and shifts it closer to the margin

of error (Cook & Rasmussen, 2005; Chen et al., 2022). If a system is shifted by one or both pressures, the boundary of acceptable performance can be crossed and a system failure or adverse event may occur as can be seen in Figure 1 (Cook & Rasmussen, 2005; Chen et al., 2022). This can also be explained as a 'drift into failure' which was theorised by Dekker (2011). Drifting to failure is the gradual, incremental decline into disaster that is propelled by various pressures such as environment pressures, technological pressures, economic pressures, and social pressures (Cook & Rasmussen, 2005; Chen et al., 2022). These pressures push the system to gradually drift into failure as the way in which the system operates changes and moves from a zone where every day work is safe, to where it is no longer safe (Dekker & Pitzer, 2016). The boundary that is crossed will determine the nature of the failure that was experienced (Cook & Rasmussen, 2005; Chen et al., 2022). For example, if the boundary of performance failure is crossed, it is most likely a system performance failure which can be an accident or an incident.

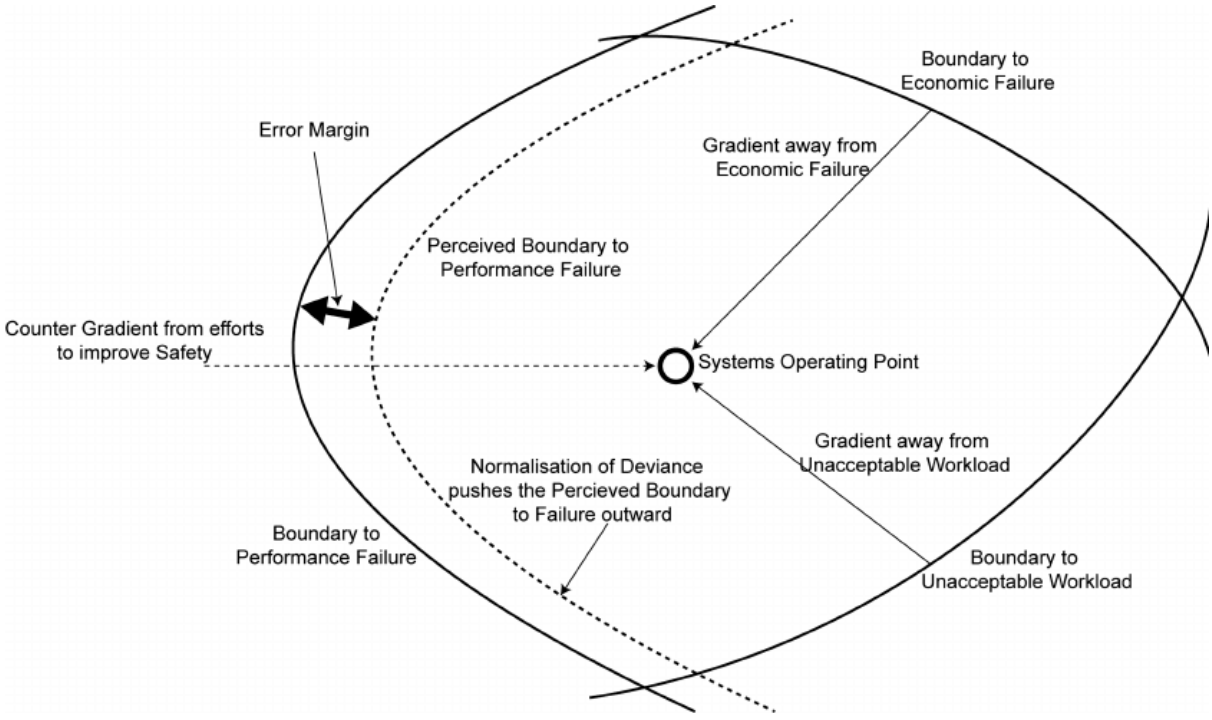

Figure 1: Rasmussen's Dynamic Safety Model (Rydenfalt et al., 2013).

The inclusion of The Dynamic Safety Model allows for a different systems lens to be used when investigating accidents/incidents. The different lens views accidents/incidents as the product of interactions or the lack of interactions between the different components of a system as well as across different hierarchical levels of

the system which means that using these HFE tools is beneficial when investigating accidents or incidents. In saying this, accident investigations have not always taken a systems approach to understand why and how accidents happen. It is therefore relevant to review how accident investigation, and more specifically the models that have underpinned this process, have evolved over time.

2.5 THE EVOLUTION OF ACCIDENT INVESTIGATION

An accident or incident investigation is a procedure taken for the purpose of preventing future accidents and incidents (Adole., 2020; Lindberg et al., 2010). The process includes the gathering and analysis of information with regards to the accident or incident, the drawing up of conclusions which includes determining the causal factors and lastly the generating of safety recommendations to assist with the prevention of future events (Adole., 2020; Lindberg et al., 2010). Individual beliefs often play a role in the outcome of investigations, which can be through biased opinions or assumptions an investigator may have formed (Adedigba et al., 2016; Lindberg et al., 2010). An investigator's bias can often result in an analysis that is narrowly focused which can result in an investigation that is completed inadequately (Adedigba et al., 2016; Adole, 2020; Lindberg et al., 2010).

To reduce bias in investigations, applying accident and incident investigation models and methods are beneficial (Adedigba et al., 2016). Accident investigation models play a vital role in the design of methods for accident investigation (Aedigba et al., 2016). An accident investigation model provides a conceptual representation of accident causation, and a method allows for a way to apply the theory. Accident methods systematically identify the causes and consequences of an adverse event and identify how these may have significantly contributed to an accident (Adedigba et al., 2016). Accident methods have been classified into three model categories; sequential models, epidemiological models, and systemic models (Wienen et al., 2017). Over time, the number of accident investigation methods have increased but have also shifted from the perspective of sequential models and epidemiological models to more systemic models as the complexity of systems in which accidents are occurring is increasing (Wienen et al., 2017). This shift of models will be unpacked and discussed below.

2.5.1 Sequential Accident Models

Early models and methods of accident investigations required investigators to consider the direct and underlying factors of an accident to establish responsibility and assign blame (Vincoli, 1994; Wienen et al., 2017). These models, known as sequential models, view accidents as a sequence of events (Hollnagel & Speziali, 2008). It is assumed that an adverse event or root cause initiates the start of a sequence of events that lead to an accident or incident (Hollnagel & Speziali, 2008). The sequence of events is based on the assumption that a cause-effect relationship between each event is linear and deterministic. (Underwood, 2013). In essence, the accident is the result of a root cause; if the root cause is highlighted and removed, it will prevent accidents or incidents from reoccurring (Armstrong et al., 1988; Hollnagel & Speziali, 2008; Tuli et al., 2017; Underwood, 2013).

Leveson (2004) argues that the root causes identified using sequential methods are helpful when losses that are caused by physical component failures or human actions in systems. However, this approach poorly defines the cause-effect relationship between the management, organisational and human elements of a system (Underwood, 2013). It cannot explain how the interactions between these components trigger an accident/incident (Underwood, 2013).

An example of a model that falls under the category of sequential models is Heinrich's Domino Model (Heinrich., 1931), according to which, an accident is the product of a set of events occurring in sequence that eventually led to this adverse event (Heinrich, 1931; Stanton et al., 2019). Factors leading to the event are visualised as a series of dominos standing on edge; it appears to be a linear sequence. When there is an unsafe act, a physical or mechanical hazard is present, the first domino (factor) falls, and a chain reaction is caused and leads to the accident. Heinrich (1931) posed his theory as a single cause leading to an accident.

Another model that falls into the category of sequential models is the Human Factors Model. This model states that an accident's root cause is human error (DeJoy, 1990; Shahab Hosseinian & Jabbarani Torghabeh, 2012; Wittmer et al., 2021). These errors are categorised as being the result of overload, inappropriate worker response, and

inappropriate activities (DeJoy, 1990; Shahab Hosseinian & Jabbarani Torghabeh, 2012). An error caused by overload is when the work task is greater than the worker's capability (DeJoy, 1990; Shahab Hosseinian & Jabbarani Torghabeh, 2012). This includes physical and psychological factors but recognises the influence of other environmental, internal, and situational factors (DeJoy, 1990; Shahab Hosseinian & Jabbarani Torghabeh, 2012). Inappropriate worker responses refer to when there is an interaction between a hazard that the worker has met and what safety measures she/he uses to prevent an adverse outcome (DeJoy, 1990; Shahab Hosseinian & Jabbarani Torghabeh, 2012; Wittmer et al., 2021). In essence, the error is seen as the worker's and their response to their incompatible workstation (DeJoy, 1990; Shahab Hosseinian & Jabbarani Torghabeh, 2012; Wittmer et al., 2021). Lastly, inappropriate activities refer to those which may result from a lack of training and misjudgment of risk leading to an accident/incident (DeJoy, 1990; Shahab Hosseinian & Jabbarani Torghabeh, 2012).

The limitations of event-chain (cause-effect) causality models are that social and organisational factors are neglected, and human error accountability can neither simply nor effectively model human behaviour by separating actions and decisions into single events (Hollnagel & Speziali, 2008). Human error, as part of understanding accident causation, has been and is still used widely by researchers. However, the utility, validity, and relevance of the concept of human error as what causes accidents is being questioned as there is a shift to a more systems perspective (Read et al., 2021). The concept of human error has the potential to have value in describing behaviour that proceeds from an individual expectation and intention and can be valuable in the design of a system however, recently, some authors argue that it is important to focus on all types of performance rather than just errors and failures alone (Read et al., 2021). This shift will be discussed below as it shifts from sequential methods to epidemiological methods to systems methods.

2.5.2 Epidemiological Accident Models

Epidemiological models try to understand accidents and incidents as the result of both latent and active failures interacting within an operating system (Reason et al., 2006). Latent failures refer to subtle contributory factors that may lie dormant for an extended

period until they contribute to an accident, while active failures are considered as errors and violations that have immediate negative results and are usually caused by an individual while working (Reason et al., 2006). Organisational factors often contribute to latent failures where, for instance, decisions made by individuals within the organisation may negatively impact performance, such as fatigue or workload, which may contribute to unsafe acts (Underwood, 2013; Wienen et al., 2017). Conversely, active failures refer to unsafe acts made by operators and involve errors and violations (Reason et al., 2006), where an error is an action or decision which was not planned, and a violation is a deliberate departure from a rule or procedure that is in place (Xu et al., 2022)

An example of an epidemiological model is the Swiss Cheese Model of accident causation used in risk management, which compares human-designed systems to Swiss Cheese Slices (Reason, 1997). The “cheese slices” are seen as barriers to preventing failures, and the holes are seen as individual weaknesses within each level in the system (Reason et al., 2006). A failure occurs when the holes in the “cheese slices” align and release or allow for an accident, as all defenses are passed through, and the accident is the result (Reason et al., 2006).

Compared to sequential models, epidemiological models better understand and characterize the influence that factors of an organisation have in accident causation (Hollnagel & Speziali, 2008; Underwood, 2013; Wienen et al., 2017). Despite this more holistic view of accident causation, these models are still based around cause-effect principles of models that are sequential as they describe the linear process of accident causation (Hollnagel & Speziali, 2008; Underwood, 2013; Wienen et al., 2017). A more contemporary view of accident causation recognises that accidents and incidents arise as the result of unpredictable and non-linear interactions within systems. In light of this, systems approaches are useful to map and understand these contributory factors.

2.5.3 Systemic Accident Models

The shift towards the adoption of a more systems perspective has demonstrated the limitations of cause-effect models when trying to understand why accidents happen (Read et al., 2021). Sequential methods based on sequential models cannot

exhaustively explain accident causation in relation to the modern sociotechnical systems (Hollnagel et al., 2001). However, these methods are useful in identifying key contributing factors and therefore as part of the package of tools that get applied to an accident investigation (Read et al., 2021).

Adopting a systems perspective and using systemic methods has been recognised as an important step towards understanding that outcomes emerge from interactions that occur between multiple system components within a sociotechnical system, often in unpredictable and dynamic ways (Coury et al., 2010; Read et al., 2021; Sklet, 2002). These systemic models are underpinned by systems theory (Hollnagel & Speziali, 2008; Underwood, 2013; Wienen et al., 2017), which argues for the utility in understanding the structure and behaviour of systems through an interdisciplinary lens (Underwood, 2013b).

In systems theory, complex systems are viewed as a hierarchy of organisational levels, with each level of the system that is more complex than the one beneath it (Leveson, 2011). A complex system comprises of multiple smaller systems, and the interactions between these systems creates the complexity within the system (Read et al., 2021). Rather than treating accidents and incidents in complex systems as a sequence of cause-effect events, systems approaches describe emergent outcomes of a system as the result of uncontrolled interrelationships between subsystem components (Hollnagel & Speziali, 2008; Underwood, 2013; Wienen et al., 2017). Therefore, systemic models do not look at accidents as the results of just latent or active failures but argues that accidents occur because of humans and technology operating in ways that seem reasonable under normal conditions, but, in hindsight, unsafe conditions emerge within the system (Hollnagel & Speziali, 2008; Underwood, 2013; Wienen et al., 2017). Systemic approaches and methods that are based on systems thinking and systems theory uncover many causal factors contributing to the accident and help to identify many changes that can prevent future accidents/incidents (Leveson, 2011). Some authors contend that models that are based on systems theory allow for a more powerful accident analysis that will assist in the learning from these events and there are several systems analysis methods based on systemic models

that can be used (Leveson, 2011). Systems based analysis methods will be discussed in the next section.

2.5.3.1 System Based Analysis Methods

There is a range of various system-based analysis methods that have been employed (Read et al., 2021). These include, Causal Analysis Using Systems Theory (CAST), which is based on the Systems Theoretic Analysis Model and Processes model (STAMP) (Leveson, 2004, 2011); the Functional Resonance Analysis Method (FRAM), which provides a method to describe outcomes by using the concept of resonance arising from the variability in everyday operations (Hollnagel, 2004, 2012) and the Human Factors Analysis and Classification System (HFACS) which allows investigators to systematically identify active and latent failures within an organisation that may have contributed to an accident (Shappel & Wiegmann, 2000). This is achieved by identifying organisational influences, unsafe supervision, preconditions for unsafe acts and unsafe acts (Shappel & Wiegmann, 2000). HFACS does not consider failures outside of the organisation that is involved (Salmon et al., 2020). Over and above these, the Networked Hazard Analysis and Risk Management System (Dallat, Salmon, and Goode 2018), Cognitive Work Analysis (Vicente, 1999) and lastly AcciMap (Rasmussen, 1997) are other commonly applied methods. AcciMap includes a multilayered causal diagram where the various causes of an accident are arranged in accordance with their causal remoteness from the adverse outcome (Rasmussen, 1997). These methods consider the important components of complex systems and take the system as a unit of analysis rather than just looking at human behaviour in isolation (Read et al, 2021). The increasing complexity of systems necessitates the use of appropriate tools to understand and learn from these interactions (Dallat et al., 2019). Rasmussen's Accimap and Leveson's CAST will be used to analyse the accident in this thesis as both these methods support the identification of contributory factors up to and including regulatory and government levels of the system which is not included in other methods such as FRAM and HFACS (Salmon et al., 2020). These two methods are now discussed in more detail below.

2.6 RASMUSSEN'S RISK MANAGEMENT FRAMEWORK AND ACCIMAP

Rasmussen views safety or a lack thereof as an emergent property that manifests through interactions within the different levels of a system (Rasmussen, 1997; Waterson et al., 2017), which is elegantly captured in his hierarchical risk management framework (Rasmussen., 1997). The risk management framework defines various levels of a system which includes government, regulators, companies, company management, staff, and work done to be involved in an organisation's production and safety management (Rasmussen, 1997). Each level within the system is involved with safety management by controlling hazardous processes that originate from laws, rules, instructions, and the act of doing work (Rasmussen, 1997).

For systems to function safely and accurately, vertical integration is important as decisions that are made at the top levels of the organisation need to be reflected in actions and decisions that are made at the bottom levels of the system (Branford et al., 2007; Salmon et al., 2012; Waterson et al., 2017). Concomitantly, information pertaining to work occurring at lower levels (staff, equipment, and work done), needs to transfer up the hierarchy so that decisions and actions made at the top are well-informed (Salmon et al., 2012). Without this important vertical integration within a system, systems can lose control of the processes they should be controlling, which may lead to an accident (Branford et al., 2007; Salmon et al., 2012; Waterson et al., 2017). The basic idea behind Rasmussen's framework is that there are different levels within a system, and the actions and decisions made at different levels can shape how individuals behave as well as safety. Adversely the risk of error, incidents or accidents are increased (Trotter et al., 2014; Wang et al., 2021). Thus, accidents or incidents are multifactorial in terms of the factors that contribute to them and are shaped by decisions or assumptions made by various system actors, not just a single decision of an actor in isolation.

In the evolution of Rasmussen's work, he then outlined a systems-based technique called AcciMap that graphically represents system-wide failures, decisions, and actions involved in accidents (Branford et al., 2007; Salmon et al., 2012; Waterson et al., 2017). AcciMap was developed by Rasmussen (1997) as part of a process that generates a proactive risk management strategy for complex sociotechnical systems.

It consists of a multilayered diagram by which the contributory factors of an accident are arranged according to their causal remoteness from the outcome. In essence, it is useful towards identifying how factors within all parts of the complex sociotechnical system have contributed to an organisational accident (Rasmussen, 1997). Identifying causal factors and the interrelationships between them is one way of highlighting problem areas that need to be addressed so that safety within a system can be improved, but it can also allow for similar occurrences to be prevented as best as possible (Branford et al., 2007). AcciMap follows Reason's (2000) systems approach to accident investigation as it acknowledges influences and constraints on an individual's behaviour but aims not to blame these individuals for their mistakes. Rather, it tries to uncover system deficiencies that allowed for these errors to occur or failed to prevent these actions from causing an accident/incident. It thus represents a shift from blame to identifying and repairing system deficiencies so that further accidents/incidents can be prevented (Reason., 2000; Trotter et al., 2014; Wang et al., 2021).

There are several advantages to AcciMap as an approach. Firstly, it allows investigators to gather and arrange large amounts of information that link the numerous causes or interactions that have led to the accident or incident (Branford et al., 2007; Salmon et al., 2012; Waterson et al., 2017). It allows for the investigator to identify the level of the sociotechnical system where each factor came from, and how these factors came together to cause the accident/incident (Branford et al., 2007; Salmon et al., 2012; Waterson et al., 2017). This method is useful for not only being able to explain why something has happened but also for assisting the investigator in placing the data gathered in a logical sequence to allow for the understanding of the complexity of the interactions or combinations thereof that have resulted in an unwanted outcome (Salmon et al., 2012; Waterson et al., 2017).

Secondly, AcciMap uses a systemic view of accident causation as it goes further than just the immediate causes at the level of the decisions made by the person involved but allows various factors to be uncovered throughout the whole system (Branford et al., 2007; Salmon et al., 2012; Waterson et al., 2017). These contributing factors include factors from the individuals directly involved, organisational, governmental,

regulatory and, in some cases, societal factors (Rasmussen, 1997, Branford et al., 2007). The AcciMap diagram highlights all the factors that contributed directly to the accident and highlights the causes of each of these factors so that decisions, events, and conditions within the system that led to the accident/incident can be identified (Branford et al., 2007; Goncalves Filho et al., 2019a; Rasmussen, 1997; Salmon et al., 2012; Waterson et al., 2017).

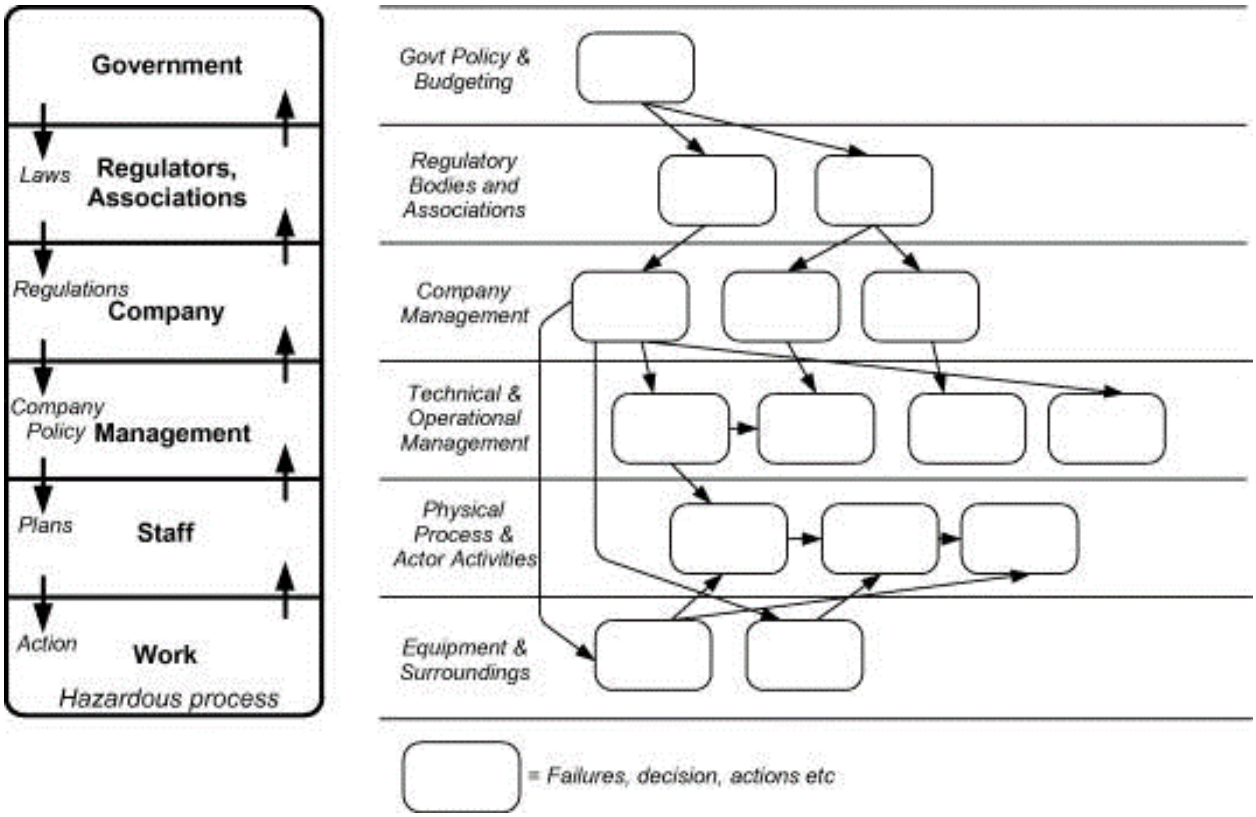

Figure 2: Rasmussen's AcciMap Method (Left) and the Risk Management Framework (Right) (taken from Svedung & Rasmussen, 2002).

