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**AUTOMATION IN AVIATION:
AN ADVANCEMENT OR HINDRANCE TO AVIATION SAFETY?
THESIS**

Presented in Partial Fulfillment of the Requirements for
the Master of Science Degree in the Graduate School
of Texas Southern University

By
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2023

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**AUTOMATION IN AVIATION: AN ADVANCEMENT OR HINDRANCE TO
AVIATION SAFETY?**

By

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Texas Southern University, 2023

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Transportation at large is becoming increasingly automated, and aviation has often been at the forefront of this technological movement. Automation's presence in the cockpit has been quite advantageous by improving economics, enhancing safety, and arguably reducing workload. However, its implementation has also presented several challenges, including but not limited to complacency and overreliance on automation, manufacturer design errors, and automation surprise. To overcome these challenges and mitigate safety issues preemptively, methods and strategies must be devised to improve the implementation of automation in aviation. Upon review of eight case studies from accident reports where the use of automation was a contributing factor, several recommendations were developed to improve the implementation of automation in aviation. Airline operators should encourage the use of manual flying skills when applicable and ensure that crews are competently educated and trained on automated systems. Manufacturers on the other had should increase the collaboration during the design phase with both the end user and regulatory agency, strengthen the utilization of the Human Centered Approach to systems integration and improve Human Factors and Ergonomics studies for instrumentation to improve ease of use for pilots. As the world

becomes more technologically advanced, the delicate relationship between man and machine must be carefully managed.

Keywords: Automation, complacency, ergonomics, human factors, safety

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LIST OF ABBREVIATIONS

A/T: Autothrottle

AOA: Angle of Attack

ATC: Air Traffic Control

CFIT: Controlled Flight Into Terrain

ECAM: Electronic Centralized Aircraft Monitor

EICAS: Engine Indication & Crew Alerting System

FAA: Federal Aviation Administration

FADEC: Full Authority Digital Engine Control

FMS: Flight Management System

GPWS: Ground Proximity Warning System

HCI: Human Computer Interaction

ILS: Instrument Landing System

MCAS: Maneuvering Characteristics Augmentation System

PF: Pilot Flying

PM: Pilot Monitoring

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CHAPTER 1

INTRODUCTION

As the world becomes increasingly technologically advanced, many day-to-day tasks are becoming automated. The transportation industry is one that has taken full advantage of this to improve mobility. Automation in aviation refers to the ability of a system to perform tasks that would usually be performed by a human with limited or no intervention.

Automation and its span of control vary by functions in the cockpit. In general, automation can be viewed according to these stages:

- **Information Acquisition:** The retrieval of information from data and information from several sources. For instance, the autopilot acquires impact pressure information from the pitot tube.
- **Information Analysis:** The interpretation of the data that results in meaningful information. For example, the impact pressure is calibrated to produce an accurate airspeed indication.
- **Decision Making:** The system creates suggestions, diagnoses, or recommendations based on the interpreted information. For instance, the autopilot uses the calibrated airspeed indication to determine whether the speed the aircraft is traveling at is appropriate.
- **Action:** The ability to manipulate control surfaces, adjust flight parameters, and perform functions without direct human intervention based on the

- system's decision-making process. For instance, the FMS is programmed to execute an approach to land and automatically adjusts thrust to maintain to correct airspeed.

Collectively, these stages allow the aircraft to operate nearly all phases of flight through automation (Parasuraman, 2008).

Aviation has long been the safest mode of transportation due to a series of factors including but not limited to systems of redundancy, crew resource management, extensive crew training, as well as automation. However, aviation safety is primarily reactive as opposed to proactive. It is important to assess the nature of reaction to determine whether implementing increased automation can play a role in reducing infractions.

Importance/Relevance of Topic

The reactive methodology “involves analysis of past outcomes or events. Hazards are identified through investigation of safety occurrences. Incidents and accidents are an indication of system deficiencies and therefore can be used to determine which hazard(s) contributed to the event.” (ICAO, 2021, p. 2-12). When accidents occur, investigators from the responsible agency identify the probable cause of the accident, as well as contributing factors; most notably they provide critical recommendations to prevent reoccurrence of the accident. These recommendations are quite an effective tool in the enhancement of safety, however identifying and mitigating risks and hazards prior to an accident is ideal.

Conversely, a proactive approach “involves collecting safety data of lower consequence events or process performance and analysing the safety information or

frequency of occurrence to determine if a hazard could lead to an accident or incident. The safety information for proactive hazard identification primarily comes from flight data analysis (FDA) programmes, safety reporting systems and the safety assurance function.” (ICAO, 2021, 2-12). By preemptively identifying and mitigating safety risks and hazards, scores of lives can be saved.

Automation’s role in the cockpit has become increasingly profound over time. It has evolved from performing relatively simple tasks such as maintaining pitch and attitude to being involved in nearly all phases and aspects of flight. This brings about a host of benefits such as improved economics, reduced workload, and enhanced safety. On the contrary, it has also created a host of disbenefits and challenges such as complacency/overreliance on automation, automation surprise, and subpar manufacturer design, which have begun to contribute to recent accidents. These factors that have been contributors to accidents must be mitigated before they compromise and tarnish aviation’s safety record.

Research Objective

The study’s primary objective is to identify methods and strategies to improve the implementation of automation in aviation. The study will utilize a series of case studies regarding aviation accidents in which the use of automation was a contributing factor. The official accident reports will present recommendations which will be analyzed to devise the methods and strategies for improvement.

- To identify potential challenges and issues in the implementation of automation in aviation

- Collect, analyze, and interpret data that illustrates the deficiencies in the implementation of automation in aviation.
- Use research findings to present strategies and methods to improve the implementation of automation in aviation.

Structure of Thesis

This document is segmented into five chapters. The first chapter is the Introduction and establishes the basis of the research. The second chapter contains extensive Literature Review regarding previous research on the topic. The third chapter outlines the Methodology to conduct the research. The fourth chapter highlights the Results and Discussions of the findings from research. The fifth and final chapter presents the Summary, Conclusions, and Recommendations.

CHAPTER 2

LITERATURE REVIEW

Automated technology introduced to a well-designed system will produce greater efficiency. However, when introduced to a flawed system, it exacerbates the deficiencies within that system. Automation has played a pivotal role in aviation's stellar safety record and improving efficiency. Conversely, poor implementation also presents challenges and safety issues. As air transportation becomes increasingly automated, it is paramount that methods and strategies are developed to further enhance the exceptional safety record possessed by the aviation industry.

Advantages of Automation in Aviation

Since the advent of flight, cockpits have become gradually more automated. This is a direct result of the host of benefits to the aviation industry. Most notably, it is argued to offer improved economics, reduced workload, and enhanced safety. These benefits allow aviation to be the pinnacle of automation success.

Improved Economics

Airlines provide essential services to society, but they are first and foremost businesses. A business priority is always to be profitable. Airlines embrace the economic benefits of automation that include but are not limited to "better fuel consumption, lower maintenance costs, selection and training costs, and operational flexibility."(Chialastri, 2012, pp. 88-90).

Fuel costs are one of the largest balance sheet items on an airline's financial books. Automation has aided in the reduction of these costs through weight saving and constant fine tuning of pitch and navigation to provide peak performance. In addition, engine control systems such as Full Authority Digital Engine Control (FADEC), have tremendously improved fuel efficiency of newer aircraft. Autonomous engine control units such FADEC systems respond to pilot inputs, but also use data from sensors reading engine temperatures, engine pressure, fuel flow, air density, among others to optimize engine performance.