Another advantage of using AcciMap is that it assists in developing safety recommendations, as the events are shown systemically, allowing for factors to be identified and potentially corrected to prevent potentially hazardous situations from arising again (Hulme et al., 2019). Identifying factors at higher levels within the system (organisational level and upwards) allows for corrective action and decisions that can benefit a broader range of factors that can act as a great preventative measure (Waterson et al., 2017). With reference to the above advantages of the AcciMap, Table III includes several examples of accidents that used AcciMap in their analysis. The table highlights what each accident or incident identified as contributory factors.

Contributory factors across industries seem to be consistent, with factors being lack of training, inaccurate risk perception, inexperience, fatigue, inadequate policy management, inadequate oversight, inadequate design of working factors. All these contributing factors are systemic in nature, accenting to why using an AcciMap can be beneficial when trying to identify systemic contributing factors.

There are also limitations associated to the application of AcciMap. Firstly, it is a generic approach and does not use different categories of failures across the different levels of analysis. Secondly, it merely describes the events and actions rather than the components of the system. Thirdly, there is little information about system boundaries and structure in terms of the system being investigated which leads to reliability of AcciMap being questioned as many of the AcciMap diagrams differ from user to user (Salmon et al., 2012, Waterson et al., 2017). Lastly, if the accurate mindset is not used when collecting data and performing the analysis, the AcciMap can still take a more traditional approach where the sharp end is focused on. Salmon et al. (2020) demonstrated this in their analysis of 23 different articles that captured the application of AcciMap for different accidents, in which a total of 5587 contributory factors were used. These factors ranged across the six AcciMap levels generated for this study, equipment, and surroundings (1695); physical processes and actor activities (2992); technical and operational management (414); local area government planning & budgeting (250); regulatory bodies and associations (114); and government policy and budgeting (122) (Salmon et al., 2020). This means that nearly 80% of the contributory factors were situated in the physical processes and actor activities and equipment and surroundings level (Salmon et al., 2020). In addition, 50% of the contributory factors were found in relation to the sharp end of the systems operations. Lastly, the contributing factors were identified as judgement and decision making and compliance, violations and unsafe acts at the physical processes and actor activity levels (Salmon et al., 2020).

These findings highlight the limitation that users of AcciMap have customarily used it with a traditional view of accident causation (Salmon et al., 2020). In saying this the AcciMap analyses have also identified contributing factors beyond the sharp end, including regulatory bodies and the government (Salmon et al., 2020). This article

suggests that education needs to be improved as well as data collection systems to ensure that AcciMap is applied in a way that is consistent with its theoretical underpinnings (Rasmussen, 1997) and further that individuals analysing may benefit from using an AcciMap classification scheme (Salmon et al., 2020). The abovementioned article highlighted three main recommendations: the need for more and better education in systems thinking, improvement of data collection systems, and to ensure there is usage of an AcciMap classification scheme (Salmon et al., 2020). The above-mentioned recommendations will be taken into consideration when applying AcciMap in this thesis.

2.7 STAMP-CAST

The Systems-Theoretic Accident Model and Process (STAMP) model of accident causation was designed around three basic concepts: safety constraints, hierarchical safety control structure, and process/mental models (Nelson, 2008; Leveson, 2020b). STAMP views a system as many interconnected components that interact through feedback control loops (Nelson, 2008; Leveson, 2020b). Systems are forever changing as they always adapt to their environment to constantly achieve their outcomes (Nelson, 2008; Leveson, 2020b). When these systems achieve their outcome and all components work optimally, safety becomes an emergent property (Nelson, 2008; Leveson, 2020b). As a system adapts over time, its original design needs to ensure the appropriate safety constraints are enforced to ensure safe operations (Nelson, 2008; Leveson, 2020b). According to STAMP, an accident takes place because of inadequate processes that involve interactions among people, societal and organisational structures, engineering activities, and physical system components, such that the risk of an accident increases due to a system's incapability to adapt to the changes in its operations because of the environment in which it operates (Nelson, 2008; Leveson, 2020b).

The STAMP model defines safety management, not as the prevention of component failures but rather, as creating a safety control structure that enforces behavioural safety constraints and ensures that effectiveness is constant and adaptations within the system happen over time (Nelson, 2008; Goncalves Filho et al., 2019a; Leveson, 2020b). STAMP is used to identify the safety constraints that have been violated and

determine why controls were not enforcing these constraints effectively (Nelson, 2008; Goncalves Filho et al., 2019a; Leveson, 2020b). To prevent a failure, safety margins and external and internal factors need to be increased (Nelson, 2008; Goncalves Filho et al., 2019a; Leveson, 2020b).

The difference between STAMP and other models of accident causation is that STAMP goes past simply placing blame on component factors for accidents and rather allows for other reasons to be identified in terms of why failures may have occurred, and this can be done through the implementation of methods that are underpinned by STAMP (Nelson, 2008; Goncalves Filho et al., 2019a; Leveson, 2020b). The process as to why an event took place is usually incomplete, and investigators tend to lean towards assigning blame to an operator where a learning opportunity is lost (Leveson, 2011). An accident analysis method or technique needs to provide a framework or process that allows for a greater understanding of the events that led up to an accident and identifies the systemic causal factors involved (Leveson, 2011). STAMP is a framework that has two tools. The two tools that are based off STAMP's framework are Casual Analysis using Systems Theory (CAST) and Systems-Theoretic Process Analysis (STPA). STPA is a hazard analysis technique which is used prior to an accident and CAST is an analysis method used after an accident has occurred. Since this study is investigating an accident that is already happened the next section will discuss the theoretical underpinnings of CAST.

Table III: AcciMap applied in different industries and findings on contributing factors

Application of AcciMap in different industries			
Author & Year	**Country**	**Industry**	**What was found**
(Tabibzadeh & Meshkati, 2015)	United States of America	Oil and Gas	Pressure for time and cost saving, lack of training, failing to identify and evaluate all risks, communication, training, experience, copious amounts of gas on the rig surface, alarms did not go off, and the activation of emergency disconnect system was not successful.
(Lee et al., 2017)	South Korea	Maritime	Inadequate oversight of government, no onsite government authority present, inadequate oversight and enforcement mechanisms from regulatory bodies, corruption and collision between government officials, communication, inexperience, not enough money spent on safety education, overloading of ship, ships were not in working conditions, too much weight added on ship, inadequate training, and human error.
(Hamim et al., 2019)	Bangladesh	Transportation	Lack of monitoring of development goals, insufficient monitoring to ensure road safety, insufficient allocation of funds, limited police forces to enforce laws, roads are inadequately designed, high speeds, risky overtaking's, no road traffic signs, and no safety barriers.
(Gholamizadeh et al., 2022)	Iran	Oil	Inadequate inspection and inadequate policy of labour organisation, inadequate safety management systems, inadequate policy in refinery management, lack of efficient crises management systems, inappropriate design, failure to perform standard manoeuvres, lack of equipment, and defects in operations.
(Torres et al., 2022)	Canada	Aerospace	Fatigue, distraction, interruptions, improper mental representation, lack of space, workplace layout, shift scheduling, overtime allocation, inadequate design of working factors, budget allocation, client requirements, supply chain, and technical requirements.

2.7.1 Casual Analysis Using Systems Theory (CAST)

Sociotechnical systems are complex, and this is due to the different levels of interactions between humans, technology, time, as well as operating and organisational environments (Leveson, 2011; Salmon et al., 2016; Düzgün & Leveson, 2018). Analysing an accident that has taken place in a sociotechnical system requires an understanding of the system's safety structure (Leveson, 2011; Düzgün & Leveson, 2018). Previous authors have argued that there are several broad limitations that hamper accident investigations. These include root cause thinking, the oversimplification of causal explanation, hindsight bias, superficial treatment of human error, a blame culture, and the use of models that do not fit the complex multifactorial world of today (Leveson, 2019). The CAST analysis, created by Leveson, attempts to move away from these limitations (Leveson, 2019).

CAST is used to understand a past accident so that it can be prevented in the future (Leveson, 2011; Düzgün & Leveson, 2018; Goncalves Filho et al., 2019a). CAST highlights why something happens rather than who made it happen (Leveson, 2011; Düzgün & Leveson, 2018; Goncalves Filho et al., 2019a). The focus of CAST is to not only understand what an individual did wrong but also understand why the individual might have done the wrong action or made the wrong decision (Leveson, 2011). The CAST analysis technique does not only analyse events that include the loss of life but rather can be used to understand causal factors of any sort of undesired or adverse outcome that has led to a loss that an organisation or stakeholder would want to avoid in the future (Düzgün & Leveson, 2018; Leveson, 2019; Li et al., 2020a). The objective of any accident analysis is to learn how to prevent losses. Therefore, it cannot be summed up as something like a "root cause," but rather the objective is to learn as much as possible from the analysis (Düzgün & Leveson, 2018; Leveson, 2019; Li et al. 2020). CAST analysis is a retrospective analysis tool that identifies all potential scenarios that may have led to a loss. However, CAST does not specify a process for accident investigation; rather, it is a way to document and analyse the results that come from the process. This approach therefore allows investigators to fully understand why an accident occurred by identifying important and relevant questions that need to be asked (Leveson, 2011; Dügün & Leveson, 2018; Goncalves Filho et al., 2019a).

Investigators need to remove any bias when investigating and look at why an individual behaved the way they did, given the information they had at the time (Düzgün & Leveson, 2018; Goncalves Filho et al., 2019a; Leveson, 2011CAST Analysis can help show how an accident process unfolded by depicting the system safety control structure, safety constraints that were violated at each level of the control structure, and why these violations may have occurred (Düzgün & Leveson, 2018; Goncalves Filho et al., 2019a; Leveson, 2011). Thus, weaknesses in the safety control structure may be identified, and changes that will not eliminate all symptoms but may potentially limit the causal and systemic factors through redesigning the system can be seized (Düzgün & Leveson, 2018; Goncalves Filho et al., 2019a; Leveson, 2011).

2.7.1.1 The process of using Causal Analysis Using Systems Theory

The CAST process starts by taking a systemic view and exploring what hazards may have been involved in an accident under investigation. It is then able to consider the loss from perspectives of each level of the structure (Leveson, 2011). Each operator in the system is analysed by focusing on understanding and highlighting the safety requirements and responsibilities, controls in place, context of unsafe actions, and the reasons for their inadequate communication or actions based on mental models (Leveson, 2011). A mental model is the individual's thought process about how something works in the real world (Leveson, 2011). An example of how this process works is discussed in the example below.

2.7.1.2 An example of the application of Causal Analysis Using Systems Theory (CAST)

An example within the aviation industry where the CAST method was applied led investigators to identify more causal factors that surpass the operator error (Nelson, 2008). Nelson (2008) investigated the Comair 5191 aircraft that failed to take off at the Blue Grass Airport in Lexington (http://sunnyday.mit.edu/papers/nelson-thesis.pdf). The aircraft ended up speeding off the end of the runway, hitting a wall, the perimeter fence, and an area that is wooded before eventually stopping and catching fire. The first investigation performed on this accident was conducted by National Transportation Safety Board (NTSB) in the United States of America. The investigation revealed that the accident resulted from a pilot error where the pilot breached cockpit

protocol. The flight crew were instructed to take off from runway one, Instead, they lined up the aircraft on a different runway which was much shorter. The crew began the takeoff without cross-checking and verifying that the airplane was on the correct runway before takeoff. A CAST analysis was then performed, allowing the investigator to consider other aspects of the accident (Nelson, 2008). Nelson (2008) concluded that a contributor to the accident was the ongoing construction happening at the airport where there was inadequate signage and outdated maps, a different conclusion from that of the National Transportation Safety Board in the US. The conclusion that the NTSB reached was that the cause of this accident was due to decisions made by the crewmembers on the flight (Nelson, 2008). It was reported that flight crewmembers failed to use the cues and aids that were available to identify the aircraft's location on the airport surface, and blame was also placed on the flight crewmembers' failure to cross-check (Nelson, 2008).

It is evident from the outcome of both methods that the NTSB used an approach that wanted to identify the human error and to place blame on the human on the ground level, whereas Nelson (2008) took a more systemic approach and shifted away from simply placing blame on humans and towards identifying how interactions between the pilot and the environment may have contributed towards the accident. The CAST analysis led to identifying factors such as the controller not issuing correct information, not monitoring the takeoff, the airport having inadequate signage, as well as Controller and Crew duty/rest regulations having not been updated to be consistent with modern scientific knowledge about fatigue and its associated implications.

Apart from the abovementioned example that applied CAST, there have been several other accidents and incidents that have applied CAST within different industries. Table IV highlights the different accidents and incidents that have used CAST and shows that the contributing factors that have been identified in each of these accidents/incidents are consistent across industries. The consistent contributing factors identified included inadequate oversight of the regulator and operator, inadequate training, lack of experience, poor awareness, inadequate supervision, and inadequate communication. These contributing factors are systemic in nature, highlighting the critical need for the application of robust systems-based analysis tools

in the investigation of complex accidents/incidents. Therefore, this warrants a discussion around the practical implications associated with the application of both the CAST and AcciMap analysis tools.

2.8 COMPARISON OF ACCIMAP AND CAUSAL ANALYSIS USING SYSTEMS THEORY

It is important that the methods that are used for the analysis of an accident can address all levels within a system, as they need to identify the underlying, multiple causes that interact with one another and lead to accidents (Stanton et al., 2019). Both AcciMap and CAST address all levels in the system that ranges from equipment and environment to government policy and budgeting (Stanton et al., 2019). AcciMap has been rated well in terms of ease of use, application time, training demand, and simplicity of interpretation and it allows for the ability to analyse the spread of events through the different levels (Stanton et al., 2019; Zhang et al., 2018). CAST identifies the role of constraints in safety management (Zhang et al., 2018) and is based on STAMP which begins the violations of safety constraint. CAST is then used to identify why the design of the control, or the implementation of safety constraints is not appropriate or why the system cannot be controlled by the safety constraints if they are appropriate (Zhang et al., 2018).

AcciMap and CAST methods depend on systems thinking paradigm for their successful application which allows for the analysis of components within the systems structure (Kim et al., 2016; Leveson, 2004; Rasmussen & Svedung, 2000; Zhang et al., 2018). However, there are differences that have been found in terms of system structure between the models (Kim et al., 2016; Leveson, 2004; Rasmussen & Svedung, 2000; Zhang et al., 2018). AcciMap considers the management of safety to be a control problem that involves all levels of a system (Kim et al., 2016; Zhang et al., 2018). This method uses a graphical representation that depicts the flow of causal factors which includes sociotechnical factors, where it highlights the interactions among levels of the complex system that may have led to an accident (Rasmussen., 1997; Kim et al., 2016; Zhang et al., 2018).

Table IV: CAST applied in different industries and what these authors said about the tool.

Application of CAST in different industries			
Author & Year	**Country**	**Industry**	**What was found**
(Torres et al., 2022)	Canada	Aerospace Manufacturing	Flaws in the creation process, incorrect installation of parts, omission of an operation, time gap, lack of tools with adequate tracking/feedback, distractions, and interruptions
(Chowdhury et al., 2022)	Bangladesh	Maritime	Inadequate oversight of training, inadequate oversight led the company to cut costs with regards to safety constraints, incompetence, and insufficient training
(Kim et al., 2016a)	South Korea	Maritime	Inadequate inspection, lack of experience, poor awareness, conditions, inadequate training, environmental limitations, deficiencies in loading criteria, non-compliance, insufficient qualified individuals, inadequate monitoring, or feedback channels established so that private agencies are supervised, inadequate supervision, missing communication, and cooperation
(Li et al., 2020b)	Taiwan	Gas	Inadequate supervision, inadequate evaluation of pipeline, inadequate safety and emergency response training of staff, inadequate emergency response, failed to evacuate local people, lack of training and inadequate monitoring and feedback channels

CAST views systems as a hierarchical structure that consists of multiple control levels. Each level in the structure imposes constraints on the activity that is done in the subsequent level below (Kim et al., 2016; Leveson, 2004; Rasmussen & Svedung, 2000; Zhang et al., 2018). CAST defines a sociotechnical control system as two basic hierarchical control structures, one for system development and one for system operation, whereas AcciMap focuses on system operation without considering development. It is important that a systemic approach is assumed to address all levels, so that contributory factors can be understood, and systems-based recommendations can be developed (Stanton et al., 2019). To better understand the depth and importance of both these methods, a comparison of methods will take place whereby both AcciMap and CAST will be used to analyse an aviation accident.

2.9 RELIABILITY AND VALIDITY OF ACCIMAP AND CAST

Goncalves Filho et al., (2019; 1), examined the reliability and validity of both AcciMap and CAST. The researchers compared the results of four studies that examined the South Korea Sewol Ferry accident using both tools (Goncalves Filho et al., 2019a). Goncalves Filho et al., (2019; 1) compared the recurrence of the same contributing factors over the four studies that used CAST and AcciMap. It was identified that the CAST method had a 65% recurrence of the same contributing factors throughout the four different studies and AcciMap only had a 38% recurrence of the same contributing factors across the studies. Through this Goncalves Filho et al., (2019; 1), concluded that CAST had a higher reliability than AcciMap as the researchers identified more of the same contributing factors throughout their analysis. However, in this study the validity of both CAST and AcciMap was valued at 8% and was based on the recurrence of contributing factors that were identified by both CAST and AcciMap for each study (Goncalves Filho et al., 2019a).

Although the above identifies that the reliability and validity of AcciMap and CAST are quite low, AcciMap and CAST are still useful accident analysis methods that allow for the understanding and uncovering of systemic contributing factors to an accident (Hamim et al., 2022). The reliability of AcciMap is influenced by the ability to identify the interactions and links between contributing factors and construct a representative diagram (Salmon et al., 2020). The reliability of CAST relies on the ability to effectively

apply systems thinking principles to identify systemic factors, interactions, and emergent outcomes from the accident or incident being investigated. The reliability of CAST can also be increased if there is a more user-friendly classification of control and feedback failures (Salmon et al. 2012). The validity for both AcciMap and CAST is based off how well the analysis depicts the interactions between contributing factors as well as how well the systemic influences are highlighted (Salmon et al., 2020). There is a strong need to improve the reliability and validity of these Human Factors and Ergonomics systems-based tools and it has recommended that there needs to be further research on this (Hulme et al., 2022). To enhance the reliability and validity of these methods whilst that research is ongoing, a thorough application, bias mitigation, critical evaluation of findings, and possible software assistance have been highlighted as measures that could assist with this (Hulme et al., 2022).

2.10 SUMMARY AND RATIONALE OF THE THESIS

The aviation industry is a complex system with many interacting components. While it is considered to be one of the safest among the four major transport sectors, accidents and incidents persist. Accidents are considered an undesirable and unplanned event that leads to a loss, whether it be property damage, human life, injury, or environmental pollution. An incident is also an undesirable and unplanned event, but it does not result in a complete loss only minimal damage or injury. Accidents and incidents occur due to many reasons. Historically the general perspective held around why accidents occur was attributed to a linear cause of events where human error and bad weather was a common factor in most accidents or incidents. As the complexity of the industry increased the perspective as to why accidents and incidents occurred has also changed. Human error and weather continue to play a part in aviation accidents today however, it has become evident that accidents emerge as a result of a combination of systemic factors interacting with one another. The frames of reference of accident causation have also evolved simultaneous to the ways in which accidents are investigated. Accidents have evolved from using sequential methods based on sequential models where accidents are described as a line of events and methods used were restricted to finding root causes. There was then a shift to epidemiological methods based on epidemiological models where an accident was described as latent failures that contribute to the development of unsafe acts which resulted in an adverse

event. The most recent paradigm shift involves systemic methods that are based on systemic models. Systemic models describe an accident as the result of interactions between different components within the system and between the system. Human Factors and Ergonomics as a systems discipline is able to implement systems-based analysis tools to accidents.

In South Africa the Accident and Incident Division (AIID) of the South African Civil Aviation Authority uses the ICAOs Annex 13 to investigate accidents or incidents occurring in the country. The Annex 13 does not include a systems analysis method. Therefore, in collaboration with the AIID, two systems-based analysis methods will be used to investigate an accident already investigated using the Annex 13. There is a need for the implementation of systems-based analysis methods given the high accident rates in the general aviation sector within South Africa. The two systems-based analysis methods that will be used for the purpose of the present study are AcciMap and Causal Analysis using Systems Theory.

3 CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

The research design of this thesis is a retrospective, descriptive analysis of an accident using two established methods. This study applied two systems-based analysis methods, 1) Causal Analysis using Systems Theory (CAST) and 2) AcciMap, to the V5-NRS Cessna Conquest 441 accident that took place on 16th August 2015 in Cape Town. The analysis was based on the final report published by the Accident and Incident Investigation Division (AIID) of the South African Civil Aviation Authority (SACAA) (https://www.baaa-acro.com/sites/default/files/2021-11/V5-NRS.pdf). The South African Civil Aviation Authority's Accident and Incident Investigation Division investigated this accident, and the final report was published on the 1st of February 2017. This AIID's investigation used the ICAO's Annex 13 procedure (https://pilot18.com/wp-content/uploads/2017/10/Pilot18.com-ICAO-Annex-13-Aircraft-Accident-and-Incident-Investigation.pdf). For completeness, a brief overview of the V5-NRS Cessna Conquest 441 is provided below.

3.2 OVERVIEW OF THE V5-NRS CESSNA CONQUEST 441 ACCIDENT

On the 15th of August 2015 at 23h51 a Cessna 441 Conquest II aircraft, with two flight crew members and a paramedic on board departed from Eros Airport in Namibia to Cape Town International Airport on a medical evacuation flight. The aircraft landed at Oranjemund in Namibia where a male patient and his daughter were collected. Around 02h06 on the 16th of August 2015, the aircraft departed en route to Cape Town. At 03h43, the aircraft contacted Cape Town International Airport Area Air Traffic Control (ATC), and the aircraft was then placed under radar control. Around 03h55, The flight crew were informed by the ATC that there was a complete radar failure. At that time the aircraft was on a descent to 6500ft when the crew was advised to prepare for a Very High Frequency Omni-Directional Range (VOR)[1] approach for runway 19 at Cape Town International Airport. At 04h29, while on approach for landing at Cape Town International Airport, all contact was lost with the

[1] Very High Frequency Omni-Directional Range (VOR) is a non-precision landing approach that assists flight crew with lateral guidance only (Oliveira, 2020).

flight crew of the aircraft and at approximately 05h56, the aircraft's wreckage was located approximately eight nautical miles (8nm) to the North of the Cape Town International Airport in the Tygerberg Mountains. All five individuals on board the Cessna 441 aircraft were fatally injured, and the aircraft was destroyed on impact and post impact fire.

Through the investigation done by the AIID it was uncovered that the aircraft struck terrain during Instrument Meteorological Condition (IMC)[2] while on the VOR approach for Runway 19 at the Cape Town International Airport. The Instrument Landing System (ILS)[3] was working at the time, however on approach the ATC controller only provided the flight crew with a VOR approach for separation with an outbound aircraft as the radar was not able to be serviced. This accident was investigated and the process of applying the two systems tools is described below.

3.3 OVERALL APPROACH TO THE ANALYSIS

To analyse the V5-NRS Cessna Conquest 441 accident, six workshops were conducted between the researcher and supervisors of this study and a Human Factors Specialist/Pilot who had experience with the application and interpretation of both tools in accident investigation. There was regular feedback between the parties to ensure that the analysis was set out in a logical way, that the wording used was accurate to mitigate any bias and processes of the aircraft were understood correctly. The next sections describe the design and processes employed for the methods used.

3.4 ANALYSIS METHODS

3.4.1 Causal Analysis Using Systems Theory (CAST)

CAST is a causal analysis tool that is based on Systems Theoretic Accident Model and Processes (STAMP) (Leveson, 2004) which is used in the analysis of accidents to identify and make recommendations with regards to system design. These recommendations can be implemented to prevent future accidents or incidents. CAST

[2] Instrument Meteorological Condition (IMC) is when a pilot flies primarily by reference of instruments rather than by visual reference, usually because of flying through low clouds (Bouhsine et al., 2022).

[3] An Instrument Landing System (ILS) is a precision runway landing approach that is based off two radio beams that provide the flight crew with both vertical and horizontal guidance during the landing approach (Coello et al., 2023).

aims to investigate the control structure and identify where there were inadequacies when trying to enforce safety constraints. The application of CAST assists in revealing not only the role of humans, but the systemic contributors / factors that shaped the behaviour of the humans within the system. CAST has five main components to the analysis method which are depicted in Figure 3 below.

While the figure shows the analysis as a series of components, it is important to note that this process is not strictly linear. Decisions and questions asked toward the end of the process may lead to revision of decisions and questions asked earlier in the process.

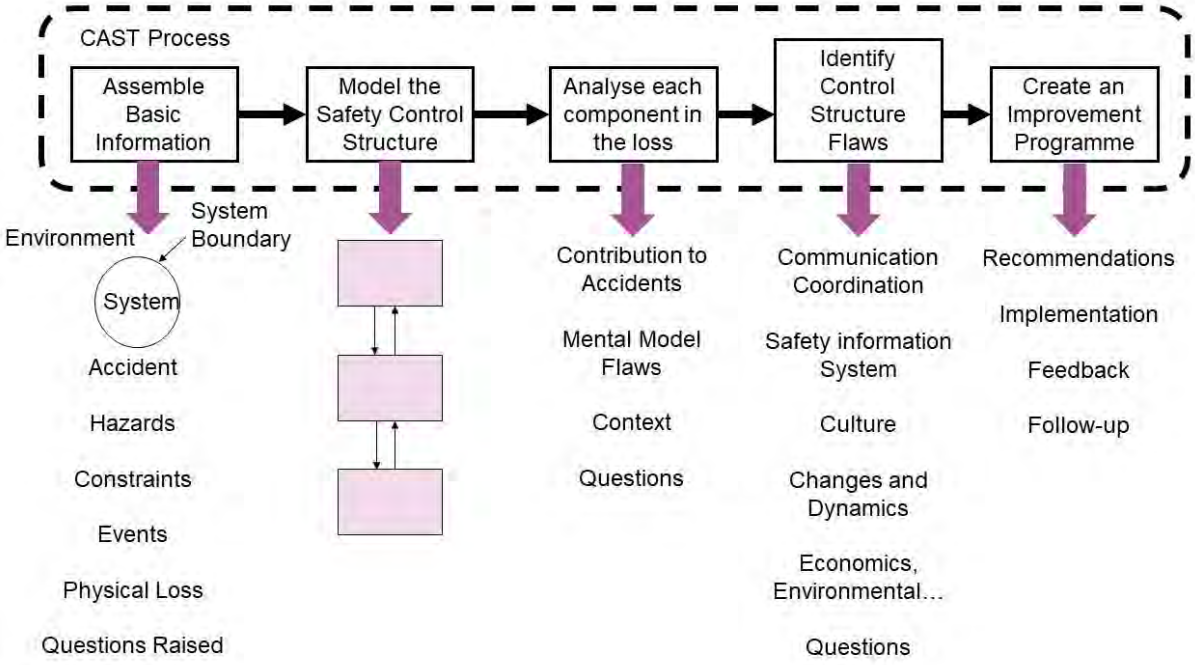

Figure 3: The five components to a CAST analysis (CAST Handbook, Leveson 2004).

The analysis process is now described further in terms of the analysis conducted on the V5-NRS Cessna Conquest 441 accident.

1. **Assemble Basic Information**

As a first step, basic information of the accident was gathered which included collecting data. In this step it is important to ensure that there is no bias when gathering the information and that no blame is assigned to the components contributing to the accident. The following is what data was collected.

a. The system involved in the loss event was identified and a boundary was put in place for the analysis.
b. The loss event was described which included the hazardous state the system was in which led to the event. A hazardous state within a system is the way in which the system is operating that may lead to an accident or incident if no action was taken to get the system out of operating in a hazardous state.
c. The system safety requirements and the constraints of the CFIT event were identified.
d. The physical loss was analysed in terms of the equipment and controls, the requirements of the physical design of the aircraft that are there in place to prevent CFIT accidents, the actual physical controls (emergency and safety equipment) included in the design that prevent a CFIT, failures and unsafe interactions leading to the CFIT, missing or inadequate physical controls which, if in place, may have prevented the accident, and any contextual factors that influenced the events that took place.

The rest of the analysis aimed to identify the limitations of the safety control structure that allowed for this CFIT loss event and how the system could be strengthened or improved to learn from and prevent future, similar accidents.

2. Model the Safety Control Structure

This step illustrated the Safety Control Structure that was involved in the V5-NRS Cessna Conquest 441 Accident. This consisted of all controllers who had responsibilities in relation to the accident. The control structure uses the concept of a feedback control loop. Figure 4 shows a simple feedback control loop which illustrates the relationship between responsibility, authority, and accountability of each controller. The controller has responsibilities in terms of enforcing safety constraints; to enforce these responsibilities the controller issues control actions and the control actions are required to prevent hazards in the current state of the controlled process. From this controlled process the feedback is given back to the controller.

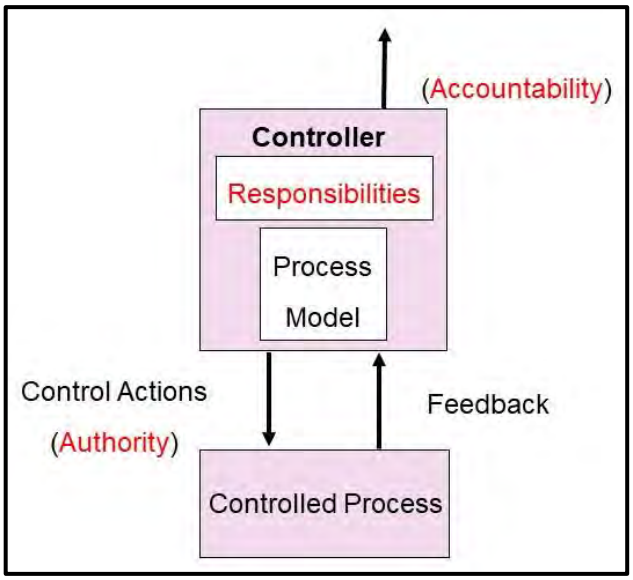

Figure 4: A Simple Feedback Control Loop (Leveson, 2019).

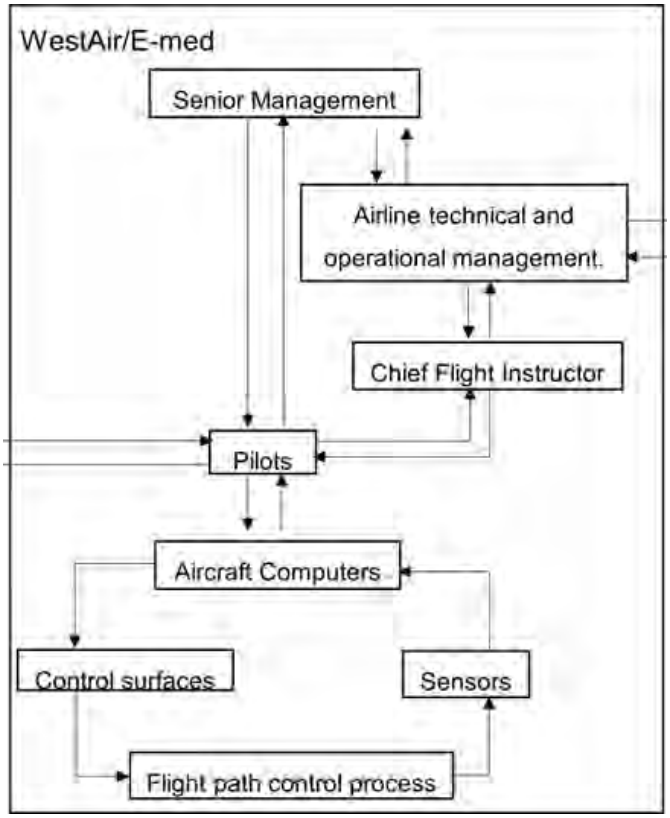

Figure 5: This is a part of the Safety Control Structure of the V5-NRS CAST report, the Safety Control Structure can be seen in its entirety in the results section.

3. Analysis of Components

Upon completing the modelling of the Safety Control Structure, each controller in the Safety Control Structure was analysed in terms of their responsibilities that were

relevant to the accident, their contribution to the hazardous state, their mental/process model flaws contributing to actions and contextual factors that explain the actions, decisions, and the mental/process model flaws.

The controllers analysed were the Flight Crew, Air Traffic Controllers (ATC), WestAir (the operator), Namibian Civil Aviation Authority and South African Civil Aviation Authority. The analysis included the following headings: Responsibilities related to the CFIT, Contribution to hazardous state, Unanswered questions, Recommendations, and two tables that include mental model flaws and contextual factors explaining the actions, decisions, and process model flaws.

4. Control Structure Flaws

This step of the CAST analysis included a more expanded overview of the entire system. It focuses on factors that affect the interactions and behaviour of all components working together within the system to prevent the system from being in a hazardous state (Leveson, 2019). Systemic factors allow for an understanding of why components did not adhere to their safety responsibilities and why together the components did not satisfy the safety constraints of the system (Leveson, 2019). This allowed for the identification of why accidents happen systemically rather than just isolating the behaviour of one single component (Leveson, 2019). Some systemic factors that can be considered in this section are, Communication and Coordination, The Safety Information System, The Design of the Control Structure and Safety Control System, Culture, Changes and Dynamics and internal and external economic related factors.

The implementation of CAST on the V5-NRS Cessna 441 accident discussed the following control structure flaws: The Design of the Control Structure and Safety Control System, Culture, Changes and Dynamics and internal and external related factors.

5. **Create an Improvement Programme**

Recommendations were generated to address the identified causal factors of each safety control structure component. The recommendations were tabulated, and the level of implementation was highlighted. Below is an example of how it was structured.

Number	Recommendation	Implementation
R1	Ensure recurrent pilot training includes case studies on CFIT accidents during non-precision approaches, effective tools to trap errors (e.g., multi-crew checklists and mnemonics) as well as Crew Resource Management training that provides multi-crew situational awareness, leadership, and teamwork type training.	**Operators**

The process of writing the CAST analysis up was important as going through each section of the CAST ensuring that it is easy to read and understand for someone who is new to this was of utmost importance.

3.5 ACCIMAP

The AcciMap approach provides a way to analyse accident and incidents that occur in complex socio-technical systems (Igene et al., 2021). The AcciMap is beneficial for organising and communicating information in relation to events and conditions that contribute to the accident (Waterson et al., 2017). The information gathered with regards to causal factors are organised into levels that represent different levels within the socio-technical system in which the accident occurred. Brandford et al. (2009) provides nine steps that need to be followed when creating an Accimap. The first eight steps are in relation to how the AcciMap is constructed, while the ninth relates to the recommendations generated through the outcomes of the AcciMap. The nine steps followed in this study are outlined below.

Step 1: Create a blank AcciMap where the causes can be arranged

A blank AcciMap was created on PowerPoint where the page was separated into five sections with the headings on the left-hand side and horizontal lines separating each level. These four headings represent the levels of a sociotechnical system. The AcciMap traditionally consists of four levels as depicted in Figure 6, with these being External stakeholders, Organisational, Physical Processes and Actor Activities and

Outcomes. Another level was added to the AcciMap of the V5-NRS Cessna 441 accident to allow for a better understanding of the contributing factors of each section in the Operators system. Thus, instead of the normal four levels this AcciMap had five levels:

1) Regulatory bodies and Associations.
2) Company Management and Planning & Budgeting
3) Technical and Operational Management
4) Physical Processes and Actor Activities
5) Outcomes

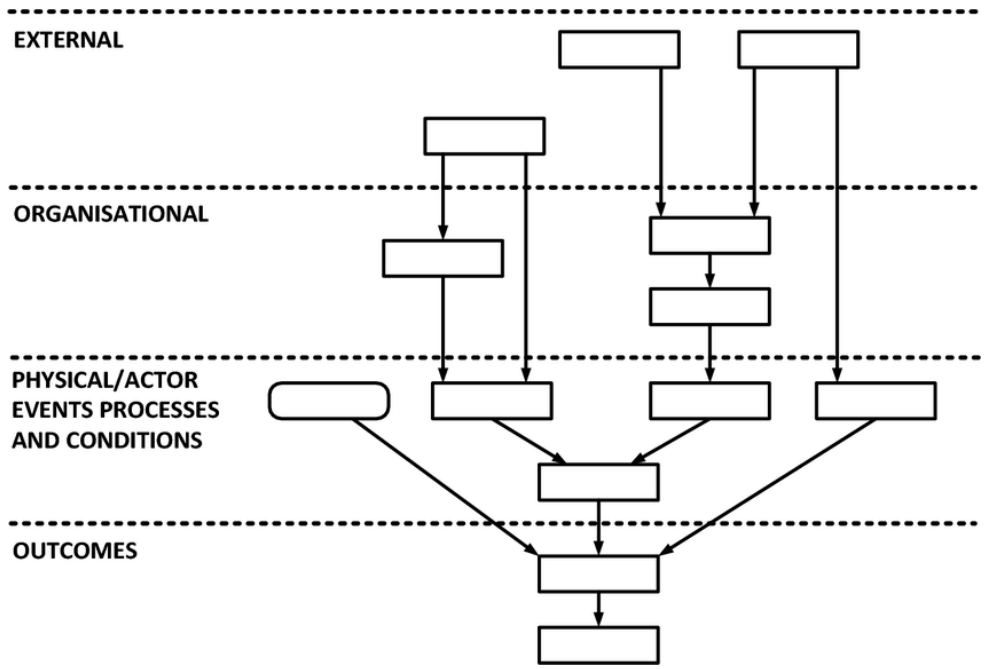

Figure 6: A Standardised AcciMap Format (Igene et al., 2021).

Step 2: Identify and Highlight the outcomes

After collecting all necessary data, the negative outcomes were identified and inserted in the outcomes level of the AcciMap. In the case of the V5-NRS accident, there were three negative outcomes that were taken from the final report published by the South African Civil Aviation Authority. The outcomes were: 1) the accident itself, 2) the post impact fire and 3) five individuals were fatally injured either on impact or due to the post impact fire.

Step 3: Identify all the causal factors

All causal factors identified from the final report, were listed on a separate Word document. To limit the list to causal factors that were relevant, boundaries were set in place based on the guidelines provided by Brandford et al. (2009). These boundaries were: 1) Causal Factors were included if they had practical significance and if something could be done about them, 2) Causal Factors were included if they were necessary to make sense of how and why the accident occurred.

Step 4: Identify and place each of these causal factors in the appropriate AcciMap Level

Each causal factor identified needed to be allocated to an AcciMap and this was the purpose of Step 4 (Branford et al., 2009; Igene et al., 2021; Salmon et al., 2012). These different levels, as described by Branford et al. (2009) included:

1) **External level (Regulatory bodies and Associations):** This level includes causes that were beyond control of the organisation or organisations.
2) **Organisation level (Company Management and Planning and Budgeting):** This level incorporates causes relating to organisational processes. Contributing Factors were placed in this level if they were within the control of the organisation in terms of planning and budgeting.
3) **Organisation level (Technical and Operational Management):** This level includes causal factors that related to processes within the organisation's technical and operational management.
4) **Physical Actor/Events/Processes and Conditions level:** These were the immediate precursors to the outcome/outcomes.
5) **Outcome level:** This level referred to the actual outcome of the incident/accident.

In Table VI shows some examples of what could be included at each respective level of the AcciMap.

Step 5: Preparing and understanding of causes of the accident

The identified causal factors were put into small textboxes that explained what they were but ensured that the explanation was brief, and clear (Branford et al., 2009; Igene

et al., 2021; Salmon et al., 2012). Each causal factor was placed in the appropriate AcciMap level. This process was done alongside a specialist in the field of aviation so that technical processes and context-specific information related to the V5-NRS accident could be understood.

Table VI: Defining what each AcciMap level consists of and examples (adapted from Hopkins (2000a), Kletz (1993), Rasmussen & Svedung (2000), Reason (1997), Snook (2000), Vicente & Christoffersen (2006), and Woo & Vicente (2003).

Level	Categories of Cause
External level (Regulatory bodies and Associations)	Government, regulatory body insufficiencies and societal influences such as historical events, politics etc.
Organisation level (Company Management and Planning and Budgeting)	Policy and Procedures, Training, experience, supervision, Culture, Compliance with procedures, violations and unsafe acts and Risk Management, Manuals and Procedures, Human Resources and Training.
Organisation level (Technical and Operational Management)	Planning and preparation, personnel management and recruitment, and compliance with procedures, violations, and unsafe acts.
Physical processes and actor activities	Physical Sequence of events including technical failures. Environmental Conditions, physical and mental states of actors (Fatigue, ill health, inattention etc.), mistakes, misinterpretations, loss of situational awareness.
Outcomes	Accidents/Incidents, Fatalities, Injuries, or any event that has led to a loss.

Step 6: Add the links to the causal factors

The causal factors were arranged in the AcciMap so that they were directly above the effects even if the effects were in the same level or not (Branford et al., 2009; Igene et al., 2021; Salmon et al., 2012). A causal link was then inserted between a cause and its effect.

Step 7: Fill in any necessary gaps in the diagram

This step consisted of filling in any missing information in the causal chains so that any relevant causal factor was included in the diagram. Each chain needed to go as

far as possible, aiming to reach the organisational level (Branford et al., 2009; Igene et al., 2021; Salmon et al., 2012).

To identify any missing causal factors, the researchers assessed each causal factor on the diagram and determined why it occurred. All factors were to be included in terms of its occurrences or how it failed to prevent the event (Branford et al., 2009; Igene et al., 2021; Salmon et al., 2012). As many factors as necessary were added so that an individual reading the AcciMap would easily understand the sequence of events (Branford et al., 2009; Igene et al., 2021; Salmon et al., 2012).

Step 8: Check the logic behind the causal chain
All the different causal chains were refined to ensure that the AcciMap was easy to read and understand, that all arrows were pointing downward leading toward the outcomes and that all causes were only listed once.

These 8 steps assisted in the completing of the AcciMap, showing all causal factors and the links between them. This process was completed on PowerPoint and once the AcciMap was completed it was transferred into an image that was inserted into Microsoft Word.

Step 9: Safety recommendations were formulated
All causal factors identified in the AcciMap analysis were interrogated in terms of which of those could be changed, controlled, or compensated for so that the event could be avoided in the future.

Brandford et al. (2009) argued that safety recommendations must be practical to implement. Identifying the individuals who oversee the implementation of change was important in this step as it ensures the accountability of continuous improvement.

The AcciMap assisted with identifying critical faults and gaps in the aviation system which led to the accident. Examples of a critical fault was that there was inadequate oversight and inadequate training. Identifying these gaps enabled the development of context specific recommendations. This AcciMap aimed to identify whether an HFE

lens and systems-based analysis tools would elicit different or similar contributing factors and recommendations compared to those that were articulated in the final report published by the South African Civil Aviation Authority.

3.6 REFLEXIVITY ON THE ROLE OF THE RESEARCHER IN THE PROCESS

As a researcher with a background in Human Factors and Ergonomics, but no previous knowledge of aircraft technical systems such as navigation systems, flight controls, and regulations, as well as no previous experience with the two systems-based methods used, it is essential to acknowledge the potential limitations and biases that may arise from the lack of expertise. This was also an opportunity to analyse the accident through a different lens, a Human Factors and Ergonomics lens which is different to how accidents are investigated in South Africa and may allow for different information and recommendations to be identified.

In saying this to mitigate the abovementioned limitations the researcher consulted with an aviation expert (with experience both in flight operations and in accident investigation) for clarity on terms and processes that were unfamiliar. The researcher also practiced using the AcciMap method for a smaller scaled incident to understand how the tool worked and how to create the actual Accimap diagram. The researcher was also guided through the implementation of CAST on a different aviation incident that was being investigated by the consultant expert, which allowed for a better understanding of the implementation of the tool, what type of language was used, and how to ultimately produce a good analysis using AcciMap and CAST. The next section will go into reflexivity on the use of one method before the other.

3.6.1 Reflexivity on the use of one method before the other

In this thesis, the method used first was Causal Analysis using Systems Theory (CAST) followed by AcciMap. Completing the analysis in this way had both advantages and disadvantages. The use of CAST first provided a deep understanding of the accident as a complex system with many interacting components which allowed for an easy transition to AcciMap as it allowed for the individual events and actions to be highlighted and understood in relation to the broader system. The limitation to this was trying to distinguish what contributing factors would have been highlighted if the

AcciMap method was used first. To mitigate this the aviation expert and supervisors in the team with experience in the use of these tools critically went through both of the analyses and asked questions surrounding how I identified specific contributing factors to ensure that it was as accurate as possible.