Traditional aircraft relied on a system of cables, pulleys, levers, and hydraulic actuators to manually manipulate all the flight control surfaces. The manual linkages are heavy, complicated, and costly to maintain. Fly-by-wire technology interprets pilot control movement and converts it to electronic signals that manipulate the flight control surfaces. "The fly-by-wire system constitutes a fast-forwarding in aircraft design, from mechanical linkage to large hydraulic actuators to computer-assisted fly-by-wire systems. The use of the fly-by-wire system has generated huge satisfaction for the aircraft industry by lessening the weight of the flight control system, by creating multiple redundancy flight control systems, which increases the flight safety of all aircraft equipped with the fly-by-wire system." (Nicolin, 2019, p. 217). While pilots lose some of the tactile feel of manual controls, the benefits of safety and economics far outweigh the disadvantages.

Another major economic benefit of automation is the reduction of crew members in the cockpit. Earlier models of aircraft with analogue instruments, often referred to as steam gauges, required additional members in the cockpit to monitor the numerous

instruments. The flight engineer or second officer would solely be assigned to monitoring engines and systems. With the advent of the Glass Cockpit, Flight Management System, and Engine Indicating and Crew Alerting System (EICAS)/ Electronic Centralized Aircraft Monitor (ECAM), that role has become redundant. Airlines were able to save millions of dollars in human resources as a result. Furthermore, training costs are lowered as many of the functions performed by pilots are outsourced to automation, shortening training time, and reducing costs. The improved economics has contributed greatly to making air travel more accessible and available to the greater population.

Reduced Workload

Always stay ahead of the aircraft, is a popular phrase and piece of advice in the aviation community. It is used to reinforce the importance of managing workload. While its exact definition is rather vague, staying ahead of the aircraft involves ample anticipation of upcoming tasks, continual attention to flight parameters, and ensuring that tasks are never compiled to an unmanageable level, and ultimately performed at a delayed pace. By performing some of the tasks that pilots would perform manually, it can be argued that automation, in many cases has dramatically reduced the workload in the cockpit.

One of the first instances of automation in aviation was evident in the invention of the gyroscopic stability system by Sir Hiram Maxim in the early 1900s. This was followed by the research conducted by the Wright Brothers and the development of their very own stability augmentation system. However, it was Lawrence Sperry's Automatic Pilot design in 1914 that was the most successful application of the gyroscopic stability augmentation design. In an airshow, he was able to demonstrate the ability of the aircraft

to maintain the pitch with no human intervention by raising his hands up completely free of the control column. This system allowed the pilot to perform other tasks while not having to maintain pitch. Nowadays aircraft automation can perform nearly all phases of flight, even landing, which is arguably the most difficult part of flying. Airbus is currently conducting tests in their Autonomous Taxi, Take-off, and Landing project and has successfully conducted an entire flight completely autonomously. (Airbus, 2020).

While automation dramatically reduces active workload, it is argued by many that it conversely increases cognitive workload, because automated systems must be constantly monitored throughout the entire duration of the flight. As the workload increases, the pilot tends to delegate to the automation system a series of functions to minimize the workload. It is important to specify that the physical workload (the number of actions performed within a given time frame) differs from the cognitive workload in that the latter implies a thorough monitoring, understanding and evaluation of the data coming from the automation system.” (Chialastri, 2012 p. 96). There is not a consensus on whether or not automation reduces workload.

Enhanced Safety

The introduction of automation in aviation has contributed to a drastic improvement in safety. While there were many safety initiatives such as Crew Resource Management among others that were also being introduced, there is a correlation between enhanced safety and automation. “Safety has always been proclaimed by the aviation industry as its primary objective. An examination of air carrier accidents by Lautmann and colleagues (1987) suggests that more highly automated aircraft have had substantially less accidents than earlier aircraft.” (Billings 1996, p. 90).

The arguable reduction in workload, fatigue, heightened reliability, and maintenance contributed by automation has all aided in aviation's unmatched safety record. According to the Bureau of Transportation Statistics, aviation for the past 21 years has been the safest mode of transportation (Bureau of Transportation Statistics 2023). When micro analyzed, Part 141 airline operations far exceed any other mode of transportation regarding fatalities. "Automation, or the mechanization of processes and tasks formerly carried out by humans, is nearly ubiquitous and has helped to improve the efficiency and safety of a variety of tasks by reducing human error in high-stakes situation." (Merritt, 2019, p.2). Safety is the number one priority in all sectors of transportation. However, due to the dynamics of aviation, safety practices are further heightened.

Challenges of Automation in Aviation

"Automation in the aviation world plays a pivotal role nowadays. Its presence on board airplanes is pervasive and highly useful in improving the pilots' performance and enhancing safety. Nevertheless, certain issues have emerged in the recent past that evidence automation misuse by pilots." (Chialastri, 2012, p. 81). Some of the major challenges are Complacency & Overreliance on Automation, Automation Surprise, and Poor Design by Manufacturers.

Complacency & Overreliance on Automation

One of the critical issues that can be created by automation is overreliance which often leads to a loss of situational awareness and skill degradation. Initial flight training for beginner pilots, stresses the importance of demonstrating proficient manual flying skills. Basic flight maneuvers such as recovering from an aerodynamic stall, maintaining

airspeed and altitude, and navigation are all taught without the aid of automation. Its prevalence in the cockpit has made many complacent in the flight deck. Complacency as it relates to aviation is "A mental state where an aviator acts, unaware of actual danger or deficiencies. He still has the capacity to act in a competent way - but for some reason, or another, this capacity is not activated (Fahlgren 1990).

There are numerous similar incidents and accidents where an airman's complacency led to a lack of situational awareness and ended in disaster. "Investigations of several major aviation incidents suggest that one contributing factor is pilot complacency, or the failure to adequately monitor the performance of an automated system. Pilots who become complacent may fail to quickly correct automation failures, contributing to major incidents." (e.g., Wiener, 1981; Hurst and Hurst, 1982; Casey, 1998; Funk et al., 1999). Complacency is a critical topic in automation safety and has been identified as one of the top five issues related to cockpit automation" (Merritt 2019, p.2). Automation should serve as a tool to improve and enhance a pilot's performance, not degrade one's ability to manually fly an aircraft.

Automation Surprise

Automation surprise is the second challenge of automation implementation in aviation and is a direct result of inadequate knowledge of the system. As with practically every system, it has capabilities and limitations. When airmen are not adequately informed of the span of control that the system possesses, it can lead to disaster. "The interaction between pilots and technologies on board the aircraft raises some concerns regarding an acknowledged problem: the automation surprise. This occurs when pilots no

longer know what the system is doing, why it is doing what it does and what it will do next.” (Chialastri, 2012, p. 94).

Research shows that automation can reduce workload, however when it fails during high workload situations, such as takeoffs and landings, it can increase workload exponentially. Automation tends to fail during those critical phases of flight where altitude, speed, and time is limited. The automation surprise during this period shortens the amount of time the crew has to troubleshoot the issue and incorrect responses at such low altitudes are often fatal.

“When approaching the runway, the airplane’s configuration demands a higher workload, the communication flow with air traffic controllers increases and the proximity to the ground absorbs much of the pilot’s attention. Once all the fast-paced activities are handled with the aid of automation, the pilot may shed some of the workload. When automation fails or behaves in a “strange” manner, the workload increases exponentially.” (Chialastri, 2012, p. 94). Automation surprise often leads to increased workload and when not effectively managed, can lead to tragedy.

Poor Design by the Manufacturer

The next challenge involves poor design by manufacturers. Aviation’s stellar safety record is largely attributed to its system of redundancy. It is a well-known fact that a single system failure should not affect the safety of passengers and crew. Should the aircraft lose an engine, it can rely and fly on the other. Should it lose both engines, the Auxiliary Power Unit (APU) can provide electricity for critical systems, despite a lack of thrust. Should the APU fail, the RAM air turbine (RAT) can be deployed and provide

electricity using outside airflow. Similar systems of redundancy are found throughout nearly all aspects of the aircraft. Even the lavatories have levels of redundancy.