This reflexivity reinforced the importance of taking a multidisciplinary approach to investigations, as a multidisciplinary team allows for a better understanding of accidents/incidents. With the above-mentioned reflexivity in mind, the next section comprised of the results of the analysis done by the researcher on the V5-NRS aviation accident.

4 CHAPTER 4: RESULTS OF ANALYSIS

4.1 CAUSAL ANALYSIS USING SYSTEMS THEORY REPORT

4.1.1 BASIC INFORMATION

4.1.1.1 System involved:

V5-NRS Cessna 441 aircraft, its equipment, flight crew, operator management, manufacturer, and regulating authorities.

4.1.1.2 Loss Event

There was a loss of life of five passengers on board: the pilot in command, the First Officer, the Paramedic, the patient, and the patient's daughter. There was also a complete hull loss of the aircraft. This occurred as the aircraft had a CFIT as defined by the International Civil Aviation Organisation (ICAO) at approximately 4h30 on the 16th of August 2015.

4.1.1.3 Precursory Hazards

System Hazard 1: Secondary Surveillance Radar Failure

Secondary surveillance radar is a radar system used by Air Traffic Controllers (ATC) (de Florio, 2016). The radar measures the bearing and distance of targets using the reflections of radio signals (de Florio, 2016). The signals identify the aircraft's altitude and other information depending on the mode of the radar (de Florio, 2016). If this radar fails ATC will not be able to identify the location of the aircraft. If there is a radar failure there needs to be safety constraints in place to prevent adverse events, these safety constraints are listed below.

Safety Constraints[4]:

1. Air Traffic Controllers must communicate any changes to the aircraft's route.
2. Air Traffic Controllers need to communicate any changes to the aircraft's approach to landing.
3. Pilots must have effective training and recency of practice in using approaches that may be used in navigating the aircraft to land safely.

[4] A safety constraint is a constraint in the form of a specific safeguard, this can include safety mechanisms, safety design features or safety implementation techniques.

4. Pilot training must have the fidelity of the simulation, which includes flight test data models, for accurate aircraft handling during the approach to landing using the VOR Landing System. A VOR landing approach is a non-precision approach that provides lateral guidance only.
5. Flight crew needs to conduct flight operations at night during such conditions safely.

System Hazard 2: Lack of operator training

Operator training ensures that the aviation industry has availability to qualified and competent employees so that there is efficient planning, coordinating, managing and operating of complex operations within airports, airspaces and aircraft. Lack of operator training may result in decrease in safety performance and may lead to accidents or incidents. To ensure that there is not a lack of operator training the safety constraints that need to be in place are listed below.

Safety constraints:

1. Multi-crew training for operations.
2. Regulators have training programmes in place.
3. Simulator training.
4. Operator conversion programmes.

4.1.1.4 Proximal Events

1.Cape Town air traffic control cleared aircraft on a standard arrival to Runway 19.

2.Area control informed crew about the complete radar system failure. However, aircraft was cleared for VOR approach onto runway 19.

3.When they were cleared for VOR approach runway 19, the radial they needed to fly in on to get to the VOR was 010°.

4.The crew conducted the VOR approach, but it was hypothesized that when the aircraft took the turn the crew did not reset the bearing selector to 007° and they left it on bearing 010°.

5.This lead the aircraft back into the track they were already flying in, and that track made them collide with the Tygerberg mountain in Cape Town.

Figure 7: Proximal Events of the V5-NRS Cessna Conquest 441.

Table V below is a tabulated version of the above proximal events with the inclusion of questions raised during those events.

Table V: Questions Raised from the Proximal Events in the above figure 7.

Number	Event	Questions Raised
1	The aircraft flew from Namibia to Cape Town. When being controlled by the Area Control Centre in Cape Town, they were rerouted to Runway 19.	*Why was the aircraft rerouted last minute?*
2	The aircraft was told that Area Control had a complete radar failure. Area Control received no confirmation that the aircraft received this information. However, the crew was asked if they were on an Instrument Landing System Approach (ILS) in which the crew stated they were cleared for a VOR approach to runway 19. Area Control allowed the aircraft to proceed with the VOR approach even though they had access to other landing approaches such as the ILS.	*Why was there a complete radar failure? How did this radar failure impact the aircraft? Why was the crew cleared for the VOR rather than the ILS approach when the ILS was available to use?*
3	The crew conducted the VOR approach, but it is hypothesised that when the crew took the inbound turn, they did not reset the bearing selector to 007° but instead left the bearing on 010°.	*Why did the crew not change the bearing selector? Why was there no extra warning about the selector degree not being changed?*
4	This led the aircraft back onto the track they were already flying in, which led them to collide with the Tygerberg mountains.	*Why did the crew not take note of the GPS in the cockpit that would have shown them that they were flying into a mountain?*

4.1.1.5 Controlled Process

Requirements for Physical Protection against Hazards

1. Provide advanced warning of a complete radar failure.
2. Provide advanced warning of cloud coverage in the area.
3. Protect against having an aircraft flying into a mountain.
4. Protect the aircraft using other GPS tools to ensure the aircraft does not fly into a mountain.

Controls

The safety equipment in place to prevent a CFIT accident include:

1. Eurocat X (Secondary surveillance radar system).
2. A-SMGCS GPS receiver (a system providing routing, guidance, and surveillance of aircraft).
3. VHF omnidirectional range (VOR) with a piece of distance-measuring equipment (DME).
4. Garmin GTN 750 touchscreen GPS/Navigation/Communication/Multi-Function Display unit.
5. Garmin GTN 650/Navigation/Communication unit.

Failures

1. The Eurocat X radar system failed, but no other safety controls failed.

Unsafe Interactions:

1. The Eurocat X radar system had a complete failure mid-flight.
2. The Air Traffic Controller and flight crew lost communication mid-flight.
3. The flight crew proceeded with the VOR landing approach, where it is hypothesised that the crew did not reset the bearing selector to the new coordinates on the inbound turn. It appears that the pilot failed to change the VOR inbound radial from 010° to 007° as they were cleared for the inbound on a radial of 010°.

Missing physical controls that might have prevented the accident:

1. TAWS (Terrain advisory and warning system). TAWS provides a distinguishing warning to pilots when their aircraft is in close proximity to potentially hazardous terrain.

Contextual factors:

1. According to the final report the Pilot in Command and First Officer were exposed to a high workload environment but seemed calm and relaxed without the presence of anxiety moments before the accident.
2. The crew had limited training on a Cessna 441.

Summary of the role of the physical components in the incident:

1. The Eurocat X radar system failed and if TAWS was installed on the aircraft the accident would have been avoided.

4.1.2 SAFETY CONTROL STRUCTURE

The below figure on the next page (Figure 8) is the safety control structure of the system in which the V5-NRS accident occurred. The safety control structure consists of all controllers who have responsibilities in relation to the overall safe operations. The controllers or components that had control in this accident are the following, Pilots, Aircraft Avionics, Air Traffic Controllers, Airline technical and Operational Management, Senior Management, and the Namibian and South African Civil Aviation Authority. The safety control structure depicts what controllers interact with who in this process.

The Safety Control Structure guides the analysis as each component in the structure is analysed in terms of their responsibilities, contributions, mental model flaws and contextual factors in relation to the accident. The analysis of components can be seen in the next section.

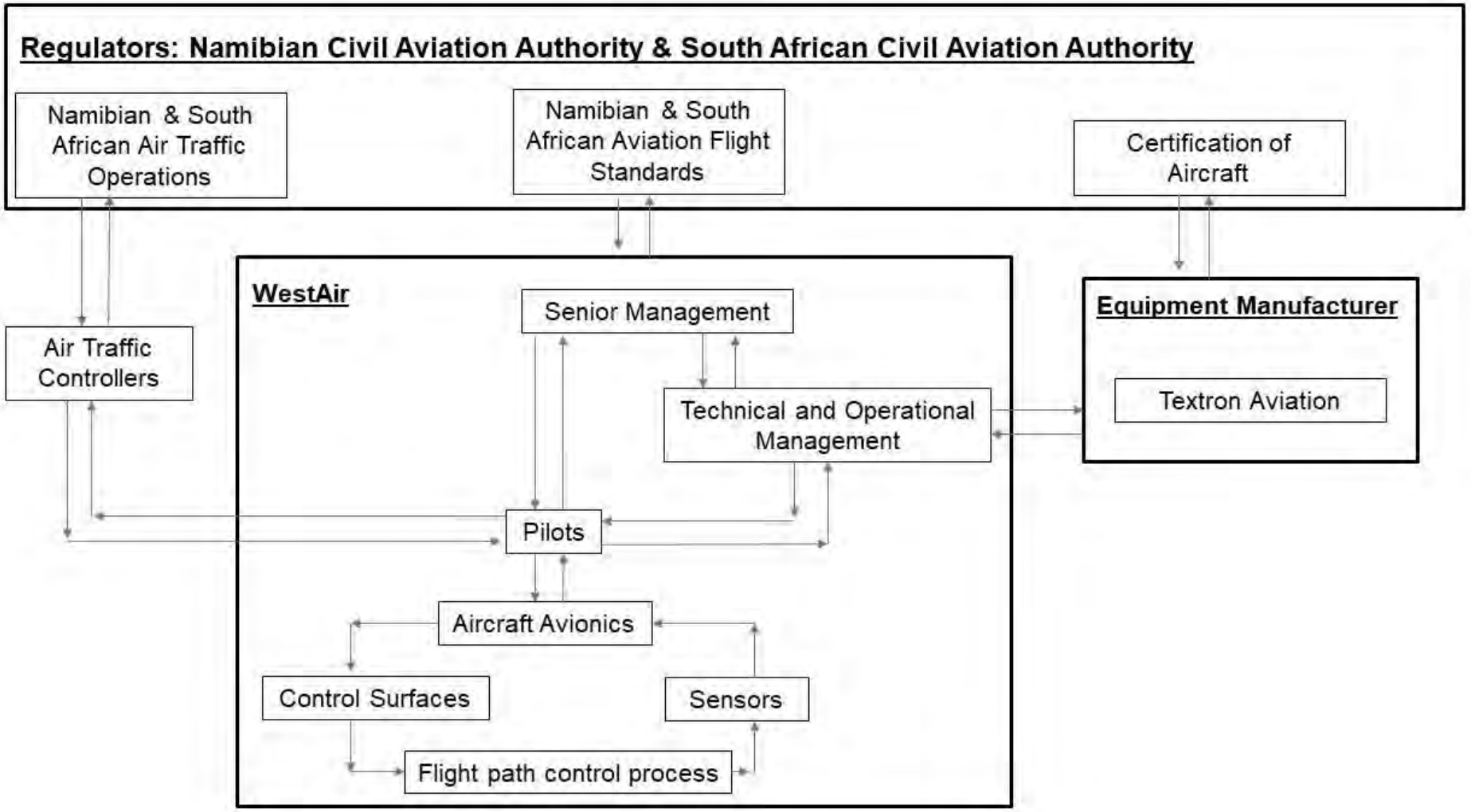

Figure 8: Safety Control Structure that prevents an aircraft from having an accident/incident.

4.1.3 ANALYSIS OF COMPONENTS:

4.1.3.1 Pilots

Responsibilities related to the Controlled Flight into Terrain:

1. To manage the aircraft's flight path.
2. To coordinate and communicate decisions and plans to prioritise the safety, efficiency of the aircraft, and patient comfort.
3. Read the operations manual in regular intervals to ensure that both pilots are up to date with what is required in the aircraft and are aware of any changes in the manual.
4. To operate the aircraft within its performance limits and recover from any exceedances.
5. To communicate with Air Traffic Control

Contribution to hazardous state:

1. Based on the radar track, it appears that, on the inbound turn, the Omni Bearing Selector remained on the previous radial used when cleared inbound by ATC. This meant that the aircraft descended for the approach from the correct altitude and in the correct manner, but on radial 007°, rather than 010°.

The below Tables, Table VI and VII identifies the mental model flaws and contextual factors relating to the pilots involved with this accident.

Table VI: Flaws in the mental/process models of the pilots in terms of contributing actions.

Why? (Flaws in the mental/process models contributing to actions)	Questions Raised.
They thought they were on the correct radial.	*Why did they not change the Omni direction selector? What cross-checks were done by the Pilot Monitoring? Did they double-check that the radial bearing had been changed? Were they aware that they had to change the radial bearing? Did the ATC warn them about the Tygerberg Mountains being in the middle of the two radial bearings?*

Table VII: Contextual Factors that explain the actions, decisions, and process model flaws of the Pilots.

Contextual Factors explaining the actions, decisions, and process model flaws.	Questions Raised
Evidence collected during the AIID investigation stated that the Pilot in Command and First Officer were exposed to a high workload environment and the pilots started their shift at 23h15 and were flying through the night having the accident at approximately 04h29. An example of a high workload being present is at a few stages of the descent where the aircraft was beneath the minimum obstacle clearance altitude (MOCA) that is indicated on the approach plate for a specific point.	*Were the pilots fatigued? Did this affect the decision-making pre-accident? Is there fatigue management? Did the company track fatigue of their pilots? Did the crew realise that they were flying below the minimum obstacle clearance altitude (MOCA)?*
The pilot flying was trying to ensure that the aircraft was on the inbound radial when the ATC called and requested to know if they were on the ILS for Runway 19.	*Did this cause confusion in the cockpit as the pilot monitoring said they were cleared for VOR, and not the ILS? Why was there this confusion? Was there communication lost between the ATC and flight crew? Why and how?*
The co-pilot had limited training on this aircraft and did not have any formal training on the two GPS systems that were installed on her side of the aircraft cockpit	*Why did the pilot have limited training? Are there training regulations within the organisation? How is the training programme designed? How did the organisation appoint a pilot on a trip where they are not familiar with the equipment? Why are there no minimum requirements for co-pilots in the manual?*
The Pilot in Command does not have a clear vision of the Omni Bearing Selector from the right-hand seat. This could result in parallax error in reading the instrument, especially on small differences (e.g., 003°). A parallax error is when an object shifts due to the angle it is being viewed from.	*Why was there no requirement for dual instrumentation?*

There was a large crew gradient between the Pilot in command and the co-pilot. The Pilot in command was well-experienced, and he was the older of the two. The co-pilot was younger, and she had very few years of experience	*Would the crew gradient affect the confidence or comfortability of the co-pilot to communicate anything serious with the pilot in command?*
The crew was not used to flying in weather conditions like the conditions in Cape Town on the day of the accident.	
The crew had inadequate training on the Cessna 441 aircraft.	
The flight crew did all their training in Namibia, where they did not encounter low cloud coverage very often. On their descent into the Cape Town International Airport, they reached a low cloud coverage area over the Tygerberg Mountains. This created an element of uneasiness for the flight crew as they had to navigate through low cloud coverage.	*Why did the flight crew not do any simulation training in cloud coverage? Did they do any training where they knew how to deal with an aircraft's navigational equipment when there is low cloud coverage? Has the flight crew been trained in dealing with the landing equipment when there is cloud coverage? Has the crew been equipped to deal with those sorts of emotions during that circumstance?*
The flight crew was told that there was a complete radar failure and that they needed to prepare for the VOR landing approach.	*How recently have the pilots been trained in using the VOR landing approach? Did they know how the VOR system worked? Did the crew hear that they could also use the ILS for landing? Why was this not communicated earlier? Why was there a radar failure? Why was the radar failure not communicated earlier to the crew? Why was the radar failure picked up late?*
Both GPS systems were on the co-pilot side of the aircraft and with her limited training with regards to these systems it was possible that these instruments caused confusion rather than aiding.	

Unanswered Questions:

1. What training do the pilots undergo to ensure they are equipped for such situations?
    a. Why were the pilots trained so little in flying this aircraft before flying it?
2. When last did the crew train for a VOR landing?
3. Did ATC communicate the coordinates of the Tygerberg mountains?
4. What fatigue management programme is in place to mitigate fatigue and manage workload and duty time of the crew?
5. If the crew had used the ILS landing system, would this accident have been avoided?

Recommendations:

1. Ensure recurrent pilot training includes case studies on CFIT accidents during non-precision approaches; on effective tools to trap errors (e.g., multi-crew checklists and mnemonics) as well as Crew Resource Management training that provides multi-crew situational awareness, leadership, and teamwork type training.
2. Implement a fatigue risk management system (FRMS) for Part 138 (Air Ambulance) operators.
3. Include different weather forecasts in simulation training flights.

4.1.3.2 Aircraft Avionics:

Responsibilities related to the Controlled Flight into Terrain:

Garmin Navigation Equipment

1. Display lateral and vertical navigation aids through waypoint, procedure, and terrain databases.
2. Display continuous, reliable, and accurate positioning information for all phases of flight using GPS.
3. Provide pilots with their exact location data, which includes aircraft position, aircraft track, speed as well as proximity to terrain.

VOR Equipment (VOR antenna, VOR frequency selector, and a cockpit instrument)

1. Enables aircraft to determine its position and stay on course by receiving radio signals that is transmitted by a network of fixed ground radio beacons.

Contribution to hazardous state:

None

4.1.3.3 Air Traffic Navigation Services in South Africa

Responsibilities related to the Controlled Flight into Terrain:

1. Monitor and direct aircraft movement on the ground and in the air.
2. Control all traffic on the ground as well as at airport runways and taxiways.
3. Provide pilots with landing and take-off instructions.
4. Transfer departing flights to other traffic control centers and accept control of arriving flights.
5. Update pilots about the weather, runway closures, and other information that is deemed critical.
6. If there is an aircraft emergency airport response staff need to be alerted.

The below Tables, Table VIII and IX identifies the mental model flaws and contextual factors relating to the Air Traffic Controllers involved with this accident.

Table VIII: Flaws in the mental/process models of the Air Traffic Navigation Services in terms of contributing actions.

Why? (Flaws in the mental/process models contributing to actions)	Questions Raised.
The ATC believed that the flight crew was following procedures and did not need further assistance as no assistance was requested.	
The ATC believed that the crew was cleared for an ILS landing, not VOR landing, however the ATC allowed the aircraft to go ahead with the VOR approach even though the crew had access to other landing approaches. This confusion came 19 minutes before the aircraft went missing.	*Why was this communication not done earlier? Why was there this confusion? Why did the ATC ask about ILS landing when the flight crew had been informed that the ILS was not operating in Cape Town?*

Table IX: Contextual Factors that explain the actions, decisions, and process model flaws of the Air Traffic Navigation Services.

Contextual Factors explaining the actions, decisions, and process model flaws.	Questions Raised
As the aircraft was descending there were several stages where the aircraft was below the minimum obstacle clearance altitude (MOCA). The aircraft also failed to fly the correct headings during a certain phase of the VOR approach. The crew failed to rectify any of the above.	*Even though the Secondary Surveillance Radar Failure occurred, could they assist in identifying if the aircraft was on the correct path and if they were flying below the MOCA?*
During the landing approach, the aircraft was able to be seen on the Surface Movement Radar that is located on the airfield. The ATC was not aware of the above information as it was only available after the accident had occurred and been investigated.	*Why did ATC not check this? Does ATC know that the surface Movement Radar can pick the aircraft up outside the airport? Why was this only recovered after the accident had happened? If the ATC had known this, would the accident have been prevented?*

Unanswered Questions:

1. Where did the confusion come from between the ATC and Flight crew?
2. Does ATC know that the surface Movement Radar can pick the aircraft up outside the airport?

Recommendations:

1. Non-precision approaches should be the last resort when radar failure occurs. First resort should be the ILS.
2. The controls over the date management system and the radar software need to be overseen and kept up to date to avoid a system failure with date conflicts.

4.1.3.4 Technical, operational, and safety management of the Operator (WestAir)

Responsibilities related to the Controlled Flight into Terrain:

1. Ensure that pilots are trained so that they can fully understand how the systems operate and understand all associated procedures.

2. Ensure that flight operations follow the best practices and that pilots have the required information and skills for effective decision-making.
3. Oversight and training need to be provided to flight dispatchers and policies and procedures promote safe operations.
4. Ensure sufficient skill level for the integration of manufacturer, regulator, industry working groups and internal safety reporting and incident data into pilot training.

Contribution to hazardous state:

1. Inadequate flight crew training on multi-crew operations.
2. Inadequate flight crew recurrent training on the VOR landing system.
3. Inadequate operator conversion programmes to flying a new aircraft for the first time.
4. Inadequate simulator training.
5. Inadequate training on the Garmin GTN 750/650 systems.

The below Tables, Table X and XI identifies the mental model flaws and contextual factors relating to the pilots involved with this accident.

Table X: Flaws in the mental/process models of the Technical, operational, and safety management of the Operator in terms of contributing actions.

Why? (Flaws in the mental/process models contributing to actions)	**Questions Raised.**
Management did not hold accurate risk perception and oversight was not seen as important.	*Why was the risk perception inaccurate? Why was an oversight not seen as important? Does the organisation have a risk management programme?*

Table XI: Contextual Factors that explain the actions, decisions, and process model flaws of the Technical, operational, and safety management of the Operator.

Contextual Factors explaining the actions, decisions, and process model flaws.	Questions Raised
CFIT has occurred in the flying industry several times, so it can be reasonably hypothesised that the organisation had frequency bias when it came to CFIT. Essentially, they have been inadequately training their pilots, but CFIT has not happened to them, so their training is adequate to them.	*What sort of safety culture does this organisation have? What oversight was in place to ensure that the training was adequate? How was the training seen as adequate? Was the training programme updated as recommended?*
Evidence collected by the AIID during an interview state that because of limited resources there was ineffective oversight conducted on the operator. Thus, it can be reasonably hypothesised that the organisation had access to information about CFIT and what the contributing factors were but due to inadequate resources the organisation could not implement this information into their training.	*Why were there inadequate resources?*
It can be reasonably hypothesised that the organisation's perceived risk was inaccurate as the regulator did not relay information to the organisation about the links to CFIT.	*Why would the regulator withhold information that would impact the procedures of the organisation? Is it legal for the regulator to hold such information?*

Unanswered Questions:

1. What safety culture does the organisation have?
2. What oversight was in place to ensure that the training was adequate?
3. Why were there inadequate resources?
4. Why would the regulator hold information that would impact the procedures of the organisation?

Recommendations:

1. Implement processes for collaborative (training, operations, dispatch, technical, safety) risk management and effective hazard identification methods to prevent CFIT.

2. Implement a generative safety culture through communication, adequate training, an adequate reporting system, and involve workers in what happens within the organisation.
3. Ensure the training programmes with regards to different landing systems are effective in preventing CFIT accidents.

4.1.3.5 Senior Management of the Operator (WestAir):

Responsibilities related to the Controlled Flight into Terrain:

1. Provide effective oversight of all operational, regulatory compliance and safety management activities.
2. Ensure sufficient financial resources and capacity for the effective functioning of the safety management system.
3. Ensure aircraft airworthiness according to requirements by regulators and manufacturers as well as internal safety management processes.
4. Ensure sufficient resources and capacity for the effective training of pilots, complying with safety, manufacturer, and regulatory requirements.

Contribution to Hazardous state:

1. Inadequate resources allocated to the Safety and Training departments to ensure that there is sufficient training of Pilots.
2. Inadequate oversight on training programmes.

The below Tables, Table XII and XIII identifies the mental model flaws and contextual factors relating to the pilots involved with this accident.

Table XII: Flaws in the mental/process models of Senior Management at WestAir in terms of contributing actions.

Why? (Flaws in the mental/process models contributing to actions)	Questions Raised.
Safety and Training were not a priority for resource allocation.	*Why is safety not a priority for resource allocation? Why is the training of pilots not a priority for resource allocation?*
Training Programmes were not a priority for oversight of senior management.	*Why was oversight over training programmes not a priority within the organisation?*

Table XIII: Contextual Factors that explain the actions, decisions, and process model flaws of the Senior Management at WestAir.

Contextual Factors explaining the actions, decisions, and process model flaws.	Questions Raised
There were limited resources given and inadequate oversight from the NCAA on the operator.	*Why did the NCAA limit resources given to the operator? Where were the resources allocated? Why did the NCAA not oversee the function of the operator?*
The training organisation was operating with a training procedural manual that had not been approved by the Namibian CAA after there had been amendments made in February 2015.	*Why were they using a training manual that had not been approved by the Regulator (NCAA)? Did this training manual include all requirements from the legislation?*

Unanswered Questions:

1. Why was safety not a priority for resource allocation?
2. Why was there no oversight of senior management on training conducted in the organisation. (Do not need oversight from the NCAA to oversee training conducted within your own organisation.)

Recommendations:

1. Increase the resource allocation to training and safety within an organisation.
2. Ensure an effective flight operations skill level is represented within the executive to achieve satisfactory oversight of resource allocations and employ more skilled professionals to ensure adequate oversight within an organisation.
3. Allocate more resources and responsibility to the safety and training department.

4.1.3.6 Aircraft Manufacturer (Textron Aviation)

Responsibilities related to the Controlled Flight into Terrain:

1. It is the responsibility of an aircraft manufacturer to ensure that an aircraft is made with no design or manufacturing flaws or defects.
2. Ensure aircraft manufacturing and maintenance is in accordance to the certification, engineering, operational and safety requirements.

3. Provide the operators with adequate knowledge and technical support to operate and fly the aircraft safely.

Contribution to a hazardous state:

None.

Recommendations:

None.

4.1.3.7 Namibian Civil Aviation Authority

Responsibilities related to the Controlled Flight into Terrain:

1. Oversee the operator in terms of the implementation of and compliance with aviation regulations and safety programmes that relate to CFIT.
2. Ensure that Namibian registered aircraft conducting commercial air ambulance operations are equipped with technology that provide timely and distinctive warnings to the flight crew when the aircraft is in close proximity to potentially hazardous surfaces.

***Contribution to hazardous state*:**

1. Ineffective oversight of the operators Safety and Training departments related to the CFIT.
2. The aircraft was not fitted with equipment that would have provided the terrain warnings to the crew.

The below Tables, Table XIV and XV identifies the mental model flaws and contextual factors relating to the Namibian Civil Aviation Authority who were involved with this accident.

Table XIV Flaws in the mental/process models of the Namibian Civil Aviation Authority in terms of contributing actions.

Why? (Flaws in the mental/process models contributing to actions)	Questions Raised.
It was believed that the Oversight of Safety management and training was sufficient to prevent CFIT.	*Why was this not an important aspect of oversight? Why was there risk perception inaccurate?*
The aircraft weighed less than 5.7 tons and therefore the regulations did not force the operator to fit a TAWS system.	

Table XV: Contextual Factors that explain the actions, decisions, and process model flaws of the Namibian Civil Aviation Authority.

Contextual Factors explaining the actions, decisions, and process model flaws.	Questions Raised
The NCAA had limited resources.	*Where were the limited resources allocated to? Why was oversight of the operators, not a priority?*
There were ineffective hazard identification and risk management methods for the impact of inadequate training of pilots and CFIT.	*What hazard identification and risk management systems are in place?*
The Risk Perception on the complete hull loss of an aircraft weighing less than 5700kg or less than 10 passengers' capacity is inaccurate.	*What hazard analysis and risk management methods do the NCAA use for aircraft in this category? Is the loss of an aircraft weighing 4467 kgs and with 5 people on board an acceptable risk?*

Unanswered questions:

1. Why was oversight of operators' safety and training programmes, not a priority?
2. What were the resources allocated to?
3. What hazard identification and risk management system are in place?

Recommendations for the Namibian Civil Aviation Authority:

1. NCAA to oversee and create a strong company safety culture through looking at safety practices within the organisation dynamically.

2. Reassess legislation regarding the installation of TAWS on aircraft that weigh less than 5700 Kgs or less than 10 passengers.

4.1.3.8 South African Civil Aviation Authority:

Responsibilities related to the Controlled Flight into Terrain:

1. Oversight of Air Traffic Navigation Services and technology relating to preventing CFIT in South Africa
2. Oversight and publication of aeronautical information relating to instrument approach charts in South Africa
3. Oversight of foreign operators conducting air ambulance operations to South Africa (Civil Aviation Regulations Part 138)

Contribution to hazardous state:

1. Inadequate oversight of the Air Traffic Navigation Services radar equipment reliability processes.

The below Tables, Table XVI and Table XVII identifies the mental model flaws and contextual factors relating to the South African Civil Aviation Authority that was involved with this accident.

Table XVI Flaws in the mental/process models of the South African Civil Aviation Authority in terms of contributing actions.

Why? (Flaws in the mental/process models contributing to actions)	Questions Raised.
SACAA perceived that Radar Failure would not increase the Risk of CFIT.	*Is there sufficient flight operations expertise in the skill level of the SACAA inspectors?*

Table XVII: Contextual Factors that explain the actions, decisions, and process model flaws of the South African Civil Aviation Authority.

Contextual Factors explaining the actions, decisions, and process model flaws.	Questions Raised.
The SACAA had engineers working on the issue at the time and did not expect an accident to occur due to the radar failing and they had manual measures in place to guide the aircraft to landing.	*Are there alternative measures sufficient in assisting aircrafts to a safe landing?*

Recommendations:

1. Ensure the oversight over the controls in place to ensure reliability in the secondary radar surveillance system and ensure that all equipment is monitored and upgraded before expiry date.
2. Reassess legislation based on foreign air ambulance operations in South Africa to ensure minimum equipment onboard includes TAWS for Part 138 operations.

4.1.4 CONTROL STRUCTURE FLAWS

4.1.4.1 Design of the Control Structure and Safety Control System

The overall safety control system (Safety Management System) was inadequate. The final report that was published by the South African Civil Aviation Authority identified that lessons were not learned from previous CFIT accidents, incorrect assumptions were made about the link between inadequate training and CFIT accidents, inadequate hazard analysis and risk assessment procedures were used.

The design of the control structure is effective other than communication between the regulators (SACAA and NCAA) and WestAir. There seems to have been a lack of communication in terms of CFIT accidents and what could be a contributing factor. The risk management and hazard identification were inadequate as well as the legislation in place with regards to the installing of TAWS on aircraft below the weight of 5700 kgs needs to be revised as there is an inaccurate risk perception. The Regulators and WestAir's management should critically analyse hazard identification and risk management methods to identify more modern, effective methods that should

be used when there is a complete radar failure or for aircraft that weigh less than 5700 kgs.

4.1.4.2 Culture

The NCAA, CAA and WestAir have characteristics of having a reactive safety culture. Characteristics of a reactive safety culture according to Hudson (2001) is regulators or organisations acting after things have gone wrong, where failure is covered up, information that they have access to is ignored or hidden, and new ideas are not welcomed and discouraged. In the case of this accident, it is evident that the SACAA, NCAA and WestAir act after things go wrong as an accident must occur before an investigation happens to create change.

It has been hypothesized that the regulators and organisations of this accident had ignored information with regards to CFIT accidents which is another characteristic of a reactive culture. It has been proven regularly that there is a relationship between the lack of training and CFIT accidents yet the training programmes in place are inadequate in ensuring flight crew are adequately trained in avoiding a CFIT accident.

4.1.4.3 Changes and Dynamics

There were not any changes done at the level of organisations however, there were some changes in terms of environmental conditions (Crew was not used to the conditions that they were flying in at the time of the accident) and the crew was also new to flying in a Cessna 114 conquest aircraft). The control structure flaw is related to crew experience and familiarity with the environmental conditions as well as the specific model of the aircraft, thus the crew's lack of experience and familiarity with flying in those environmental conditions and the use of that specific aircraft model may have contributed to the accident. There have also been advancements in GPS equipment that was on board and the equipment therefore needs to be upgraded.

4.1.4.4 Internal and External Economic and Related Factors

There were external and internal economic and related factors that played a role in this accident. The final report states that due to limited resources there was inadequate oversight on the part of the operator from the NCAA. There were questions

raised about if there is sufficient flight operations expertise in the skill level of the SACAA inspectors and if there are not it could be due to financial constraints.

4.1.5 Recommendations

The above information about the components of the Safety Control Structure as well as the broader contextual factors of the system assists with the generation of recommendations. A table of these recommendations can be found at the end of this section and the recommendations will be discussed fully in Chapter 5 of this thesis.

4.2 ACCIMAP ANALYSIS REPORT

4.2.1 Accimap for the V5-NRS Cessna Conquest 441 Accident

This section uses the AcciMap framework to analyse the V5-NRS Cessna Conquest 441 accident, which occurred on the 16th of August 2015, in Cape Town. The five layers considered for this analysis are: 1) Outcomes 2) Physical Processes and Actor Activities 3) Technical and Operational Management 4) Company Management and Planning & Budgeting 5) Regulatory bodies and Associations.

This AcciMap framework illustrates the contributing factors to the V5-NRS accident from each of the above levels. It highlights the interactions of the different contributing factors that include the decision makers and key role-players in the levels. The AcciMap, Figure 9, provides a diagrammatic representation of the causal factors that resulted in the V5-NRS Cessna Conquest 441. These causal factors are a series of interrelated decisions, events, and conditions, that together represent the critical faults, gaps, and latent failures that contributed to the V5-NRS Cessna Conquest 441 accident.

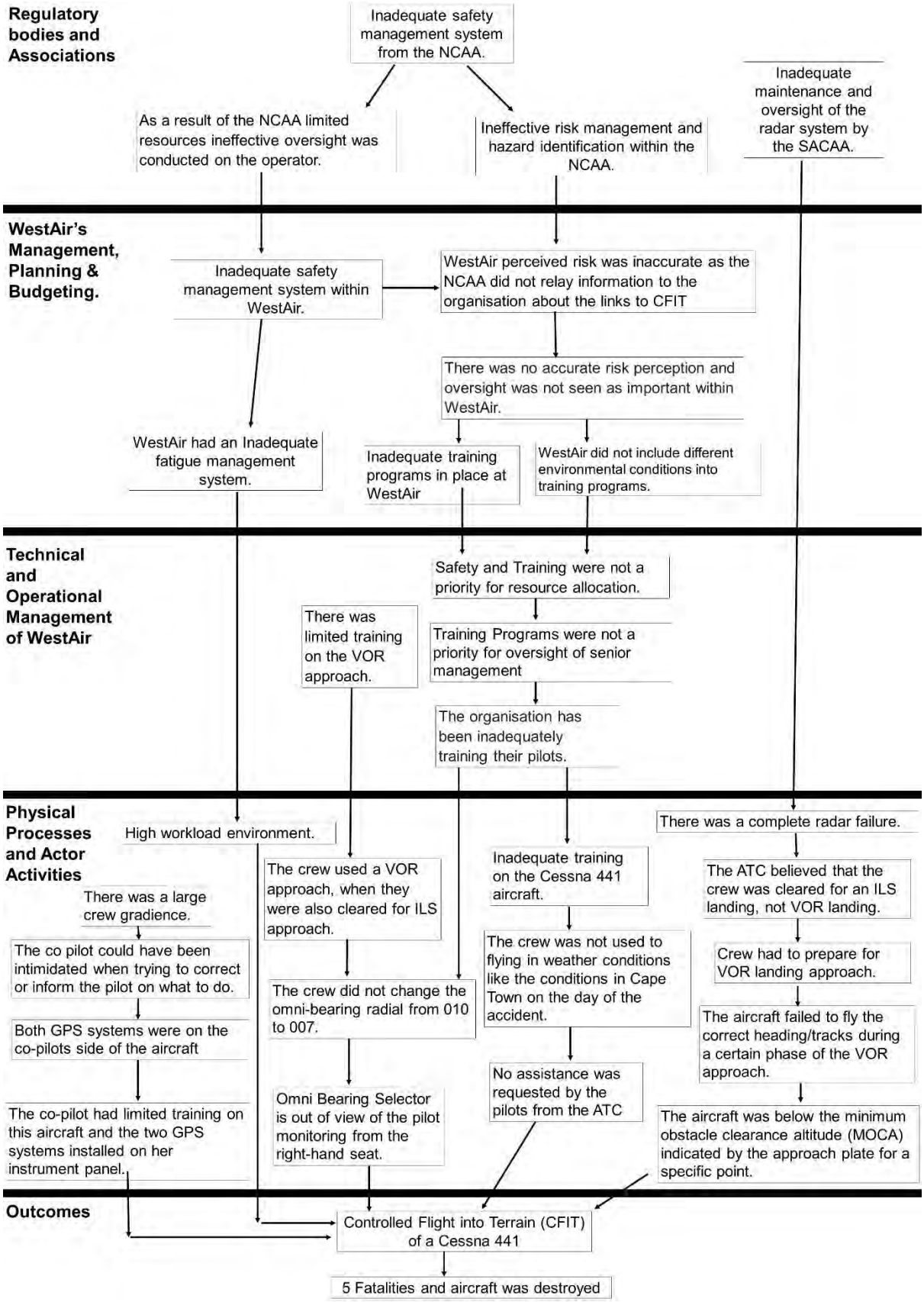

Figure 9: AcciMap of the V5-NRS Cessna Conquest 441 accident

There was a total of 30 contributing factors identified and illustrated in the AcciMap. The AcciMap is broken down into five levels.

1. Regulatory bodies and Associations
2. WestAir's Management and Planning & Budgeting
3. Technical and Operational Management of WestAir
4. Physical Processes and Actor Activities
5. Outcomes

4.2.2 The Accimap Framework of the V5-NRS Aviation Accident

The below paragraphs go into detail in terms of the contributory factors related to each level of the AcciMap. There will be an extract from the complete AcciMap under each level and the words italicised in the below paragraphs are the identified contributory factors the V5-NRS Cessna 441 Conquest II accident.

4.2.2.1 Regulatory bodies and Associations

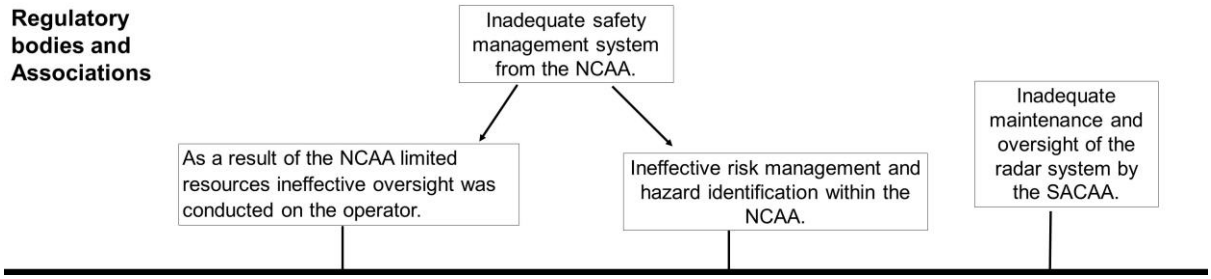

Figure 10: An extract of the contributory factors at the level of the Regulatory bodies and Association.

During the investigation and subsequent interviews conducted with the NCAA, it was evident that there were *limited resources* which resulted in the *ineffective oversight* on the operator there was *ineffective hazard identification and risk management methods* for the impact of *inadequate training* of pilots and CFIT.

The South African Civil Aviation Authority had *inadequate maintenance and oversight of the secondary surveillance radar system* as the radar system had a date where it needed to be updated but the SACAA did not ensure that the update was done by the ATNS.

4.2.2.2 WestAir's Management and Planning & Budgeting

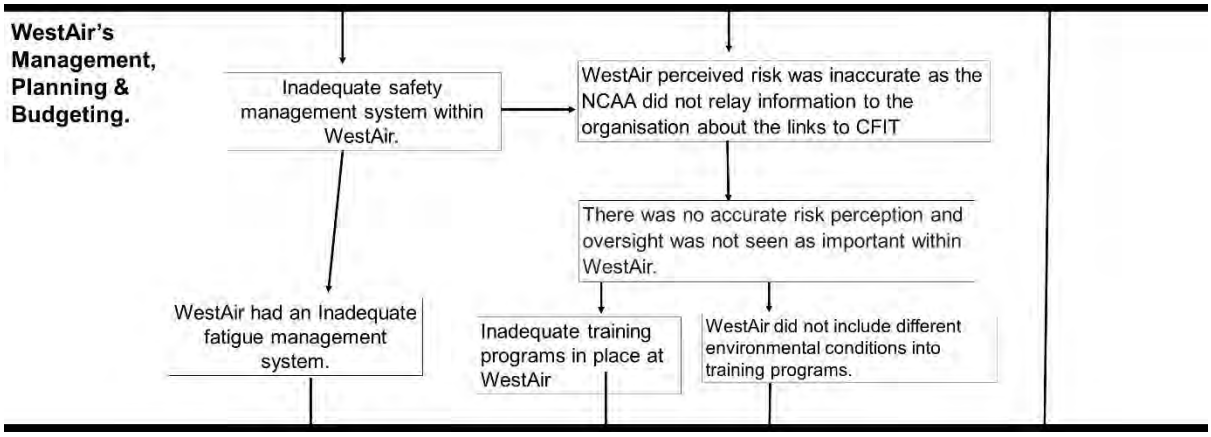

Figure 11: An extract of the contributory factors at the level of Company Management and Planning & Budgeting.

The role of WestAir company and its senior management is to ensure that there are standards and policies within the company and that these standards and policies are adhered to. At the time of the accident, there were *limited resources given and inadequate oversight from the NCAA on the operator*. Thus, WestAir was operating on a daily basis with a training procedural manual that was not approved by the regulator (NCAA) even after amendments were made to the manual in February 2015 before the accident occured. If the NCAA had approved the amendments, they could have identified that pilots may not have been trained adequately and an intervention could have been made to prevent accidents/incidents. It was highlighted that WestAir *did not have the proper procedures* in place for the following: crew pairing, fatigue management training or any way of tracking fatigue risks. The crew in the cockpit experienced a *high workload environment* and had to *fly in early hours of the morning* on the day of the accident which would have affected their circadian rhythm and could have led to *fatigue*. There was a *large crew gradient* which may have affected the dynamics of the cockpit.

Cockpit gradient refers to the authority and power someone holds that may be higher in a hierarchical structure. In essence, it refers to the level of communication that the crew pair can achieve in ensuring the flight is successful. In the V5-NRS accident there was a steep crew gradient; the Pilot in Command was a 53-year-old male who had 6353.0 total hours of flying while the first officer was a 24-year-old female who had a

total of 1394.8 flying hours to her name. Thus, the Pilot in Command was a lot more experienced in terms of age and flying hours compared to the first officer which could have led to an unstable power dynamic.

Fatigue is multifaceted and is often associated with *irregular schedules (night shift work and extended work hours),* which disrupt or shorten sleep that the flight crew experiences. The crew members on board the V5-NRS started their shift at 23h15 on 15th August 2015, flew through the night from Namibia to Cape Town and the accident took place at approximately 4h30 on 16th August 2015. *The crew members on board were on standby since Saturday morning* and there were no available procedures governing pilots' standby duties. It was also reported that the crew members were exposed to a high workload environment which could have contributed to fatigue.

4.2.2.3 Technical and Operational Management of WestAir.

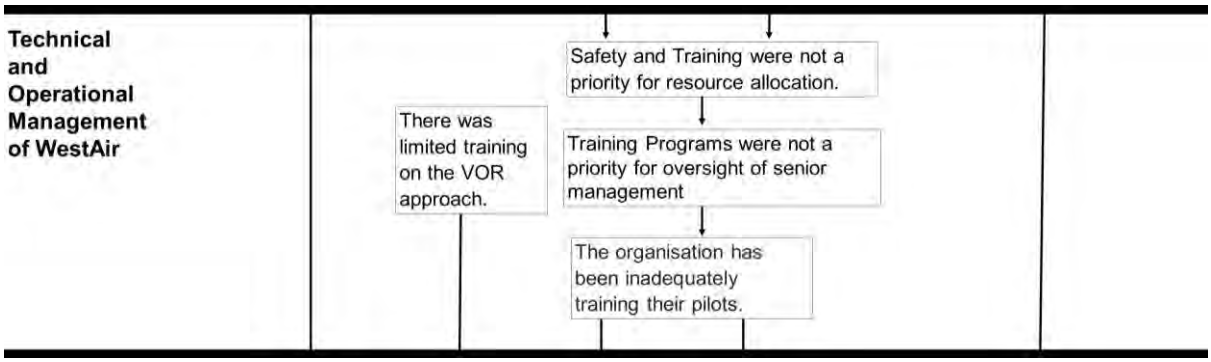

Figure 12: An extract of the contributory factors at the level of Technical and Operational Management of WestAir.

The secondary surveillance radar failure and the pilots not changing the omni-bearing selector during the VOR landing approach contributed to the Controlled Flight into Terrain accident. The major question then is why the radar failed and why the pilots did not change the bearing selector. Attention is automatically shifted to the oversight of equipment maintenance within the South African Civil Aviation Authority and training programmes at WestAir.