“No catastrophic failure condition should result from the failure of a single component, part, or element of a system. Experienced engineering judgment and service history should show that a catastrophic failure condition by a single failure mode is not a practical possibility. The logic and rationale used in the assessment should be so straightforward and obvious that the failure mode simply would not occur unless it is associated with an unrelated failure condition that would, in itself, be catastrophic.”
(FAA).

Boeing’s Maneuvering Characteristics Augmentation System (**MCAS**) is a prime example of poor manufacturer design. The system was designed and certified for the 737 MAX to enhance the pitch stability of the airplane – so that it feels and flies like other 737s. Boeing placed very high-bypass ratio engines on an airframe that is over 50 years old, which dramatically shifted the aircraft’s center of gravity. As an attempt to defy physics, this system proves the severity of poorly designed automation and was primarily responsible for the death of 346 passengers and crew.

Pilots should be able to revert to manual flight quickly and easily when necessary. When automated systems are designed without this consideration, it can prove to be deadly. In some incidents and accidents, the crew were unable to swiftly disable or correct an action from the autopilot. Manufacturers must design automated systems where the crew are ultimately in control of the aircraft.

Improving the Implementation of Automation

Aviation safety has historically been reactive as opposed to proactive. An accident will occur and from those findings, recommendations are made to improve going further. A proactive approach to improving the implementation of automation in aviation would undoubtedly be more effective. By identifying deficiencies in the implementation process, potential safety risks and hazards can be mitigated prior to an accident. Key points include collaboration during the design phase, human centered approach, and human factors and ergonomics.

Collaboration During the Design Phase

A suggestion is the inclusion of users throughout the entire design phase. Engineers, airmen, and airlines should be thoroughly involved throughout the entire process. Airmen in particular, should be heavily involved in the design of automated systems as they are the end-user. “User involvement in design and development captures the complete system, including the technical architecture, its functionality, the operational procedures applied, and training needed” (CAA, 2016, p.20).

Human factors engineering involves the application of human factors principles in the design and engineering of machines. This practice, in theory, improves the efficiency of operation by focusing on Human-Computer Interaction (HCI). Human factors specialists and psychologists work alongside engineers to design systems that are user-friendly. “Let the engineer learn more about man—and the psychologist more about the machine. Together, with other human factor experts, they will help industry to supply all of us products of greater efficiency, comfort, and safety” (Warren, 1956, p.534). However, as aforementioned, the end user, the pilots, are not a core part of the process.

Moreover, there is a lack of regulatory intervention during the design phase. Regulators often evaluate the finished product of a system or an aircraft but are not actively involved or influential during the initial phases. This can often lead to manufacturers creating flawed equipment as there is no external scrutiny until near the completion process.

Human Centered Approach

The second component of improving the implementation of automation is to use a human centered approach. Whether or not automation is a tool or a replacement for airmen is a topic of popular discussion in the industry. Regardless, in this era, “Humans are often responsible for preventing incidents and averting disasters by detecting situations that are outside the norm and managing those situations. They have the unique ability to identify new or unusual ways to react to abnormal situations and circumstances in a manner that reflects current and emerging situations. They are able to detect subtle changes in a situation, diagnose problems, adapt, and create innovative ways to solve problems, using a wealth of knowledge and experience” (CAA, 2016, p.20).

Manufacturers should consider a human centered design approach when designing automated systems, and aircraft in general. This approach requires understanding users, tasks, and environments and the inclusion of those users in design and development. Furthermore, it must be tested in iterations, refined by user-centered evaluation, and include a team that consists of multidisciplinary skills, most notably those with human performance and human factors expertise. (ICAO, 2018 p.1-4).

The most crucial takeaway of human-centered aviation is that the pilot is ultimately responsible for the safety of flight operations, must retain absolute control of

the aircraft, and must be actively involved and adequately informed. “Automation should be made more effective by improving the coupling or co-operation between humans and technology, i.e., a decidedly human-oriented view” (Sandom , 2009, p.118). Humans have the capacity to be innovative or overcome challenges that cannot be responded to by artificial intelligence.

Consider *The Miracle on The Hudson*, where Captain Sullenberger and First Officer Skiles lost both engines shortly after takeoff and with no other viable options, were able to successfully ditch the aircraft in the Hudson River and no lives were lost. Ponder on Delta Flight 1080 where the L1011’s elevator became jammed fully deflected upward, resulting in a forced nose-up attitude which almost led to a stall. Despite this loss of a critical flight control system, Captain McMahan and his crew were able to save the lives of 52 by ingeniously manipulating the aircraft solely through differential thrust settings. There are numerous accidents where the crew’s ability to adapt and overcome saved the lives of many.

Human Factors and Ergonomics

Another method of improving the implementation of automation is by strengthening human factors and ergonomics studies. According to the Federal Aviation Administration (FAA), Human Factors is defined as a "multidisciplinary effort to generate and compile information about human capabilities and limitations and apply that information to equipment, systems, facilities, procedures, jobs, environments, training, staffing, and personnel management for safe, comfortable, and effective human performance”. (FAA p.1) It seeks to study and understand human-computer interaction, their capabilities, limitations, and other characteristics. The traditional definition of

ergonomics evaluates the study of people at work. As it relates to aviation, the International Civil Aviation Organization (ICAO) defines ergonomics as “a subset of human factors that focuses specifically on designing technical systems, products and equipment to meet the physical needs of the user.”(ICAO, 2018 p. 1-3).

Instrumentation and emergency warnings can benefit from more readily, easily accessible information and a more organized warning method. Current designs might often lead to sensory overload. If a pilot is on final approach following Instrument Flight Rules (IFR), their workload is tremendous. Should they encounter an aerodynamic stall, that challenge further intensifies that workload. In emergency situations, most modern aircraft emit audible warnings, tactile input, and visual notations. In a high workload situation, all this input can lead to sensory overload, and delay an airmen’s response as they must interpret all that sensory data prior to initiating an action.

“An alternative to the view of humans mainly as a source of variability and failures is to view them as a resource that enables the system to achieve its objectives. This view acknowledges that it is impossible to consider every possible contingency during design, and therefore for technological artefacts to take over every aspect of human functioning. Humans are in this way seen as a source of knowledge, innovation, and adaptation, rather than just a limiting factor” (Sandom, 2009, p.118).

With each iteration of newer aircraft, more automated technology is being added to the cockpit. It undoubtedly plays a crucial role in the cockpit and aviation in its entirety. As with the majority of technological advances, it presents advantages and drawbacks. Similarly to how aviation had to overcome other deficient areas, special

attention must be placed on mitigating the risks associated with the implementation of automation.

CHAPTER 3

METHODOLOGY

This study investigates, analyzes, and presents recommendations to improve the implementation of automation in aviation. The primary methodology is the use of case studies. "A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident. In other words, you would use the case study method because you deliberately wanted to cover contextual conditions-believing that they might be highly pertinent to your phenomenon of study" (Yin, p.13).

This research method was chosen as it provides qualitative data from real world accidents, where automation was a contributing factor. Case study methods of research provide "a focus on interpretation rather than quantification; an emphasis on subjectivity rather than objectivity; flexibility in the process of conducting research; an orientation towards process rather than outcome; a concern with context—regarding behavior and situation as inextricably linked in forming experience; and finally, an explicit recognition of the impact of the research process on the research situation" (Kohlbacher, p.2). These will be evaluated and their prevalence in accidents are determinants in improving the implementation of automation in aviation.

The design of this study primarily utilizes official aviation accident reports where the use of automation was an influential, contributing factor in the accident. The case studies selected include the following:

- Lion Air Flight 610 (JT610) investigated by: Komite Nasional Keselamatan Transportasi (KNKT)
- Ethiopian Airlines Flight 302 (ET302) investigated by: Federal Democratic Republic of Ethiopia Aircraft Accident Investigation Bureau
- Air France Flight 447 (AF447) investigated by: Bureau of Enquiry and Analysis for Civil Aviation Safety
- Asiana Flight 214 (OZ214) investigated by: National Transportation Safety Board
- Air Inter Flight 148 (IT5148) investigated by: Bureau of Enquiry and Analysis for Civil Aviation Safety
- American Airlines Flight 965 (AA965) investigated by: Special Administrative Unit of Civil Aeronautics in collaboration with The National Transportation Safety Board
- Turkish Airlines Flight 1951 (TK1951) investigated by: The Dutch Safety Board
- Emirate Airlines Flight 521 (EK521) investigated by: Air Accident Investigation Sector of the United Arab Emirates

The cases were selected by reviewing accidents in the past 25 years, where the use of automation was a contributing factor in the accidents. Table 1 outlines some of the parameters of each case that were used to select the case.

Table 1: Case Studies' Selection Parameters

Case	Year	Geographical Location	Size of Aircraft	Trip Length	Phase of Flight	Crew Experience
JT610	2018	Asia	Narrowbody	Short/Medium Haul	Climb	Captain: 6028:45 hours First Officer: 5174:30 hours
ET302	2019	Africa	Narrowbody	Short/Medium Haul	Climb	Captain: 8122 hours First Officer: 361 hours
AF447	2009	Atlantic Ocean	Widebody	Long Haul	Cruise	Captain: 10988 hours First Officer: 6547 hours
OZ214	2013	North America	Widebody	Long Haul	Approach	PF: 9864 hours PM: 12307 hours
IT5148	1992	Europe	Narrowbody	Short/Medium Haul	Approach	Captain: 8806 hours First Officer: 3615 hours
EK521	2016	Asia	Widebody	Short/Medium Haul	Approach	Captain: 7457:10 hours First Officer: 7957:34 hours
AA965	1995	South America	Narrowbody	Short/Medium Haul	Approach	Captain: 13000 hours First Officer: 5800 hours
TK1951	2009	Europe	Narrowbody	Short/Medium Haul	Approach	Captain: 17000 hours First Officer: 2126 hours

The case studies chosen represent a range of geographies, aircraft sizes, investigating agencies, pilot experience and phases of flight (Figure 1). This range provides a holistic view of aviation

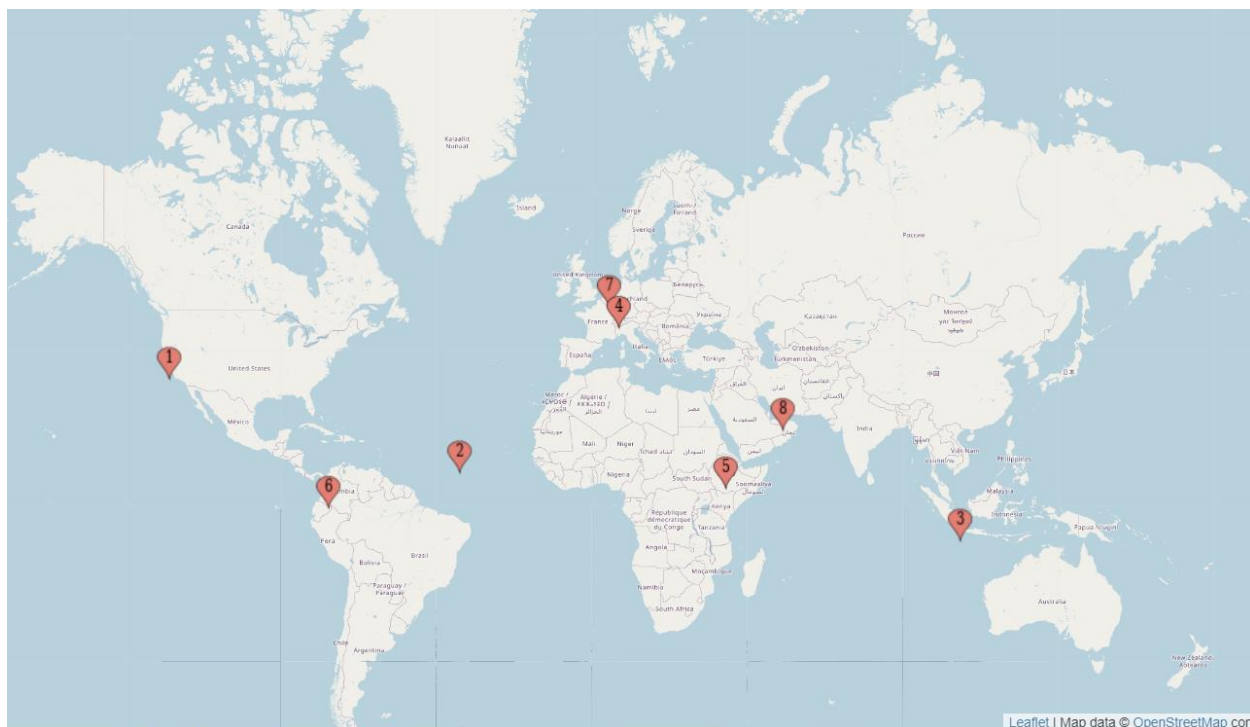


Figure 1: Map of Proximate Accident Sites

accidents and how the issue persists across borders, aircraft, and aviators. The investigating agencies in these accidents serve to ascertain the probable cause of the accident, its contributing factors, and most importantly provide recommendations to prevent reoccurrence.

CHAPTER 4

RESULTS AND DISCUSSION

Eight aviation accidents form the case studies that enable the assessment of the role of automation in aviation and what can be improved. Asiana Flight 214, Air France 447, Lion Air Flight 610, Air Inter Flight 148, Ethiopian Flight 302, American Airlines Flight 965, Turkish Airlines Flight 1951, and Emirates Airlines Flight 521 were all accidents where the use of automation was a significant contributing factor to the accident. The methodology and the cases selected provide a comprehensive view of automation in aviation by evaluating different aircraft types, journey lengths, countries, and phases of flight.

Upon review of the selected eight case studies, the findings from the accidents were used to identify deficiencies in how automation is implemented in aviation. Six parameters of deficiency in implementation were identified, measured, and analyzed. Those parameters are as follows:

- **Overreliance on Automation:** This occurs when even if it is not necessary, pilots opt to or are required by the operator's manual to utilize automation a large majority of the time.
- **Degradation of Manual Flying Skills:** Usually a by-product of an overreliance on automation, this occurs when a pilot's ability to perform relatively fundamental flight maneuvers become increasingly inept.

- Subpar Ergonomics: This occurs when the design of technical systems fails to meet the needs of the pilots.
- Inadequate Knowledge of the System: This occurs when pilots are not fully cognizant of the capabilities and limitations of a system.
- Inadequate Training: This occurs when pilots are not thoroughly trained on the operation of a system, specifically how to recover from an anomaly.
- Manufacturer Design Error: This occurs when manufacturers design systems with critical failure points or unreliable operation.

The assessment will reflect the frequency of each parameter throughout the accidents.

Case Study 1: Asiana Flight 214 (Long Haul) occurred on July 6, 2013

Background Information

Asiana Flight 214 was a regularly scheduled flight from Incheon International Airport, Seoul, South Korea to San Francisco International Airport, San Francisco, California. While on final approach to runway 28L, the crew mishandled the approach and were significantly above the glide slope. As the crew got closer to the runway, the approach remained unstable and worsened and pilots utilized the autopilot in attempt to correct the issue. To increase the rate of descent, the Pilot Flying (PF) selected flight level change speed (FLCH SPD) mode which initially resulted in a climb. To counteract the climb, the PF reduced the thrust to idle which placed the autothrottle into HOLD mode, which does not maintain airspeed. None of the crew members noticed the change in mode, nor did they realize that the aircraft began to lose airspeed. As the approach continued, the aircraft remained unstable, slow, and descended below the glidepath. Visual cues from the PAPI ground system and the aircraft instrumentation displayed that

they were too low. The crew never realized that were dramatically slow and continued to descend at an excessive rate, which led them to crash into the seawall near the beginning of runway 28L. As a result, there were three fatalities and 49 injuries. Table 1 outlines the probable cause, contributing factors, and deficiencies in automation implementation for Case Study 1.