The operator's operations manual stated that the Instrument Landing System (ILS) approach should be seen by the company as a navigational aid that is completely irreplaceable. The crew never requested to make use of this navigation aid. The

reason behind the crew not requesting to use the ILS may be due to incorrect information that was provided by the flight operations manager to the co-pilot before the flight crew had flown. The flight operations manager told the co-pilot that the information gained was a Notice to Airmen (NOTAM) that had been issued, which indicated that the ILS was not working in Cape Town. However, the crew also failed to follow up on this information as they did not read the official NOTAMs before departure.

Controlled Flight into terrain (CFIT) has occurred in the aviation industry several times. It can therefore be reasonably hypothesised that the organisation had one of two hypotheses. The first is that *WestAir had a frequency bias when it came to CFIT*. Essentially, because CFIT has not occurred in their organisation they perhaps thought that they were training their crew adequately but in actuality had inadequately trained their pilots. The inadequacy in training could have been an emergent property of having access to the information but not having adequate resources to implement this information into their programmes. In the final report it states that there were inadequate resources provided by the Namibian Civil Aviation Authority to WestAir. Thus, WestAir may have been aware of CFIT accidents but due to inadequate resources they could not implement a training programme sufficient to mitigate these links to CFIT accidents.

The second reasonable hypothesis is that *WestAir's perceived risk could have been inaccurate* as the regulator may not have relayed information about the links to a CFIT accident and therefore *did not train their pilots for these conditions*. There are several links to CFIT accidents, including non-precision approaches, training, low altitude flight in unfamiliar areas, and loss of situational awareness. The Regulator (Namibian Civil Aviation Authority) may not have relayed this information to WestAir therefore they were not training their pilots using non-precision approaches, or how to navigate through unfamiliar areas. Had the regulator relayed this information WestAir could have trained their pilots sufficiently and the accident may have been avoided. If WestAir ensures recurrent pilot training that includes case studies on CFIT accidents during non-precision approaches as well as crew resource management training that provides crew with multi-crew situational awareness, leadership, and teamwork training.

4.2.2.4 Physical Processes and Actor Activities

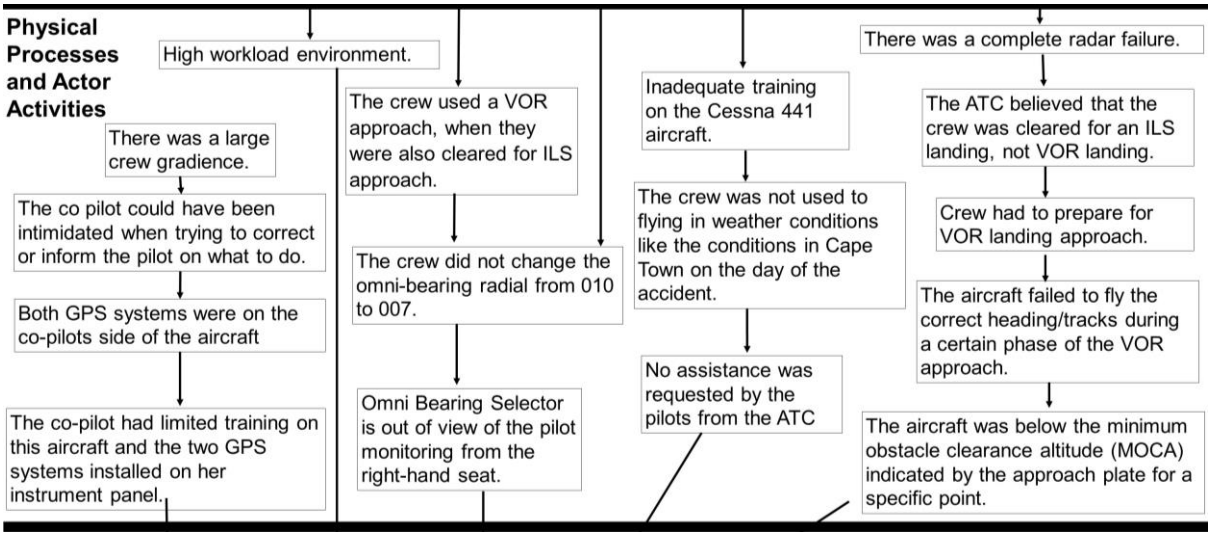

Figure 13: An extract of the contributory factors at the level of Physical Processes and Actor Activities.

As a result of a complete failure of the secondary surveillance radar, the pilots had to use the VOR landing approach. The VOR landing approach is a non-precision approach where the pilots are only provided with lateral guidance. The pilots are provided with a Final Approach Course/Chart for which they utilise a radial from the VOR to provide this lateral guidance to land the aircraft safely. The Final Approach Chart used by the pilots can be seen in Figure 14.

The flight crew attempted the VOR approach to landing, but the ATC wanted the flight crew to use the VOR landing approach chart to fly through the cloud and then continue with approach to runway 19. It is hypothesised that once the aircraft was overhead the beacon, and after it had turned onto the outbound leg, *the pilot did not change the VOR inbound radial from 010° to 007°.* Had the crew changed the VOR inbound radial the aircraft would have missed the Tygerberg mountains, and the accident may not have occurred. T*he aircraft was also below the minimum obstacle clearance altitude (MOCA) indicated by the final approach plate* (Figure 14) throughout the flight. An example of where the aircraft flew below the MOCA was at ±11DME[5] (outbound) on the radar track of the final approach chart (Figure 14). The aircraft initiated the left turn

[5] Distance Measuring Equipment: It measures the distance between the aircraft and the station on the ground.

onto the intermediate Approach Segment at an altitude of between 2600ft and 2700ft, which was 300-400ft below the MOCA of 3000ft. It is mandatory that the aircraft descend to 2000ft to reach 5.5DME however, the aircraft descended past the MOCA of 2000ft until it flew into terrain. The aircraft also failed to fly the correct heading/tracks during a certain phase of the VOR approach, which the crew failed to correct. Evidence collected during the AIID investigation, stated that the Pilot in Command and First Officer were exposed to a high workload environment and flew the aircraft through the evening with the accident taking place at approximately 4h29 on the 16th of August 2015. This may indicate the presence of fatigue, which would have influenced levels of alertness and henceforth impacted decision-making capacity.

The co-pilot had *limited training* on this aircraft and did not have any formal training on the two GPS systems that were installed on her side of the cockpit. The pilot and co-pilot had inadequate training on the Cessna 441 aircraft and did all their training in Namibia, where they did not encounter low cloud coverage very often. On their descent into the Cape Town International Airport, they reached a low cloud coverage area over the Tygerberg Mountains. This may have created an element of uneasiness for the flight crew as they had to navigate through low cloud coverage. If the crew were being trained adequately through ensuring that training programmes were based on data collected from previous accidents to ensure that the programmes are effective and up to date, and more that pilots were trained simulating different weather forecasts as well as different times of day, this accident could have been prevented.

4.2.3 Recommendations

The main characteristic of the AcciMap method is placing and creating links between events and conditions that contributed to the accident. This characteristic of the AcciMap method circumvents unfair blame of humans that are doing the work at the frontline, in this case the pilots of the aircraft. The method provides investigators with a perspective and context that is broad in terms of where the events and conditions emanated and why the actors may have decided what they did at the time. This section indicates that, for every event or decision that is made that led to the accident there is a recommendation generated that assists with a systematic framework for developing a safer aviation industry. Table XVIII and XIX is a tabulated summary of

recommendations generated through the application of CAST and AcciMap in this thesis. These recommendations will then further be discussed in chapter 5.

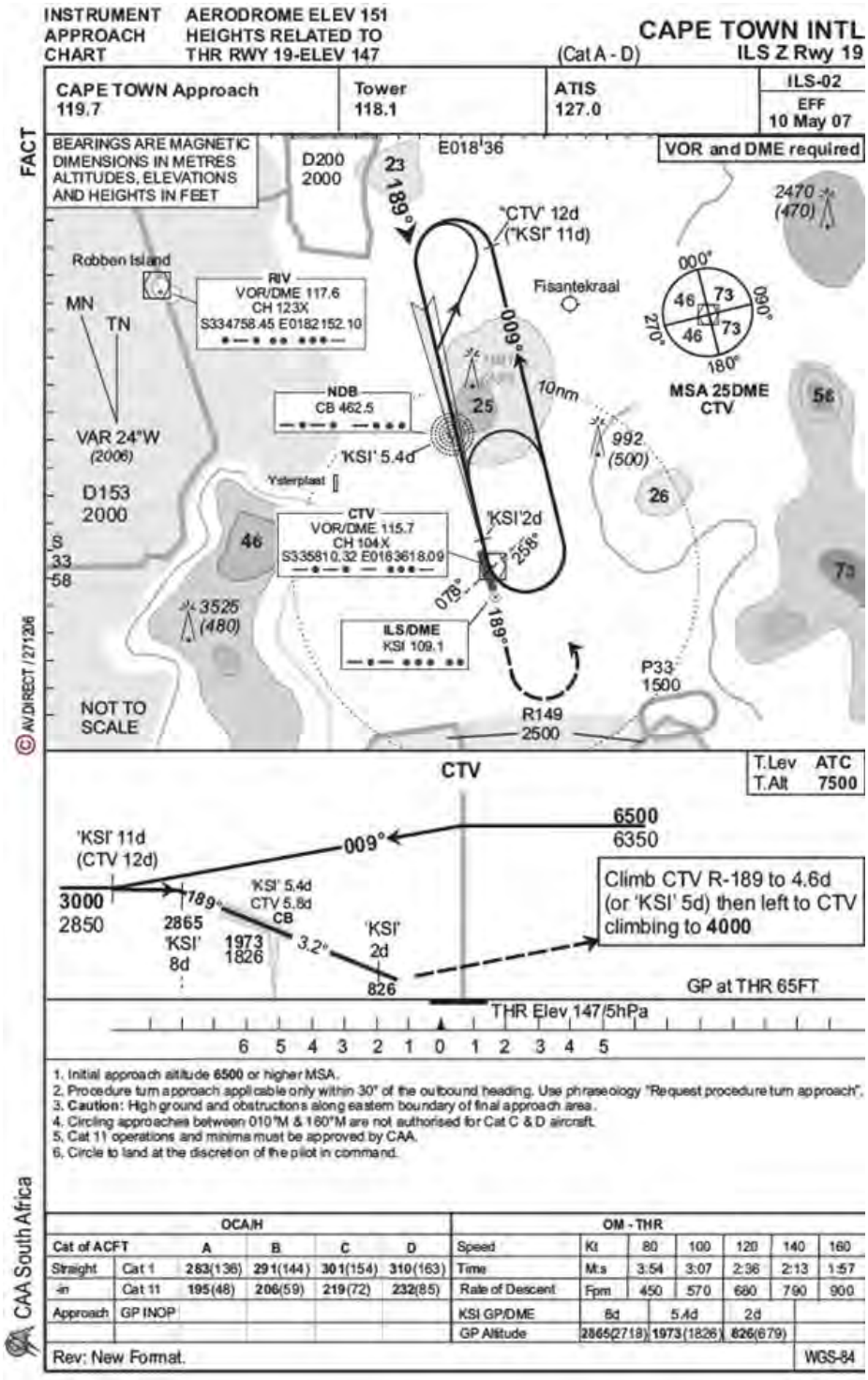

Figure 14: Cape Town International Airport Runway 19 Final Approach Chart (AIID final report of the V5-NRS Cessna 441 Conquest II accident).

Table XVIII: Summary of Recommendations generated by the Causal Analysis using Systems Theory on the V5-NRS Cessna 441 Conquest II accident.

Number	Recommendation	Implementation
R1	Ensure recurrent pilot training includes case studies on CFIT accidents during non-precision approaches, effective tools to trap errors (e.g., multi-crew checklists and mnemonics) as well as Crew Resource Management training that provides multi-crew situational awareness, leadership, and teamwork type training.	**Operators**
R2	Implement a fatigue risk management system (FRMS) for Part 138 (Air Ambulance) operators.	**Operators**
R3	Include different weather forecasts in training flights.	**Operators**
R4	Non-precision approaches should be the last resort when radar failure occurs. First resort should be the ILS.	**Regulator**
R5	The controls over the date management system and the red design of the radar software need to be overseen and kept up to date to avoid a system failure with date conflicts.	**Regulator**
R6	Implement processes for collaborative (training, operations, dispatch, technical, safety) risk management and effective hazard identification methods to prevent CFIT.	**Operator**
R7	Implement a generative safety culture through communication, adequate training, an adequate reporting system, and involve workers in what happens within the organisation.	**Operator**
R8	Ensure the training programmes with regards to different landing systems are effective in preventing CFIT accidents.	**Operator**
R9	Increase the resource allocation to training and safety within an organisation.	**Operator**
R10	Ensure an effective flight operations skill level is represented within the executive to achieve satisfactory oversight of resource allocations and employ more skilled professionals to ensure adequate oversight within an organisation.	**Operator/ Regulator**

R11	Allocate more resources and responsibility to the safety and training department.	**Regulator**
R12	NCAA to increase visibility of a healthy risk management and safety culture in their Safety Management System guidelines.	**Regulator**
R13	Reassess legislation regarding the installation of TAWS on aircraft that weigh less than 5700 Kgs or less than 10 passengers.	**Regulator**
R14	Ensure the oversight over the controls in place to ensure reliability in the secondary radar surveillance system and ensure that all equipment is monitored and upgraded before expiry date.	**Regulator**
R15	Reassess legislation based on foreign air ambulance operations in South Africa to ensure minimum equipment onboard includes TAWS for Part 138 operations.	**Regulator**

Table XIX: Summary of Recommendations generated by the AcciMap on the V5-NRS Cessna 441 Conquest II accident.

Level	Event	Recommendation
Regulatory bodies and Associations	There were ineffective hazard identification and risk management methods for the impact of inadequate training of pilots and CFIT within the NCAA.	Implement processes for collaborative risk management and effective hazard identification methods when giving oversight to operators.
	Due to limited resources, there was ineffective oversight conducted on WestaAir.	Allocate more resources and increase oversight of the safety and training department of the operator.
	Inadequate maintenance and oversight of the secondary surveillance radar system by the SACAA.	Ensure the oversight over the controls in place to ensure reliability in the secondary radar surveillance system and ensure that all equipment is monitored and upgraded before expiry date.
Company Management and Planning & Budgeting	WestAir did not include different environmental conditions into training programmes.	Include different weather forecasts in training flights.
	WestAir had an inadequate fatigue management system.	Implement a fatigue risk management system.
	WestAirs perceived risk was inaccurate as the NCAA did not relay information to the organisation about the links to CFIT therefore the risk perception and oversight was not seen as important in relation to CFIT.	Implement processes for collaborative (training, operations, dispatch, technical, safety) risk management and effective hazard identification methods to prevent CFIT.
	WestAir's training programmes were inadequate.	Ensure that training programmes are based on data collected from previous accidents to ensure that the programmes are effective and up to date.

Technical and Operational Management of WestAir.	Safety and Training were not a priority for resource allocation within WestAir.	1) Increase the resource allocation to training and safety within WestAir. 2) Ensure that there is enough flight operations skill level represented within the executive to achieve satisfactory oversight of resource allocations and employ more skilled professionals to ensure adequate oversight within an organisation.
	Training Programmes were not a priority for oversight of senior management.	Allocate more responsibility to the safety and training department.
	The organisation has been inadequately training their pilots and there was limited training on the VOR landing approach.	Ensure recurrent pilot training includes case studies on CFIT accidents during non-precision approaches, effective tools to trap errors (e.g., multi-crew checklists and mnemonics) as well as Crew Resource Management training that provides multi-crew situational awareness, leadership and teamwork type training.
Physical Processes and Actor Activities	Training was inadequate in terms of the aircraft type as well as the avionics installed on the aircraft.	Improve training programmes in relation to above recommendations.
	There was a large cockpit gradient.	Ensure that crew pairings are done with full knowledge of experience and confidence of the pilots.
	High Workload Environment.	Implement a fatigue risk management programme to manage duty periods and workload of the crew.

5 CHAPTER 5: DISCUSSION

The first aim of this thesis was to identify if, through the implementation of HFE systems-based tools, systemic contributory factors that lead to the V5-NRS Cessna 441 Conquest II accident could be determined using the existing report by the AIID. The second aim of this thesis was to identify if using the two HFE systems-based tools the actors and levels involved in the accident could be identified. The final aim was to identify if the implementation of these tools generates the same or different recommendations to that of the AIID's report.

In summary, the application of CAST and AcciMap in this thesis allowed for the elucidation of contributory factors, the classification of contributory factors across different actors (e.g., pilots, ATC) and across different levels of the system involved in this accident (e.g., Regulators, senior management, operational management) which facilitated the generation of more recommendations across these levels than those generated by the AIID. These key findings are now discussed.

The findings of this thesis using AcciMap and CAST support the arguments made by authors including Rasmussen (1997), Leveson, (2004), Hollnagel (2012), Salmon et al. (2012), Hulme et al. (2019), Read et al. (2020), Salmon et al. (2020), who contend that accidents happen because of multiple contributory factors that come from across the system that interact in a nonlinear and sometimes unpredictable way. The contributory factors at each level are now discussed below and are followed by justified recommendations following the analysis. Many of the contributing factors from the V5-NRS accident are found at the lower levels of the system (e.g., pilots, ATC) and fewer were found at the top levels (i.e., Regulators, Operators). This shows the potential limitations of the report written by the AIID which may have been enhanced by using a systems approach.

In relation to the AIID's report, which adopted ICAO's annex 13 during the investigation, the various contributing factors that have come from all levels of the system. However, there were still many contributing factors found at the sharp end. The AIID elucidated similar contributing factors found in the AcciMap and CAST

however, there was only one recommendation generated by the AIID. This recommendation was WestAir needs to implement a safety management system so that hazards are identified, and risks are mitigated with regards to operations, with a focus on fatigue risk management, human performance as well as change management. While this is indeed an important and appropriate recommendation, the broader investigation did not provide any further recommendations to any other levels and actors within the system, which may lead to certain ongoing, latent failures not being addressed within these systems. Through the implementation of AcciMap and CAST, 14/15 different recommendations, respectively, for different stakeholders within that control structure were generated. The recommendations generated will be unpacked with regards to their level of implementation in the paragraphs below. There are overlapping recommendations generated by the AcciMap and CAST, therefore recommendations will be discussed in their entirety and not in relation to the analysis from which the recommendation was generated. This discussion will start with contributory factors and recommendations generated for the flight crew, ATNS, WestAir, NCAA and SACAA.

5.1 CONTRIBUTORY FACTORS OF THE V5-NRS CESSNA 441 CONQUEST II ACCIDENT AND THE RELEVANT RECOMMENDATIONS

At the level of the crew, this analysis found that crew fatigue may have been a contributor to this CFIT accident, which is consistent with the findings of Kelly and Efthymiou (2019). In this case, crew had been on duty for an extended period of time and flew through the night, both of which likely resulted in increased sleepiness and reduced alertness due to extended wakefulness and being awake a time when one should be asleep (Behrens et al., 2022; Dawson et al., 2011; Enoka & Duchateau, 2016). This may be one reason why the bearing selector was not changed on the approach, as crew were sleep deprived and possibly inattentive to this. To mitigate the risk of fatigue, a recommendation generated for WestAir is to implement a fatigue risk management system (FRMS) or something similar for Part 138 (Air Ambulance) operators and interrogate the way in which working time is structured to ensure that crew is not on duty for extended periods of time, particularly if work occurs at night.

Alongside the flight crew experiencing fatigue, the analyses found that the flight crew had been inadequately trained. The flight crew were not trained extensively in a Cessna 441 aircraft or trained adequately in relation to the GPS systems installed on the aircraft. The accident flight was the co-pilot's first flight in a Cessna 441, which had been preceded by a conversion course that occurred only three days prior to the accident. This meant that the co-pilot in charge had 1.2 hours of flying experience in the Cessna 441 Conquest II aircraft before the flight that led to this accident. The finding that inadequate training may have contributed to this accident is consistent with previous research (Chowdhury et al., 2022; Kim et al., 2016a; Li et al., 2020b; Luxhøj & Coit, 2006; Tabibzadeh et al., 2017).The challenges associated with flying a plane that the co-pilot may have been unfamiliar with was also likely exacerbated by the weather conditions as well as the time of day at which the flight occurred.

The combination of inadequate training, fatigue, and lack of how to navigate through low cloud coverage could have resulted in reduced alertness and impaired decision making due to high workload and the effects of stress on the flight crew on the V5-NRS Cessna 441 Conquest II aircraft, an interaction that has been highlighted in previous research (Caldwell, 2005). Over and above this, the radar failure, low cloud coverage and the aircraft not being equipped with a Terrain Advisory Warning System (TAWS), may have contributed to the crew experiencing poor situational awareness, which is consistent with Kelly and Efthymiou (2019) who identified a major contributing factor leading to a CFIT accident is loss of situational awareness. The flight crew was also not trained adequately to fly in low cloud coverage with the crew inadequately being trained on the Cessna 441. Recommendations generated to mitigate this was to ensure that there is recurrent pilot training that includes case studies on CFIT accidents during non-precision approaches, effective tools to trap errors (e.g., multi-crew checklists and mnemonics) as well as Crew Resource Management training that provides multi-crew situational awareness, leadership, and teamwork-type training. Furthermore, the analysis led to the recommendation that over and above training focusing on non-precision approaches, it should also include simulation flights and practice flights in different weather conditions so that pilots are comfortable flying in different weather conditions. It is therefore the responsibility of WestAir to ensure that training programmes include different landing systems that are effective in preventing

CFIT accidents. At the regulator level, it may be pertinent for the NCAA to pass legislation with regards to the need for aircraft to be fitted with Terrain Advisory Warning System even if the aircraft weighs less than 5700kgs.

While pilot training is indeed the responsibility of the operator, in this case, Westair, it is also the responsibility of the Regulator to provide the necessary oversight to ensure that adequate training occurs. Through the V5-NRS CFIT accident analysis, it emerged that the NCAA did not have effective oversight on the operator's safety and training departments which led to the operator inadequately training their crew. Inadequate oversight and resource allocation from regulators is a consistent contributing factor to accidents captured in previous research (Kim et al., 2016b; Lee et al., 2017; Li et al., 2020b; Chowdhury et al., 2022; Gholamizadeh et al., 2022; Torres et al., 2022). To mitigate this the recommendation generated was that the NCAA needs to ensure that there are more resources and responsibility allocated to its safety and training department. This can be through ensuring an effective skill level is represented within the executive to achieve satisfactory oversight of resource allocations and if not, skilled professionals need to be employed to ensure adequate oversight within the organisation.