Table 2: Asiana 214 Accident Information

Probable Cause	Contributing Factors	Deficiencies in automation implementation
<ul style="list-style-type: none"> • Flight crew's mismanagement of the airplane's descent during the visual approach • PF's unintended activation of automatic speed control • Inadequate monitoring of airspeed • Delayed execution of go-around 	<ul style="list-style-type: none"> • The complexities of the autothrottle and autopilot flight director systems were inadequately described in Boeing's documentation and Asiana's pilot training. • Crew nonstandard communication and coordination • PF's inadequate training on executing visual approaches. • Crew fatigue • PM inadequate supervision of the PF 	<ul style="list-style-type: none"> • Overreliance on Automation • Degradation of manual flying controls • Ergonomics • Inadequate knowledge

Lessons Learned

The two most crucial flight parameters that must be diligently monitored on final approach are airspeed and altitude. Even when operating trainer aircraft such as the Cessna 172 or Grumman Tiger, beginner pilots are taught on final approach to alternate

their attention and deficiencies in automation between the aforementioned parameters and the runway. By ensuring airspeed and altitude are within range, and using visual information from outside, pilots can ensure a stabilized approach.

On a beautiful day, where weather and visibility were unparalleled, the Asiana flight crew decided to use the autopilot as opposed to manually flying the approach. This arguable overreliance on automation, coupled with fatigue, lack of knowledge, inadequate training and a degradation of manual flying skills, led to a series of errors that resulted in the fatal accident. When the autopilot began to present challenges during a high workload phase of flight, the pilots should have disengaged the system entirely and manually fly the aircraft. This form of complacency where airmen have the ability to perform adequately but don't, is becoming prevalent in accidents.

Case Study 2: Air France Flight 447 (Long Haul) occurred on June 1, 2009

Background Information

Air France Flight 447 was a regularly scheduled service from Rio de Janeiro, Brazil to Paris Charles de Gaulle, France. The Airbus A330-203 had 216 passengers, 9 cabin crewmembers, and 3 flight crewmembers. While over the Atlantic Ocean in route to CDG, the two first officers encountered airspeed anomalies which subsequently led to the disconnection of some of the automated systems. The aircraft entered a high-altitude aerodynamic stall and crashed into the Atlantic Ocean, killing all 228 occupants. Table 2 outlines the probable cause, contributing factors, and deficiencies in automation implementation for Case Study 2.

Table 3: Air France 447 Accident Information

Probable Cause	Contributing Factors	Deficiencies in automation implementation
<ul style="list-style-type: none"> • The obstruction of the pitot probes by ice crystals during cruise led to a loss of airspeed indication. This resulted in the autopilot disengaging and the Pilot Flying (PF) incorrect inputs induced a high-altitude aerodynamic stall which the crew failed to identify. The crew incorrectly responded to the stall and did not recover. 	<ul style="list-style-type: none"> • Weather • Absence of high-altitude training manually • Lack of a clear display in the cockpit of the airspeed inconsistencies identified by the computers. 	<ul style="list-style-type: none"> • Inadequate training • Ergonomics • Overreliance on automation • Degradation of manual flying capabilities

Lessons Learned

One of the first lessons taught in initial flight training is stall recovery. In short, when there is not enough airflow over the wings, the aircraft is unable to generate lift and cannot maintain altitude. Early warning signs in a trainer aircraft include but are not limited to flight control buffets and the stall warning horn. Once any indication of a stall presents itself, the PF must immediately begin the recovery procedure. To recover, the PF must push the nose over and advance the throttles over to increase the amount of airflow over the wings. Once the aircraft gains airspeed and lift, the pilot can resume normal flight operations. In modern aircraft, there are more sophisticated warnings which include audible warnings, visual warnings, and tactile warnings.

The airplane had encountered icing conditions which blocked the pitot tubes. The pitot tubes use impact pressure to measure airspeed, and when blocked can produce

erroneous airspeed indications. The automated systems, when presented with what is perceived to be erroneous data, disconnected, and required the pilots to resume flying the aircraft manually. When AF447 encountered icing conditions, it was in no immediate danger. Had the pilots maintained their current flight path and performed some troubleshooting, no accident would have occurred. Instead, when the autopilot disconnected, the PF began to maneuver the aircraft which destabilized the flight path. The crew did not in a timely fashion identify the approach to stall and when they were in a high-altitude aerodynamic stall, responded incorrectly. While the PF did advance the throttle to gain airspeed which in turn results in a gain in airflow over the wings, he held the control column nose up throughout the entire stall until the aircraft crashed in the ocean.

Most notably in the accident report was the crew's lack of Crew Resource Management and an overreliance on automated systems which led to a degradation of manual flying skills. In addition, the two pilots at the controls had never completed any training for high-altitude manual flying. Furthermore, the airplane's angle of attack was not readily accessible to pilots. All of these in addition to pilot error resulted in the death of 228 passengers and crew.

**Case Study 3: Lion Air Flight 610 (Short/Medium Haul) occurred
on October 29, 2018**

Background Information

Lion Air Flight 610 was a regularly scheduled service from Soekarno-Hatta International Airport, Jakarta to Depati Amir Airport (WIPK), Pangkal Pinang. The flight was operated by the relatively new Boeing 737 MAX 8. Shortly after takeoff, the crew

encountered issues maintaining a climb as the aircraft began to constantly pitch nose down. Unable to recover, the aircraft nosedived into a nearby body of water. Due to the velocity of the impact, all 189 passengers and crew onboard the aircraft perished.

Table 3 outlines the probable cause, contributing factors, and deficiencies in automation implementation for Case Study 3.

Table 4: Lion Air 610 Accident Information

Probable Cause	Contributing Factors	Deficiencies in automation implementation
<ul style="list-style-type: none"> The failure of the Angle of Attack sensor (AOA) triggered the activation of MCAS. The crew incorrectly responded to the repetitive nose down activations by MCAS which resulted in the crash. 	<ul style="list-style-type: none"> MCAS design that relied on a single sensor and persistently reactivated. Boeing's inadequate description of the system Crew's unfamiliarity with system and incorrect response to the activation of MCAS. Lion Air's shoddy maintenance practices. 	<ul style="list-style-type: none"> Manufacturer Design Error Inadequate knowledge of the system Ergonomics Inadequate training

Lessons Learned

The Boeing 737 MAX8 at the time of the accident was Boeing's newest aircraft. It was the fourth iteration of the aircraft. The first flight was in 1967. The aircraft's original design featured little ground clearance and low-bypass ratio JT8D engines. These engines have a relatively small diameter compared to modern engines. In the second generation of the aircraft, Boeing opted to use new CFM56 engines to power the aircraft. This posed a challenge as the CFM56 had a high-bypass ratio that had a significantly wider engine diameter. Engineers had to make alterations to the CFM56 so that the

airframe can accommodate the engines. The MAX series utilized the same 49-year-old airframe that was outfitted with even larger engines. To accommodate these engines on such an old airframe, the engines were mounted higher and further forward on the wings to meet ground clearance requirements. This, however, led to changes in aerodynamic stability and a tendency to pitch up.