The AcciMap and CAST identified that a major contributing factor was that the SACAA had inadequate oversight over the Air Traffic Navigation Services radar equipment reliability processes. In relation to the V5-NRS accident when installing the secondary radar surveillance system, the date on this particular piece of equipment had not been upgraded by the required date. Had the system been upgraded the radar system may not have failed. If the secondary surveillance radar does fail, the recommendation generated is that non-precision approaches (as in the one used in this case) should be the last resort and ATC needs to ensure that the flight crew is using precision approaches such as the ILS approaches. This approach was available at the time of the accident, but it was not clear as to why the ATCs did not give this option to the crew of the V5-NRS. This lack of regulatory oversight has been reported in previous research. More specifically, in a U.S. Coastguard aviation accident, lack of oversight was a major contributing factor (Hickey et al., 2012). Crew, in the case of Hickey et al.'s (2012) study, was inadequately trained in Crew Resource Management, cut

corners in procedures and were unable to provide accurate assessments of pilot/crew associated proficiencies which led the aircraft dropping too low to the ocean and not being able to recover, which ultimately led to the accident (Hickey et al., 2012).

While the evidence for this is scant, based upon the report that was analysed in this study, the NCAA, SACAA and WestAir appear to have a reactive safety culture. As stated in the results section, a reactive culture is characterised by regulators or organisations only acting after things have gone wrong, where failure within an organisation is covered up, information that they have access to is ignored or hidden, and new ideas are not welcomed and discouraged (Hudson, 2001). Below, some of the emergent outcomes of this analysis are discussed in relation to why it is argued that the organisations in question may have a reactive safety culture.

In relation to this case study, the NCAA, SACAA and WestAir had access to information about CFIT and how the lack of training may contribute, yet the training programs in place were found to be inadequate perhaps because an accident like this had not occurred in the organisation before. Furthermore, there is an inaccurate risk perception on the complete hull loss of an aircraft in a CFIT accident weighing less than 5700 kgs or less than 10 passengers' capacity, given the fact that the regulators do not require any aircraft that weighs below 5700 kgs to have TAWS in their aircraft. The reactive culture was demonstrated by the failure of the radar that occurred. Instead of noting that software of this caliber requires regular upgrades, the SACAA and ATNS waited for the radar to fail before doing anything about it. Therefore, to address this, the overall recommendation for the NCAA, SACAA and WestAir was the need to implement a generative safety culture through communication, adequate training, an adequate reporting system, and involve workers in what happens within the organisation but also ensure there is a healthy risk management within the Safety Management System Guidelines (Sigmann et al., 2019).

5.2 COMPARISON OF CONTRIBUTORY FACTORS FROM THE V5-NRS CESSNA 441 CONQUEST II TO THAT OF OTHER STUDIES

The contributory factors found through the application of CAST and AcciMap were broadly categorised into poor decision making by the regulator around certain

importance pieces of legislation; lack of experience of the flight crew, poor management around understanding the risk associated with fatigue, inadequate training programmes and poor judgement surrounding the link between inadequate training and Controlled Flight into Terrain accidents. These contributory factors are consistent with general contributing factors leading to accidents but are also consistent with contributory factors leading to CFIT accidents. These are consistent with contributing factors highlighted in previous studies are lack of training, communication, experience, inadequate oversight at both the regulator and operator levels, fatigue, distraction, budget allocation, technical requirements, and design deficiency (Nelson, 2008; Salmon et al., 2020; Torres et al., 2022).

Salmon et al. (2020) specifically looked at 23 different AcciMap studies within different industries where throughout they found substantially more contributing factors at the lower levels, and fewer at higher levels of systems. While the analyses focused on the causes of outdoor led accident and incidents, the relevance of these findings to this particular study is that the causes of accidents, across different contexts, manifest through consistent challenges across system levels. According to Rasmussen's standardised AcciMap Levels the contributory factors Salmon et al. (2020) identified that the contributory factors most common at the Equipment, Environment and Surroundings level were physical and natural environmental factors, technology and resources, as well as weather and climate. At the Physical Processes and Actor Activities level the contributory factors most common were judgement and decision making, compliance with procedures, violations and unsafe acts, qualifications, and experience. At the Technical and Operational Management level, the most common contributing factors were planning, preparing, following procedures, violations as well as unsafe acts. At the Local Area Government level, the contributory factors that were most common included risk assessment and management, qualification, training, experience, and competence. At the Regulatory Bodies and Associations level, the most common contributory factors were standards, policy and regulations, communication, and coordination. Lastly the most identified contributory factors at the Government Policy and Budgeting level were listed as policy, legislation, regulation, judgement and decision making. The accumulation of the contributory factors mentioned above accounted for over 50% of all the contributory factors that were

reported in the 23 AcciMap studies analyzed by Salmon et al. (2020). These common contributing factors identified by Salmon et al. (2020) are consistent with those found in this study. These contributing factors include poor decision making, training, experience, legislation, and regulation, and communication.

The V5-NRS Cessna 441 Conquest II accident was a CFIT accident, and the contributory factors highlighted in this thesis are in line with those identified in a study done by Kelly and Efthymiou, (2019). According to Kelly and Efthymiou (2019) who analysed the role human factors played in 50 Controlled Flight into Terrain (CFIT) aviation accidents, the authors identified common contributing factors including, visual and lighting conditions, pilot experience, lack of terrain warning equipment, distraction, complacency, fatigue, communication, and general skill-based errors. Most of these CFIT accidents occurred during descent and approach stages of flight.

As can be seen there are consistent contributory factors that are leading to accidents in general as well as consistent contributory factors leading to Controlled Flight into Terrain accidents. This persistence highlights the need to actively learn from and respond to these consistently identified systemic challenges that contribute to accidents across various systems.

5.3 A SUMMARY OF THE SYSTEMIC NATURE OF THE V5-NRS CESSNA 441 CONQUEST II ACCIDENT

The V5-NRS Cessna 441 Conquest II accident analyses highlighted that the accident was the result of failures and poor decision-making issues across all levels of the system which, perhaps due to economic stressors, led to high workload situations, that were exacerbated by the challenges the crew encountered when trying to land. Figure 15 shows how the system in which the V5-NRS Cessna 441 Conquest II accident occurred had several pressures that were created by systemic failures at each level of the system. This integrated model allows for an understanding of how systemic contributory factors at all levels of the system place pressure on the boundaries that would shift the operating point into the direction of performance failure and in this case led to the CFIT accident (Cook & Rasmussen, 2005).

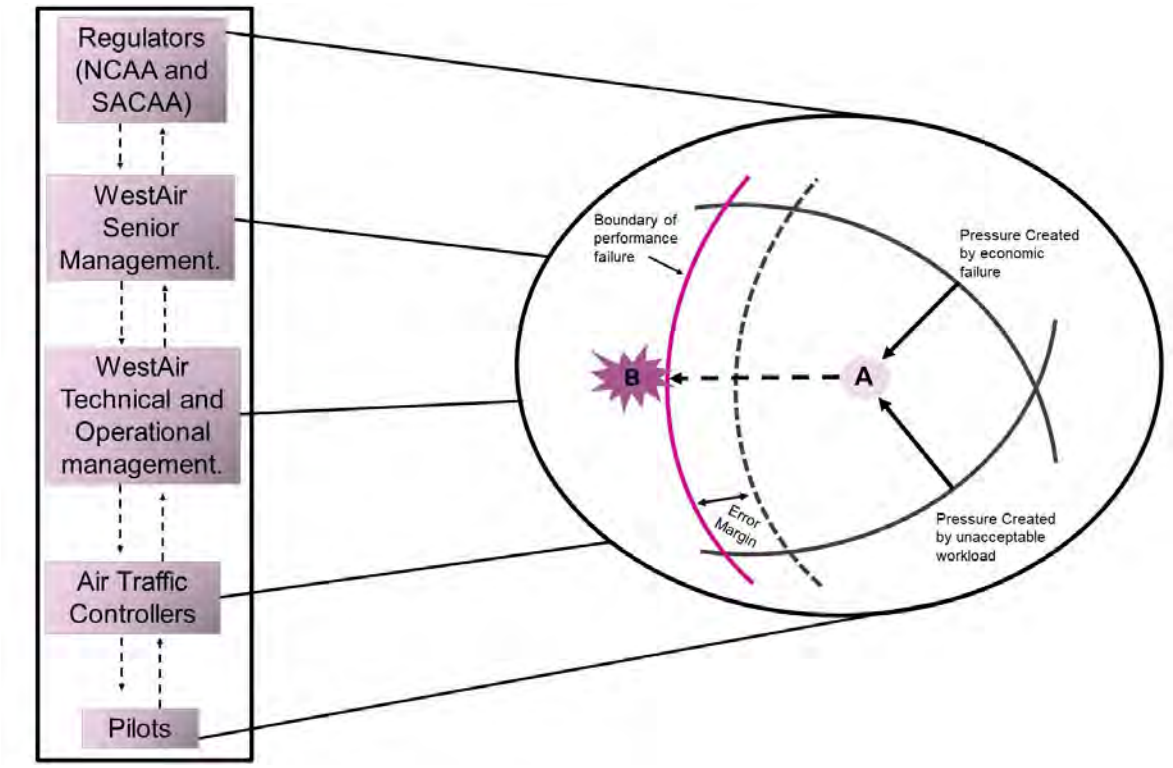

Figure 15: Adapted version of Rasmussen's Structural Hierarchy of Risk management and the Dynamic Safety Model.

By understanding and identifying systemic contributing factors that may place pressure on the operating point, counter gradients may be put in place. Counter gradients are opposing pressures placed on the operating point and shift it away from performance failure, this includes recommendations generated through investigations. The recommendations generated can be used by the AIID and other stakeholders that were involved in these accidents as counter gradients towards the prevention of future accidents.

5.4 LIMITATIONS RELATED TO THIS INVESTIGATION OF THE V5-NRS ACCIDENT

There were some limitations to this thesis. The only data involved in this accident comes from the final accident report that was published by the AIID. Thus, there was limited information that could be used as what was published was what was found from the previous investigation. No interviews could be conducted with individuals involved in the accident and no contact was made with individuals that work at WestAir, Namibian Civil Aviation Authority or the South African Civil Aviation Authority.

In relation to the implementation of the two tools (AcciMap/CAST) in this study, there needed to be an aviation specialist on the team to understand the aviation-specific processes as well as technical and operation-specific terminology. While this was necessary in the current project, it points to the need for accident investigators to be versed not only in the application of the tools, but also to have the requisite technical knowledge when investigating accidents in a certain context. A limitation of the CAST tool is that the CAST report can be very long as there is no specific way of writing it up and there is no graphical representation of the accident which may make it hard for someone to understand. In terms of the AcciMap, at first glance the AcciMap image does not describe what has happened nor does it give context which is why it is important to have a descriptive section after the image to allow for the understanding of the accident.

5.5 REFLECTIONS

As someone with very little aviation knowledge as well as very little experience using both AcciMap and Causal Analysis using Systems Theory (CAST), the analysis proved to be rather challenging. The AcciMap was a less challenging tool to implement in comparison to CAST, given that it has relatively straightforward steps and a set idea of how the information needs to be depicted at the end (AcciMap diagram) whereas CAST had clear steps but did not have a clear way of depicting the information. Additionally, having limited aviation knowledge and experience further contributed to the complexity of applying both methods. This required additional research but also emphasizes the importance of working with experts (in this case, a co-supervisor with extensive experience in aviation operations and accident investigation). Thus, it is recommended that anyone applying AcciMap and/or CAST should have a basic understanding of the operations/context in which these tools are being applied as this may assist with the ease of applying these methods. If not, investigators should be under the mentorship of experts with experience in the use of these tools, particularly CAST.

The analysis was based on a single accident report which may have included hindsight bias from the investigators, and it highlighted that there may be limited contextual

information and data within the report. Being able to sit and discuss this accident with the original investigators may have allowed for the elucidation of any other contextual factors that may have been missed as well as gaining clarity on any of the parts of the report and the accident that need more clarity. This may have added to the analysis but would not have completely changed it. In saying this the inclusion of supervisors and experts (Dr. Jonathan Davy, Andrew Todd, David Doull) was beneficial in gaining an objective, inter-rater perspective on the contextual information from the report as well as the analysis which allowed for an accurate understanding of the factors, lowered the chances of any hindsight biases based on knowledge and experience, and ensured that the analysis was easily understood.

In sum, the aim of this thesis was to highlight how it is important to use Human Factors and Ergonomics systems-based analysis tools within aviation accident investigation. The results and recommendations generated using a single accident report still indicate the utility and benefits of these tools in which the aims and objectives of this thesis are reached.

6 CHAPTER 6: CONCLUSION

The purpose of an accident or incident investigation is to learn what went wrong so that safety can be improved in the future (Dallat et al., 2019; Winfield et al., 2020). Investigations are based around four main questions, what happened, why did it happen, what does it reveal and how can the system be improved to prevent future accidents (Winfield et al., 2020). As complexity within systems like aviation have increased to ensure the improvement of safety within systems, it continues to be important to not only focus on being reactive when things have gone wrong, but also to be proactive and design systems to overcome systemic challenges that affect safety.

Through using these two systemic tools on an existing accident report, the various factors that led to the accident as well as the various actors and levels at which these factors occurred, could be brought to light. While the report by the AIID identified many systemic contributing factors, their recommendations only generated one recommendation which was aimed at the operator. In comparison the application of CAST and AcciMap allowed for the identification of more systemic contributing factors and generated multiple recommendations, with the CAST generating 15 recommendations and AcciMap generating 14 recommendations. While these will need to be interrogated by the AIID and other relevant stakeholders, they do provide some important steps towards how to prevent similar such accidents. Given the high number of general aviation accidents within South Africa it is evident and important that the application of CAST and AcciMap or other such systems tools, alongside existing methods, should be used in investigations. This will require further awareness raising and capacity building locally in South Africa to ensure the acceptance of and, hopefully the application of systems-based accident investigations methods in the attempt to improve general but broader aviation safety.

7 BIBLIOGRAPHY

Abdelghany, A., Abdelghany, K., & Azadian, F. (2017). Airline flight schedule planning under competition. *Computers & Operations Research*, *87*, 20–39. https://doi.org/10.1016/J.COR.2017.05.013

Adedigba, S. A., Khan, F., & Yang, M. (2016). Process accident model considering dependency among contributory factors. *Process Safety and Environmental Protection*, *102*, 633–647. https://doi.org/10.1016/J.PSEP.2016.05.004

Adole, A. (2020). Safety Management Systems: Applications for the Aviation Industry - *Google Books*. https://books.google.co.za/books?hl=en&lr=&id=bsXrDwAAQBAJ&oi=fnd&pg=PA125&dq=An+accident+or+incident+investigation+is+a+process+conducted+for+the+purpose+of+preventing+accidents+and+incidents.+&ots=74vXRbsfuL&sig=Oto9ely3euSIHhL2VmbmFEfcN4M&redir_esc=y#v=onepage&q&f=false

Anderson, J. R. (1987). Methodologies for studying human knowledge. *Behavioral and Brain Sciences*, *10*(3), 467–477. https://doi.org/10.1017/S0140525X00023554

Arcúrio, M. S. F., Nakamura, E. S., & Armborst, T. (2018). Human Factors and Errors in Security Aviation: An Ergonomic Perspective. https://doi.org/10.1155/2018/5173253

Armstrong, M. E., Cecil, W. L., & Taylor, K. (1988). Root cause analysis handbook. https://doi.org/10.2172/6069992

Behrens, M., Gube, M., Chaabene, H., Prieske, O., Zenon, A., Broscheid, K. C., Schega, L., Husmann, F., & Weippert, M. (2022). Fatigue and Human Performance: An Updated Framework. *Sports Medicine 2022 53:1*, *53*(1), 7–31. https://doi.org/10.1007/S40279-022-01748-2

Bergantino, A. S., Vico, K., & Walker, T. (2020). Recent Developments in Sustainable Aviation: An Overview. *Sustainable Aviation*, 1–5. https://doi.org/10.1007/978-3-030-28661-3_1

Bouhsine, T., Idbraim, S., Bouaynaya, N. C., Alfergani, H., Ouadil, K. A., & Johnson, C. C. (2022). Atmospheric Visibility Image-Based System for Instrument Meteorological Conditions Estimation: A Deep Learning Approach. *Proceedings - 2022 9th*

International Conference on Wireless Networks and Mobile Communications, WINCOM 2022. https://doi.org/10.1109/WINCOM55661.2022.9966454

Boyd, D. D. (2017). A review of general aviation safety (1984-2017). *Aerospace Medicine and Human Performance*, *88*(7), 657–664. https://doi.org/10.3357/AMHP.4862.2017

Boyd, D. D., Scharf, M., & Cross, D. (2021). A comparison of general aviation accidents involving airline pilots and instrument-rated private pilots. *Journal of Safety Research*, *76*, 127–134. https://doi.org/10.1016/J.JSR.2020.11.009

Branford, K., Naikar, N., & Hopkins, A. (2007). An investigation into the validity and reliability of the AcciMap approach [Australian National University]. https://openresearch-repository.anu.edu.au/bitstream/1885/20987/2/01_Branford_Guidelines_for_ACCIMAP_2009.pdf

Branford, K., Naikar, N., & Hopkins, A. (2009). Guidelines for AcciMap Analysis. https://www.researchgate.net/publication/245024991_Guidelines_for_AcciMap_Analysis

Bridger, R. (2017). Introduction to Human Factors and Ergonomics (4th Edition). https://books.google.co.za/books?hl=en&lr=&id=gCGeDwAAQBAJ&oi=fnd&pg=PP1&dq=Human+Factors+and+Ergonomics+&ots=ys0PTVqg9l&sig=_n0uGxJnBA77BYzYrt48qIFk7ec&redir_esc=y#v=onepage&q=Human%20Factors%20and%20Ergonomics&f=false

Bromfield, M. &, & Landry, S. (2019). Loss of Control In-Flight (LOC-I)-Time to Re-define? 1–11. https://doi.org/10.2514/6.2019-3612

Caldwell, J. A. (2005). Fatigue in aviation. *Travel Medicine and Infectious Disease*, *3*(2), 85–96. https://doi.org/10.1016/J.TMAID.2004.07.008

Carayon, P. (2006). Human factors of complex sociotechnical systems. *Applied Ergonomics*, *37*(4), 525–535. https://doi.org/10.1016/J.APERGO.2006.04.011

Carayon, P., Wust, K., Hose, B.-Z., & Salwei, M. E. (2021). Human Factors and Ergonomics in health care. *Handbook of Human Factors and Ergonomics*, 1417–1437. https://doi.org/10.1002/9781119636113.CH53

Chen, F., Xu, B., & Fan, D. (2022). Using the system dynamics model on sustainable safety development of civil aviation. *International Journal of Technology, Policy, and Management*, *22*(1–2), 3–23. https://doi.org/10.1504/IJTPM.2022.122532

Chowdhury, A. K., Huq, A. S., Sabiha Huq, A., & Haque, S. A. (2022). Investigation of a recurring type of collision on the padma multipurpose bridge pillar using Systems Theoretic Accident Model and Processes (stamp) approach. https://www.researchgate.net/publication/366530227

Coello, L. A., Jácome, F. A., Zurita, J. R., Casa, C. W., & Vélez, J. S. (2023). *Design and Simulation of an Aircraft Autopilot Control System: Longitudinal Dynamics*. 388–402. https://doi.org/10.1007/978-3-031-25942-5_31

Čokorilo, O. (2020). Civil aviation pilot education, coaching and beyond: Building capacity in the cockpit Connected Transport View project. *International Journal for Traffic and Transport Engineering*, *10*(1), 1–14. https://doi.org/10.7708/ijtte.2020.10(1).01

Cook, R., & Rasmussen, J. (2005). "Going solid": a model of system dynamics and consequences for patient safety. *BMJ Quality & Safety*, *14*(2), 130–134. https://doi.org/10.1136/QSHC.2003.009530

Coury, B. G., Ellingstad, V. S., & Kolly, J. M. (2010). Transportation Accident Investigation: The Development of Human Factors Research and Practice, *6*(1), 1–33. https://doi.org/10.1518/155723410X12849346788624

Dallat, C., Salmon, P. M., & Goode, N. (2019). Risky systems versus risky people: To what extent do risk assessment methods consider the systems approach to accident causation? A review of the literature. *Safety Science*, *119*, 266–279. https://doi.org/10.1016/J.SSCI.2017.03.012

Dawson, D., Ian Noy, Y., Härmä, M., Kerstedt, T., & Belenky, G. (2011). Modelling fatigue and the use of fatigue models in work settings. *Accident Analysis & Prevention*, *43*(2), 549–564. https://doi.org/10.1016/J.AAP.2009.12.030

de Florio, F. (2016). Air Operations Regulations. *Airworthiness*, 211–335. https://doi.org/10.1016/B978-0-08-100888-1.00009-4

DeJoy, D. M. (1990). Toward a Comprehensive Human Factors Model of Workplace Accident Causation. *Professional Safety*, *35*(5).

https://www.proquest.com/openview/e65e85026c3cec804c583ff52d088553/1?pq-origsite=gscholar&cbl=47267

Dekker, S., Cilliers, P., & Hofmeyr, J. H. (2011). The complexity of failure: Implications of complexity theory for safety investigations. *Safety Science*, *49*(6), 939–945. https://doi.org/10.1016/J.SSCI.2011.01.008

Dekker, S., & Pitzer, C. (2016). International Journal of Occupational Safety and Ergonomics Examining the asymptote in safety progress: a literature review. *International Journal of Occupational Safety and Ergonomics*, *22*(1), 57–65. https://doi.org/10.1080/10803548.2015.1112104

Douglas, A., Wiegmann, D., & Shappell, S. (2017). A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis Classification System - *Google Books*. https://doi.org/10.4324/9781315263878

Dul, J., Bruder, R., Buckle, P., Carayon, P., Falzon, P., Marras, W. S., Wilson, J. R., & van der Doelen, B. (2012). A strategy for human factors/ergonomics: Developing the discipline and profession. *Ergonomics*, *55*(4), 377–395. https://doi.org/10.1080/00140139.2012.661087

Düzgün, H. S., & Leveson, N. (2018). Analysis of soma mine disaster using causal analysis based on systems theory (CAST). *Safety Science*, *110*, 37–57. https://doi.org/10.1016/j.ssci.2018.07.028

Enoka, R. M., & Duchateau, J. (2016). Translating Fatigue to Human Performance. *Medicine and Science in Sports and Exercise*, *48*(11), 2228. https://doi.org/10.1249/MSS.0000000000000929

Environment Branch of the International Civil Aviation Organization (ICAO). (2010). *ICAO Environmental Report*. http://admin.indiaenvironmentportal.org.in/files/environmentreport_2010.pdf#page=20

Gebel, A. (2004). The Aviation Industry. *The Business of Sustainability*, 99–123. https://doi.org/10.1057/9780230524477_6

Gholamizadeh, K., Alauddin, M., Aliabadi, M. M., Soltanzade, A., & Mohammadfam, I. (2022). Comprehensive Failure Analysis in Tehran Refinery Fire Accident: Application

of Accimap Methodology and Quantitative Domino Effect Analysis. *Fire Technology*, 1–20. https://doi.org/10.1007/S10694-022-01348-6/TABLES/6

Glogovac, M., & Čokorilo, O. (2018). Promotion of Safety Culture within Serbian regulatory framework. *International Scientific Conference of the Faculty of Transport Engineering,* 1–7.