To maintain aircraft commonality and training, Boeing designed the Maneuvering Characteristics Augmentation System (MCAS). During manual flight, flaps retracted, and a high Angle of Attack (AOA), MCAS would automatically trigger a nose down input to prevent an imminent stall. MCAS relied on a single Angle of Attack (AOA) sensor, and it activates repeatedly. There were no specific training requirements to counter MCAS activation, and Boeing made several incorrect assumptions about pilot's response to its activation. The crew was not even aware of its existence.

Lion Air flight 610 experienced MCAS activation shortly after takeoff. The crew attempted to counter by using the control column and using manual electric trim. This was only a temporary solution. MCAS would reset and reactivate. The crew failed to communicate effectively, did not complete the runaway stabilizer checklist, and did not trim the aircraft carefully. On the flight prior to the ill-fated JT610, the other crew faced similar flight control issues and were able to troubleshoot the issue. They did not know it was MCAS activation but treated the malfunction as a runaway stabilizer. The crew moved stabilizer trim cutout switches to the cutout position and manually trimmed the aircraft and landed safely.

Lion Air's shoddy maintenance program, crew's subpar Crew Resource Management (CRM) skills, incorrect response to runaway stabilizer, and workload all

contributed to the accident. However, it was the manufacturer's design error and failure to inform airlines and pilots of MCAS that ultimately resulted in the accident. An automated system such as MCAS that can fully deflect primary control surfaces, should have been well described to the parties involved.

Case Study 4: Air Inter 148 (Short/Medium Haul) occurred on January 20, 1992

Background Information

Air Inter Flight 148 was a regularly scheduled domestic flight from Lyon Satolas Airport to Strasbourg Airport, in France. Shortly after cleared for the final approach, the aircraft crashed slightly over 10 miles short of the runway. Of the 96 passengers and crew onboard the aircraft, only 1 crew member and 8 passengers survived the accident.

Table 4 outlines the probable cause, contributing factors, and deficiencies in automation implementation for Case Study 4.

Table 5: Air Inter 148 Accident Information

Probable Cause	Contributing Factors	Deficiencies in automation implementation
<ul style="list-style-type: none"> • The crew's failure to manage the final approach due to pilot error and controller error, as well as the inadvertent selection of 3,300 feet per minute descent rate as opposed to 3.3 degrees. 	<ul style="list-style-type: none"> • The instrumentation failure to clearly display the descent rate differences between degrees and feet per minute. • Inefficient communication between ATC and the crew during the approach • The lack of GPWS on the aircraft. • The crew's failure to recognize the abnormally steep descent rate and fly the aircraft manually . 	<ul style="list-style-type: none"> • Inadequate Knowledge • Ergonomics

Lessons Learned

The investigation discovered the cause of the accident was Controlled Flight into Terrain (CFIT) because of human error. During the initial approach, the crew requested the ILS approach to Runway 23 which would be followed by a visual approach to Runway 05. Due to relatively high traffic and the possibility of delay, the crew instead opted for the VOR/DME approach for Runway 05. As the crew was abeam, the final approach fix ANDLO, they were cleared for the final approach. Shortly after, the aircraft crashed into Montblanc 10.5 nautical miles from the runway threshold.

The crew's mismanagement of the approach, aided by the air traffic controller's subpar guidance to the final approach fix was the probable cause of the accident. A major contributing factor to the accident was the misuse of the autopilot on final descent. The descent rate to the runway was conducted by the autopilot. However, the pilot had it set to Vertical Speed Mode instead of Flight Path Angle Mode. Vertical Speed mode is measured in feet per minute, while Flight Path Angle Mode is measured in degrees. The crew selected a value of 33, presuming the descent rate angle would be the standard 3.3 degrees, but instead the aircraft descended at 3,300 feet per minute. Descending at 3,300 feet per minute is a tremendously excessive descent rate for final approach, when the normal descent rate is approximately 800 feet per minute. The crew did not recognize the mode selection or the abnormally steep descent. The final link in the chain of events that resulted in the accident was that the aircraft was not outfitted with Ground Proximity Warning System (GPWS), which would have alerted the crew of the impending crash. Air Inter at the time opted not to retrofit and install the system on their aircraft.

While human error was the primary cause of the accident, the autopilot's role in the accident is undeniable. Airbus's instrumentation Electronic Centralised Aircraft Monitor (ECAM) did not clearly and easily display the data to the pilots. Even though feet per minute is measured throughout aviation in four digits and angles are measured in two to three digits, the design used two digits for both parameters. This aided in the crew's inadvertent selection of the mode, their inability to recognize the wrong selection, and exacerbated their inadequate knowledge of mode selections for descent.

**Case Study 5: Ethiopian Flight 302 (Short/Medium Haul) occurred
on March 10, 2019**

Background Information

Ethiopian Airlines Flight 302 was a regularly scheduled flight from Addis Ababa Bole International in Ethiopia to Kenya Jomo Kenyatta International Airport in Nairobi. The flight was operated using a nearly brand new 737 MAX8. Like the Lion Air accident that had recently occurred, the crew had issues maintaining a climb due to repetitive nose down pitch inputs by the aircraft. The crew struggled to regain control of the aircraft and ultimately crashed into the terrain. All 157 passengers and crew onboard were killed. Table 5 outlines the probable cause, contributing factors, and deficiencies in automation implementation for Case Study 5.

Table 6: Ethiopian Flight 302 Accident Information

Probable Cause	Major Contributing Factors	Deficiencies in automation implementation
<ul style="list-style-type: none"> • “Repetitive and uncommanded airplane-nose-down inputs from the MCAS due to erroneous AOA input, and its 	<ul style="list-style-type: none"> • MCAS reliance on a single AOA sensor • Manufacturer failure to provide training. • Manufacturer failure to provide sufficient 	<ul style="list-style-type: none"> • Manufacturer Design Error • Inadequate Knowledge of the System • Inadequate Training

unrecoverable activation system which made the airplane dice with the rate of -33,000 ft/min close to the ground was the most probable cause of the accident.”	information on the system.	<ul style="list-style-type: none"> • Ergonomics
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Lessons Learned

As mentioned in the Lion Air Flight 610 accident, the MAX8 was an aircraft with an old airframe that was retrofitted with relatively enormous engines. This made the aircraft inherently have a nose up tendency and MCAS was designed to compensate for the instability and to maintain commonality with earlier generations of the 737. Shortly after takeoff, the left angle of attack sensor, which measures the angle of attack (angle between the chord line of the airfoil and the relative wind), malfunctioned and produced erroneous data. This led to the activation of the stick shaker, which indicates an impending stall. Once the flaps were fully retracted, it resulted in an automatic nose down trim, which pitches the nose of the aircraft toward the terrain. The pilot flying pulled back on the control column and applied electric trim up inputs. Shortly after, the automatic nose down trim reactivated on two more occasions and the crew performed similar actions to counteract the automatic deflection of the elevators.

While battling the aircraft, the captain contacted air traffic control and alerted them of their difficulties handling the aircraft and their intent to return. Three (3) minutes later, the automatic nose trim reactivated two more times. At the last activation, the crew was unable to recover, and the aircraft nose-dived at a rate of 33,000 feet per minute and

500 knots before it crashed into the terrain. All 157 occupants of the aircraft were killed upon impact.

Unlike the Lion Air crew, the Ethiopian Crew, correctly performed Boeing’s procedure to recover from MCAS activation. However, their failure to idle thrust, combined with the high workload, unsuccessful attempts to manually trim the aircraft, and subsequent return to normalcy of stabilizer trim led to the demise of all onboard.

Case Study 6: American Airlines Flight 965 (Short/Medium Haul) occurred on December 20, 1995

Background Information

American Airlines flight 965 was a regularly scheduled service from Miami International Airport to Alfonso Bonilla Aragon International Airport, in Cali, Colombia. While on approach, the crew made a series of errors that resulted in controlled flight in terrain (CFIT) into a mountain. Of the 163 passengers and crew, only four passengers survived.