Goblet, V., Fala, N., & Marais, K. (2015). Identifying Phases of Flight in General Aviation Operations. https://doi.org/10.2514/6.2015-2851

Goncalves Filho, A. P., Jun, G. T., & Waterson, P. (2019). Four studies, two methods, one accident – An examination of the reliability and validity of AcciMap and STAMP for accident analysis. *Safety Science*. https://doi.org/10.1016/j.ssci.2018.12.002

Griffin, T. G. C., Young, M. S., & Stanton, N. A. (2015). Human factors models for aviation accident analysis and prevention. *Human Factors Models for Aviation Accident Analysis and Prevention*, 1–225. https://doi.org/10.1201/9781315587417/HUMAN-FACTORS-MODELS-AVIATION-ACCIDENT-ANALYSIS-PREVENTION-MARK-YOUNG-THOMAS-GRIFFIN-NEVILLE-STANTON

Hamim, O. F., Hoque, M. S., Mcilroy, R. C., Plant, K. L., & Stanton, N. A. (2019). Applying the AcciMap methodology to investigate the tragic Mirsharai road accident in Bangladesh. https://doi.org/10.1051/matecconf/201927702019

Hamim, O. F., Hasanat-E-Rabbi, S., Debnath, M., Hoque, M. S., McIlroy, R. C., Plant, K. L., & Stanton, N. A. (2022). Taking a mixed-methods approach to collision investigation: AcciMap, STAMP-CAST and PCM. *Applied Ergonomics*, *100*. https://doi.org/10.1016/J.APERGO.2021.103650

Hancock, P. A. (2022). How human factors and ergonomics save lives. *Applied Ergonomics*, *98*, 103585. https://doi.org/10.1016/J.APERGO.2021.103585

Heinrich: W. (1931). Industrial Accident Prevention: A Scientific Approach. *McGraw-Hill book Company*. https://scholar.google.com/scholar?cluster=15394648574116317501&hl=en&as_sdt=2005&sciodt=0,5

Hickey, J., Design, S., & Program, M. (2012). A System Theoretic Safety Analysis of U.S. Coast Guard Aviation Mishap involving CG-6505.

Hollnagel, E., Goteman, Ö. E., & Goteman, Ö. (2004). *The Functional Resonance Accident Model.* https://www.researchgate.net/publication/229010270

Hollnagel, E., & Speziali, J. (2008). Study on Developments in Accident Investigation Methods: A Survey of the "State-of-the-Art." *SKI Report*, 1–45. https://www.academia.edu/22733387/Study_on_Developments_in_Accident_Investigation_Methods_A_Survey_of_theState_of_the_Art

Hollnagel, E. (2012). Coping with complexity: Past, present, and future. *Cognition, Technology and Work*, *14*(3), 199–205. https://doi.org/10.1007/S10111-011-0202-7

Hollnagel, E., Goteman, Ö. E., & Goteman, Ö. (2004). The Functional Resonance Accident Model. https://www.researchgate.net/publication/229010270

Hudson, P. (2001). Safety Culture – Theory and Practice. 85–97. https://dvikan.no/ntnu-studentserver/reports/MP-032-$$ALL.pdf#page=85

Hulme, A., Stanton, N. A., Walker, G. H., Waterson, P., & Salmon, P. M. (2019). What do applications of systems thinking accident analysis methods tell us about accident causation? A systematic review of applications between 1990 and 2018. *Safety Science*, *117*, 164–183. Elsevier B.V. https://doi.org/10.1016/j.ssci.2019.04.016

Hulme, A., Stanton, N. A., Walker, G. H., Waterson, P., & Salmon, P. M. (2022). Testing the reliability and validity of risk assessment methods in Human Factors and Ergonomics. *Ergonomics*, *65*(3), 407–428. https://doi.org/10.1080/00140139.2021.1962969/SUPPL_FILE/TERG_A_1962969_SM2090.DOCX

Igene, O. O., Johnson, C. W., & Long, J. (2021). An evaluation of the formalised AcciMap approach for accident analysis in healthcare. *Cognition, Technology & Work 2021*, 1–21. https://doi.org/10.1007/S10111-021-00669-W

International Ergonomics Association. (2019). What is ergonomics? https://iea.cc/what-is-ergonomics/.

Janic, M. (2000). An assessment of risk and safety in civil aviation. *Journal of Air Transport Management*, *6*(1), 43–50. https://doi.org/10.1016/S0969-6997(99)00021-6

Keebler, J. R., & Fausett, C. M. (2023). Human factors in aviation and aerospace: An overview. *Human Factors in Aviation and Aerospace*, 1–9. https://doi.org/10.1016/B978-0-12-420139-2.00004-6

Kelly, D., & Efthymiou, M. (2019). An analysis of human factors in fifty controlled flight into terrain aviation accidents from 2007 to 2017. *Journal of Safety Research*, *69*, 155–165. https://doi.org/10.1016/J.JSR.2019.03.009

Kenneth, C. B., & Gould, P. (2020). *The Coupling of Safety and Security Exploring Interrelations in Theory and Practice.* http://www.springer.com/series/15119

Khosa, E. (2021). South African Civil Aviation Annual Report. https://static.pmg.org.za/SACAA_Annual_Report_2021_22.pdf

Kim, T. eun, Nazir, S., & Øvergård, K. I. (2016). A STAMP-based causal analysis of the Korean Sewol ferry accident. *Safety Science*, *83*, 93–101. https://doi.org/10.1016/J.SSCI.2015.11.014

Kirwan, B. (Barry), Rodgers, M. D., & Schäfer, D. (2017). *Runway Safety*. 63–90. https://doi.org/10.4324/9781315253015-11

Kirwan, B., Charles, R., Jones, K., Li, W.-C., Page, J., Tutton, W., & Bettignies-Thiebaux, B. (2020). *The Human Dimension in Tomorrow's Safe Aviation System*.

Kletz, T. A., & Institution of Chemical Engineers (Great Britain). (1993). *Lessons from disaster: how organisations have no memory and accidents recur*. 183. https://books.google.com/books/about/Lessons_from_Disaster.html?id=bnvLyTcwDE0C

Kucko, M. (2018). Operation of Non-Scheduled Air Services in the European Union. *SSRN Electronic Journal*. https://doi.org/10.2139/SSRN.3345647

Lee, S., Moh, Y. B., Tabibzadeh, M., & Meshkati, N. (2017). Applying the AcciMap methodology to investigate the tragic Sewol Ferry accident in South Korea. *Applied Ergonomics*, *59*, 517–525. https://doi.org/10.1016/J.APERGO.2016.07.013

Leplat, J. (1978). Accident analyses and work analyses. *Journal of Occupational Accidents*, *1*(4), 331–340. https://doi.org/10.1016/0376-6349(78)90003-2

Leveson, N. (2004). A new accident model for engineering safer systems. *Safety Science*. https://doi.org/10.1016/S0925-7535(03)00047-X

Leveson, N. G. (2011). Engineering a Safer World. *Engineering a Safer World*. The MIT Press. https://doi.org/10.7551/mitpress/8179.001.0001

Leveson, N. G. (2018). Safety Analysis in Early Concept Development and Requirements Generation. *INCOSE International Symposium*, *28*(1), 441–455. https://doi.org/10.1002/J.2334-5837.2018.00492.X

Leveson, N. G. (2019). CAST Handbook: How to learn more from accidents and incidents. 1–148.

Leveson, N. (2020b). *Safety III: A Systems Approach to Safety and Resilience Safety III: A Systems Approach to Safety and Resilience Contents*.

Li, F., Wang, W., Xu, J., Dubljevic, S., Khan, F., & Yi, J. (2020). A CAST-based causal analysis of the catastrophic underground pipeline gas explosion in Taiwan. *Engineering Failure Analysis*, *108*, 104343. https://doi.org/10.1016/J.ENGFAILANAL.2019.104343

Lindberg, A. K., Hansson, S. O., & Rollenhagen, C. (2010). Learning from accidents – What more do we need to know? *Safety Science*, *48*(6), 714–721. https://doi.org/10.1016/J.SSCI.2010.02.004

Luxhøj, J. T., & Coit, D. W. (2006). Modeling low probability/high consequence events: An aviation safety risk model. *Proceedings - Annual Reliability and Maintainability Symposium*, 215–221. https://doi.org/10.1109/RAMS.2006.1677377

Lykou, G., Iakovakis, G., & Gritzalis, D. (2019). Aviation cybersecurity and cyber-resilience: Assessing risk in air traffic management. *Advanced Sciences and Technologies for Security Applications*, 245–260. https://doi.org/10.1007/978-3-030-00024-0_13/COVER

Mohammed Elmardi Suleiman Khayal, O. (2019). Human Factors and Ergonomics.

Moray, N., & Oray, N. M. (2000). Culture, politics, and ergonomics. *Culture, Politics and Ergonomics*, *43*(7), 858–868. https://doi.org/10.1080/001401300409062

Nelson, P. S. (2008). A STAMP Analysis of the LEX Comair 5191 Accident. *Control*.

Oliveira, P. M. P. da S. (2020). *Technical and economic viability of the implementation of approach systems (radio aids) in regional airfields (Viseu airfield case study)*. https://ubibliorum.ubi.pt/handle/10400.6/10626

Oster, C. V., Strong, J. S., & Zorn, C. K. (2013). Analyzing aviation safety: Problems, challenges, opportunities. *Research in Transportation Economics*. https://doi.org/10.1016/j.retrec.2012.12.001

Papatheodorou, A., & Liasidou, S. (2016). Aviation Deregulation and Tourism in Cyprus following EU Accession. 1–14.

Qureshi, Z. H. (2009). A Review of Accident Modelling Approaches for Complex Critical Sociotechnical Systems. 1–72. https://apps.dtic.mil/sti/citations/ADA482543

Rasmussen, Jens. (1997). Risk management in a dynamic society: A modelling problem. *Safety Science*. https://doi.org/10.1016/S0925-7535(97)00052-0

Read, G. J. M., O'brien, A., Stanton, N. A., & Salmon, P. M. (2020). What is going on? Contributory factors to automation-related aviation incidents and accidents. https://doi.org/10.1177/1071181320641412

Read, G. J. M., Shorrock, S., Walker, G. H., & Salmon, P. M. (2021). State of science: evolving perspectives on 'human error.' *64*(9), 1091–1114. https://doi.org/10.1080/00140139.2021.1953615

Reason, J. (1990). Human Error. *Cambridge University Press*, 1–302. https://doi.org/10.1017/CBO9781139062367

Reason, J. (2000). Human error: Models and management. *British Medical Journal*, *320*(7237), 768–770. BMJ Publishing Group. https://doi.org/10.1136/bmj.320.7237.768

Reason, J. (2006). *Human factors: A personal perspective*. Paper presented at the Human Factors Seminar, Helsinki.

Rydenfält, C., Johansson, G., Odenrick, P., Åkerman, K., & Larsson, P. A. (2013). Compliance with the WHO Surgical Safety Checklist: deviations and possible improvements. *International Journal for Quality in Health Care*, *25*(2), 182–187. https://doi.org/10.1093/INTQHC/MZT004

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

Salmon, P. M., Goode, N., Lenné, M. G., Finch, C. F., & Cassell, E. (2014). Injury causation in the great outdoors: A systems analysis of led outdoor activity injury incidents. *Accident Analysis & Prevention*, *63*, 111–120. https://doi.org/10.1016/J.AAP.2013.10.019

Salmon, P. M., Walker, G. H., Gemma, G. J., Goode, N., & Stanton, N. A. (2016). Fitting methods to paradigms: are ergonomics methods fit for systems thinking? *Https://Doi.Org/10.1080/00140139.2015.1103385*, *60*(2), 194–205. https://doi.org/10.1080/00140139.2015.1103385

Salmon, P. M., Hulme, A., Walker, G. H., Waterson, P., Berber, E., & Stanton, N. A. (2020). The big picture on accident causation: A review, synthesis and meta-analysis of AcciMap studies. *Safety Science*, *126*, 104650. https://doi.org/10.1016/J.SSCI.2020.104650

Salvendy, G., & Karwowski, W. (2019). *Handbook of Human Factors and Ergonomics* (5th ed.).

Scribante, N. P., Pretorius, L., & Benade, S. (2019). The design of a research tool for conducting research in a complex socio-technical system. *South African Journal of Industrial Engineering*, *30*(4), 143–155. https://doi.org/10.7166/30-4-2191

Shahab Hosseinian, S., & Jabbarani Torghabeh, Z. (2012). Major Theories of Construction Accident Causation Models: A Literature Review. *International Journal of Advances in Engineering & Technology*, *4*(2), 53–66.

Shappel, S., & Wiegmann, D. A. (2000). *(PDF) The Human Factors Analysis and Classification System-HFACS*. https://www.researchgate.net/publication/247897525_The_Human_Factors_Analysis_and_Classification_System-HFACS

Shappell, S., Detwiler, C., Holcomb, K., Hackworth, C., Boquet, A., & Wiegmann, D. A. (2007). Human error and commercial aviation accidents: An analysis using the human factors analysis and classification system. *Human Factors*. https://doi.org/10.1518/001872007X312469

Sigmann, S. B., McEwen, L. R., & Stuart, R. (2019). A Community Approach to Academic Research Safety. *Trends in Chemistry*, *1*(3), 275–278. https://doi.org/10.1016/J.TRECHM.2019.03.015

Sklet, S. (2002). Methods for accident investigation. *Reliability, Safety, and Security Studies*, 1–75.

Snook, S. A. (2000) Friendly Fire: The Accidental Shootdown of U.S. Black Hawks over Northern Iraq (Princeton, NJ: Princeton University Press). https://doi.org/10.1515/9781400840977

Stanton, N. A., Salmon, P. M., Walker, G. H., & Stanton, M. (2019). Models and methods for collision analysis: A comparison study based on the Uber collision with a pedestrian. *Safety Science*. https://doi.org/10.1016/j.ssci.2019.06.008

Tabibzadeh, M., & Meshkati, N. (2015). *SPE-174020-MS* Applying the AcciMap Methodology to Investigate a Major Accident in Offshore Drilling: A Systematic Risk Management Framework for Oil and Gas Industry. 27–30. https://doi.org/10.2118/174020-MS

Tabibzadeh, M., Stavros, S., Ashtekar, M. S., Meshkati, N., & Epstein, D. J. (2017). A Systematic Framework for Root-Cause Analysis of the Aliso Canyon Gas Leak Using the AcciMap Methodology: Implication for Underground Gas Storage Facilities. *Journal of Sustainable Energy Engineering*, *5*(3), 212–242. https://doi.org/10.7569/JSEE.2017.629515

Thatcher, A., Nayak, R., & Waterson, P. (2019). Human factors and ergonomics systems-based tools for understanding and addressing global problems of the twenty-first century. *63*(3), 367–387. https://doi.org/10.1080/00140139.2019.1646925

Tian, F., Tian, Z., & Tian, Y. (2022). Research on Prediction and Quantitative Analysis of Controlled Flight into Terrain Impact Based on QAR Over-limit Events. *2022 IEEE 5th Advanced Information Management, Communicates, Electronic and Automation Control Conference (IMCEC)*, 155–163. https://doi.org/10.1109/IMCEC55388.2022.10020144

Torres, Y., Nadeau, S., & Landau, K. (2022). Applying AcciMap and STAMP to the analysis of human error in complex manual assembly. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *32*(6), 462–481. https://doi.org/10.1002/HFM.20964

Trotter, M. J., Salmon, P. M., & Lenné, M. G. (2014). Impromaps: Applying Rasmussen's Risk Management Framework to improvisation incidents. *Safety Science*, *64*, 60–70. https://doi.org/10.1016/J.SSCI.2013.11.021

Tuli, R. W., Apostolakis, G. E., & Wu, J. S. (2017). Identifying Organisational Deficiencies Through Root-Cause Analysis, *116*(3), 334–358. https://doi.org/10.13182/NT96-A35289

Underwood, P. (2013). Accident Analysis Models and Methods: Guidance for Safety Professionals. *Loughborough University*, 1–25. https://www.academia.edu/3446538/Accident_Analysis_Models_and_Methods_Guidance_for_Safety_Professionals

Underwood, P., & Waterson, P. (2013). Systemic accident analysis: Examining the gap between research and practice. *Accident Analysis & Prevention*, *55*, 154–164. https://doi.org/10.1016/J.AAP.2013.02.041

Verhoeff, M., Verhagen, W. J. C., & Curran, R. (2015). Maximizing operational readiness in military aviation by optimizing flight and maintenance planning. *Euro Working Group on Transportation*, *10*, 14–16. https://doi.org/10.1016/j.trpro.2015.09.048

Vicente, K. J., & Christoffersen, K., 2006, The Walkerton E. coli outbreak: A Test of Rasmussen's Framework for Risk Management in a Dynamic Society, Theoretical Issues in Ergonomics Science, 7, 93–112. https://doi.org/10.1080/14639220500078153

Vincoli, J. W. (1994). *Basic Guide to Accident Investigation and Loss Control.* https://books.google.co.za/books?hl=en&lr=&id=d33sBIFJ6uwC&oi=fnd&pg=PR11&dq=The+first+procedures+for+an+investigation+required+investigators+to+consider+the+immediate+and+underlying+factors+of+an+accident+to+establish+and+assign+blame+for+the+incident/accident+that+took+place&ots=tZJFqlenNf&sig=sBGWiRX34Xy4G8ehyMKk_YK34TM&redir_esc=y#v=onepage&q&f=false

Wang, L., Wu, J., Liu, M., Hu, K., Plant, K. L., McIlroy, R. C., & Stanton, N. A. (2021). Sociotechnical view of electric bike issues in China: Structured review and analysis of electric bike collisions using Rasmussen's risk management framework. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *31*(6), 625–636. https://doi.org/10.1002/HFM.20926

Waterson, P., Jenkins, D. P., Salmon, P. M., & Underwood, P. (2017). 'Remixing Rasmussen': The evolution of AcciMaps within systemic accident analysis. *Applied Ergonomics*, *59*, 483–503. https://doi.org/10.1016/j.apergo.2016.09.004

Wienen, H. C. A., Bukhsh, F. A., Vriezekolk, E., & Wieringa, R. J. (2017). *Accident Analysis Methods and Models-a Systematic Literature Review*.

Wildenboer, H. (2006). Important aspects with regard to the investigation of aircraft accidents and incidents. *47*(2), 58–65. https://journals.co.za/doi/pdf/10.10520/EJC27511

Wilson, J. R. (2000). Fundamentals of ergonomics in theory and practice. *Applied Ergonomics*, *31*(6), 557–567. https://doi.org/10.1016/S0003-6870(00)00034-X

Wilson, J. R. (2014). Fundamentals of systems ergonomics/human factors. *Applied Ergonomics*, *45*(1), 5–13. https://doi.org/10.1016/J.APERGO.2013.03.021

Winfield, A. F. T., Winkle, K., Webb, H., Lyngs, U., Jirotka, M., Macrae, C., Winfield, A., Bristol, W., Lab, R., Bristol, U., Webb, H., Lyngs, U., Jirotka, M., & Winfield, M. (2020). *Robot Accident Investigation: a case study in Responsible Robotics*. https://doi.org/10.1007/978-3-030-66494-7_6

Wittmer, A., Bieger, T., & Muller, R. (2011). *Aviation Systems. Management of the Integrated Aviation Value Chain*. Retrieved April 14, 2021, from http://www.springer.com/series/10099

Woo, D. M., & Vicente, K. J. (2003). Sociotechnical systems, risk management, and public health: comparing the North Battleford and Walkerton outbreaks. *Reliability Engineering & System Safety*, *80*(3), 253–269. https://doi.org/10.1016/S0951-8320(03)00052-8

Woods, D., Dekker, S., Woods D., (2010). Anticipating the effects of technological change: A new era of dynamics for human factors, *1*(3), 272–282. https://doi.org/10.1080/14639220110037452

Xu, J., Guo, K., & Sun, P. Z. H. (2022). Driving Performance Under Violations of Traffic Rules: Novice vs. Experienced Drivers. *IEEE Transactions on Intelligent Vehicles*, *7*(4), 908–917. https://doi.org/10.1109/TIV.2022.3200592

Xue, Y., & Fu, G. (2018). A modified accident analysis and investigation model for the general aviation industry: emphasizing on human and organisational factors. *Journal of Safety Research*, *67*, 1–15. https://doi.org/10.1016/J.JSR.2018.09.008

Yastrub, M., Pérez, M. B., & Kredentsar, S. (2020). Methods and Techniques of Effective Management of Complexity in Aviation, 438–459. https://doi.org/10.4018/978-1-7998-1415-3.CH019

Zarei, M., Banda, E., Faridan, O. V., Habibi, M., Delikhoon, M., Zarei, E., Valdez Banda, O., Faridan, M., & Habibi, E. (2022). Systems Thinking Accident Analysis Models: A Systematic Review for Sustainable Safety Management. *Sustainability 2022, Vol. 14, Page 5869*, *14*(10), 5869. https://doi.org/10.3390/SU14105869

Zhang, Y., Jing, L., & Sun, C. (2018). Systems-Based Analysis of China-Tianjin Port Fire and Explosion: A Comparison of HFACS, AcciMap, and STAMP. *Journal of Failure Analysis and Prevention*, *18*(6), 1386–1400. https://doi.org/10.1007/s11668-018-0534