Table 6 outlines the probable cause, contributing factors, and deficiencies in automation implementation for Case Study 6.

Table 7: American Airlines Flight 965 Accident Information

Probable Cause	Contributing Factors	Deficiencies in automation implementation
<ul style="list-style-type: none"> • “Flight crew’s failure to adequately plan and execute the approach to runway 19 at SKCL and their inadequate use of automation”. • “Failure of the flight crew to revert to basic radio navigation at the 	<ul style="list-style-type: none"> • Flight crew’s persistence to expedite the approach to maintain timeliness. • Flight crew’s attempt to avoid CFIT while the speedbrakes were still deployed. 	<ul style="list-style-type: none"> • Overreliance on Automation • Ergonomics • Degradation of manual flying skills

<p>time when the FMS-assisted navigation became confusing and demanded an excessive workload in a critical phase of the flight.</p> <ul style="list-style-type: none"> • Lack of situational awareness • Failure to discontinue the approach despite difficulty navigating the approach 	<ul style="list-style-type: none"> • “FMS logic that dropped all intermediate fixes from the display(s) in the event of execution of a direct routing. • “FMS generated navigational information that used a different naming convention from that published in navigational charts.’ 	
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Lessons Learned

The accident investigation determined that the crash was a direct result of pilot error and mismanagement of the approach. The crew failed to carefully plan and execute the approach. The Flight Management System (FMS) comprises of the Flight Management Computer, autopilot, navigation, and instrumentation to assist in managing flight data throughout all phases of flight. As the crew was navigating through the approach with the assistance of the FMS, they were unaware that they were navigating to the wrong fix. The FMS had removed all the intermediate fixes and utilized a naming system that differed from the official published navigational chart. The aircraft navigated to the Romeo fix as opposed to the Rozo fix, that was their intent. The Romeo NDB was near high terrain rather than Rozo that would lead toward the airport. The Ground Proximity Warning System (GPWS) alerted the crew of the impending crash. When the crew attempted to go-around, they neglected to retract the speedbrakes, which greatly reduced the aircraft’s ability to climb.

When the approach became challenging, confusing, and cumbersome, the crew should have immediately aborted and regrouped. The crew continued the approach in an attempt to maintain timeliness. The oversights, confusion, and hazardous attitudes led to the demise of many.

Case 7: Turkish Airlines Flight 1951 (Short/Medium Haul) occurred on February 25, 2009

Background Information

Turkish Airlines Flight 1951 was a regularly scheduled service from Istanbul Ataturk Airport to Amsterdam Schiphol Airport. The Boeing 737-800 crashed short of the runway on final approach. The crew botched the approach and the accident resulted in the death of all three pilots and five passengers.

Table 7 outlines the probable cause, contributing factors, and deficiencies in automation implementation for Case Study 7.

Table 8: Turkish Airlines Flight 1951 Accident Information

Probable Cause	Major Contributing Factors	Deficiencies in automation implementation
<ul style="list-style-type: none"> • The erroneous height produced by the malfunctioning left radio altimeter led to the autothrottle changing to retard flare mode which automatically reduced the thrust to idle 	<ul style="list-style-type: none"> • The crew's failure to identify the change in A/T mode. • The crew's failure to effectively monitor airspeed on final approach. • The crew's delay and incorrect performance of stall recovery. 	<ul style="list-style-type: none"> • Ergonomics • Inadequate Knowledge of the System • Degradation of Manual Flying Skills

Lessons Learned

The accident investigation determined that the failure of the radio altimeter led to the autothrottle changing modes while on final approach. The radio altimeter measures altitude above terrain. The closer to the ground, the more accurate its readings are. The captain's radio altimeter failed and displayed an altitude of -8 feet. This led to the autothrottle changing from flight idle to retard mode. The retard mode automatically decreases thrust shortly before the runway height in preparation for a flare for landing. The erroneous readings from the radio altimeter led the autothrottle to think that the aircraft was preparing for landing. The crew manually increased thrust to maintain an approach speed, but the retard mode was still engaged, so the autothrottle retarded the thrust again.

The crew failed to make adjustments to ensure the thrust setting was correct and did not notice that the aircraft began to significantly slow down and fall below the glide slope. The stick shaker activated warning of an impending stall. The crew did not in a timely fashion add full thrust which resulted in the aircraft not being able to recover from the stall. While on final approach, airspeed and altitude are especially critical. The crew failed to monitor the parameter and also failed to execute the go around correctly.

Case 8: Emirates Airlines Flight 521 (Short/Medium Haul) occurred on August 3, 2016

Background Information

Emirates Airlines Flight 521 was a regularly scheduled flight from Thiruvananthapuram, India with nonstop service to Dubai, United Arab Emirates. The

Boeing 777 crashed while attempting a go around. All the passengers and crew onboard survived the accident, but unfortunately one of the first responders died as a result.

Table 8 outlines the probable cause, contributing factors, and deficiencies in automation implementation for Case Study 8.

Table 9: Emirates Airlines Flight 521 Accident Information

Probable Cause	Major Contributing Factors	Deficiencies in automation implementation
<ul style="list-style-type: none"> • “During the attempted go-around, except for the last three seconds prior to impact, both engines thrust levers, and therefore engine thrust, remained at idle. Consequently, the Aircraft’s energy state was insufficient to sustain flight”. • Flight crew’s inability to effectively scan and monitor the primary flight instrumentation parameters. • Flight crew’s unawareness that the A/T had not responded to the TO/GA position after the commander pushed the TO/GA switch. • Flight crew’s failure to increase engine thrust to successfully initiate a go-around 	<ul style="list-style-type: none"> • The crew had a significant tailwind during landing. • The crew’s lack of training using A/T to initiate a go-around • The crew’s failure to realize that the main landing gear had touched the ground, which resulted in the TO/GA switches becoming inoperable. • The crew’s reliance on automation which is supported by the Operator’s manual which requires the use of A/T for all phases of flight. • The aircraft did not alert the crew of the inconsistency between aircraft configuration and thrust that is required for go-around. 	<ul style="list-style-type: none"> • Overreliance on automation • Inadequate Knowledge of the System • Degradation of Manual Flying Skills • Ergonomics

Lessons Learned

The crew of EK521 experienced challenging weather conditions while they were attempting a tailwind landing. During the final phases of landing, the aircraft was unable to land within the touchdown zone as the crew flared early due to a shift in wind direction. As the commander decided to initiate a go around, he pushed the TO/GA buttons on the throttle quadrant with the expectation that the autothrottle would automatically advance and monitor engine thrust throughout the maneuver. Under the relatively high workload, the crew had not realized that the aircraft's main landing gear had contacted the ground, which automatically impedes the autothrottle. The thrust remained at idle throughout the go around attempt. Hence, the aircraft did not have enough airspeed to climb.

When executing a missed approach, the most critical step of the sequence is to advance the throttles to gain airspeed and then verify that the thrust is set. Instead of manually advancing the throttle, the crew relied on automation to perform the action. This overreliance was customary in the company and the operator's manual required pilots to use the autothrottle throughout all phases of flight. However, the crew was not aware that once the landing gear touched down, the TO/GA would not respond. This coupled with the crew's failure to monitor thrust setting and the instrumentation's inability to alert the crew that the TO/GA was inhibited were also critical contributing factors.

Case Study Summary

The case studies show several categories of recurring issues that fall into the six deficiencies. Figure 2 reflects the magnitude across the case studies. Please note the case

studies reflect a plethora of aircraft, locations, trip lengths, and other variables to provide an exhaustive and thorough assessment.

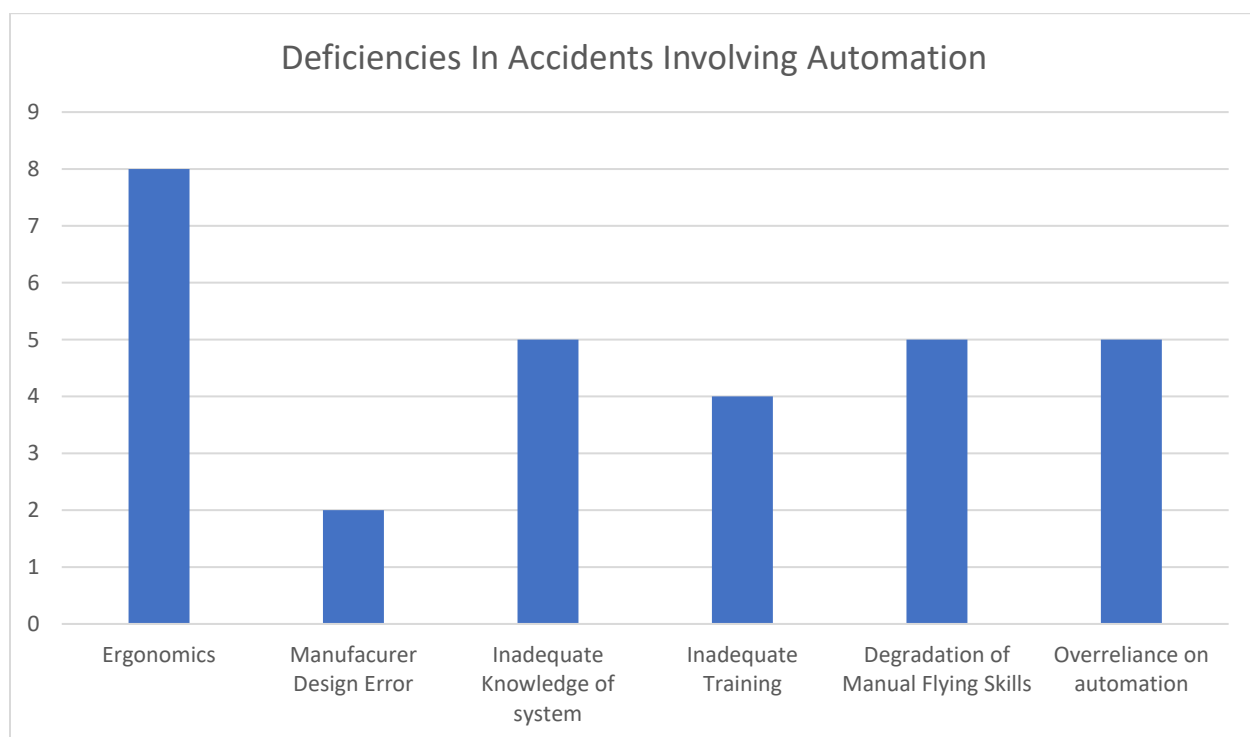


Figure 2: Deficiencies in Accidents Involving Automation.

Notably from the findings, ergonomics was an area that was deficient in each accident. The ergonomic issue that was most prevalent was that critical data was not readily available or easily accessible. That, in addition to the tendency for crew to often experience sensory overload during emergencies and high workload situations, exacerbates the ergonomic deficiency. The overreliance on automation often led to a degradation of manual flying skills. Crews can become so complacent and reliant on automation, that their manual flying skills are diminished to the point where they are unable to perform rudimentary flight maneuvers manually. Pilots in many of these accidents were using automated systems that they did not fully understand and/or were

trained on how to use. At times, manufacturers designed automated systems that were flawed from conception.

The accidents chosen as case studies highlight a plethora of issues involving automation. The deficiencies identified and analyzed must be addressed before they continue to contribute to accidents. “It is feasible to automate a wide variety of piloting tasks, but the decision to incorporate automation should be determined by the impact on overall system performance, not the availability of convenient technologies” (Harris, 1995, p.181). Proactively tackling these issues and mitigating is paramount to disrupt the chain of accidents.

CHAPTER 5 – SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary of Research

Aviation is one of the most heavily scrutinized industries on the planet. Despite its impeccable safety record, comparative to other modes of transportation, even the slightest incident becomes a major topic of discussion. It is far more safe than driving and other modes of transportation, but when something goes awry, a single accident can result in the death of hundreds of people.

Automation provides major benefits such as enhanced safety, improved economics, and arguably reduced workloads. Still as shown in the literature and case study analyses, it can lead to complacency and overreliance on automation, automation surprise, and clumsy manufacturer designs. Safety in aviation is primarily and traditionally reactive. The findings from this research can contribute proactively to mitigating some risks that are already beginning to present themselves as hazards to aviation safety.

Recommendations

Based on literature review, investigation, and findings, the following are recommendations for methods and strategies to improve the implementation of automation in aviation:

1. Reduce overreliance on automation by encouraging the use of manual flying skills when applicable.

In many of the accidents, there was an evident overreliance on automation, that often resulted in the degradation of manual flying skills. Manufacturers and operators should encourage pilots to manually fly the aircraft more often. These entities should designate a system of parameters that outlines when manual flight would be favorable. On a beautiful day with no weather issues, a relatively easy approach or departure, and a well-rested crew, pilots should be motivated to hand fly the departure and/or approach. There are currently no international standards on how much manual flying would be beneficial to aviation safety. Airlines and manufacturers should require their pilots to fly the aircraft manually for a specific percentage of time to ensure they maintain their manual flying skills.

2. Ensure that crews are competently educated and trained on automated systems.

There is a very distinct difference between education and training. An individual can be knowledgeable of a system but unaware of how to use it. Vice versa, an individual can be trained to use a system, but not be knowledgeable of its capabilities and limitations. Utilizing an automated system without being well informed of its span of control is evidently a recipe for disaster. Aircraft manufacturers must clearly, concisely, and thoroughly explain automated systems that are integral parts of the aircraft's operation. In addition, their training manuals must adequately describe procedures for use of the system under a plethora of scenarios. More importantly, it must entirely outline how to disable the system if necessary, and how to conduct flight operations when it is not engaged.

The manufacturer's syllabi and training outline must exhaustively describe the system and its practical uses. The aviation regulatory agency must vet these documents to

ensure that they adequately inform the user. Finally, the operator must make certain that those documents are adhered to and that pilots are competently knowledgeable of the system and its usage.

3. Increase the Collaboration during the design phase with both the end user and regulatory agency.

Increasing collaboration during the design phase allows the end-user, as well as regulators, to intervene earlier in the certification process of the aircraft. When these stakeholders are involved, they can offer real-world information that test pilots and engineers are not cognizant. This information is valuable and presents more complete, thorough assumptions of how pilots will respond to a system, as opposed to the manufacturer's assumptions alone. They can also contribute to a system of checks and balances, so that the manufacturer's team is not solely responsible for how a system operates.

4. Strengthen the utilization of the Human Centered Approach to systems integration.

A human centered approach to design and integration is an asset and not a liability. Humans are ultimately responsible for the safety of flight and all systems should be designed and integrated with the human as the priority. As mentioned in the literature section automation should be applied based on the needed function, not the availability of the technology. Many automated systems are introduced and designed with a view of humans as error prone. However, while human error is by far the most prevalent cause of accidents, humans also have the unique ability to adapt and overcome. Their role in the cockpit is most vital and the span of control belongs to them. Even when

automated systems are in use, airmen should be able to easily retrieve control from the system.

5. Improve Human Factors and Ergonomics studies for instrumentation to improve ease of use for pilots.

Often enough, the focus of aviation improvement is predominantly geared toward technical upgrades as opposed to psychological research and enhancements. More attention to detail must be placed on improving the relationship between humans and technology, primarily through human factors and ergonomics engineering.

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