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Development and Initial Evaluation of a Reinforced Cue Detection Model to Assess Situation Awareness in Commercial Aircraft Cockpits

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DEVELOPMENT AND INITIAL EVALUATION OF A REINFORCED CUE DETECTION MODEL TO ASSESS SITUATION AWARENESS IN COMMERCIAL AIRCRAFT COCKPITS

by

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ABSTRACT

DEVELOPMENT AND INITIAL EVALUATION OF A REINFORCED CUE DETECTION MODEL TO ASSESS SITUATION AWARENESS IN COMMERCIAL AIRCRAFT COCKPITS

Aysen K. Taylor
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Commercial transport aircraft of today vary greatly from early aircraft with regards to how the aircraft are controlled and the feedback provided from the machine to the human operator. Over time, as avionics systems became more automated, pilots had less direct control over their aircraft. Much research exists in the literature about automation issues, and several major accidents over the last twenty years spurred interest about how to maintain the benefits of automation while improving the overall human-machine interaction as the pilot is considered the last line of defense.

An important reason for maintaining or even improving overall pilot situation awareness is that the resulting improved situation awareness can assist the human pilot in rapidly solving unanticipated, novel problems for which no computer logic has been written. It is essential for the pilots to obtain cues to make appropriate decisions under time pressure. However, to date, no studies have directly examined the approach of reinforcing the relevant flight and automation status cues during flight to increase the pilot's situation awareness when a failure unexpectedly occurs.

Attitudes toward, and issues with automated systems from the pilots' perspectives were studied using a survey completed by commercial air transport pilots. The survey results were used as the framework for designing a simulation analysis, using a small group of commercial airline pilots, to assess the benefits of a reinforced cue detection model. A phenomenological assessment of open ended questions asked at the conclusion of each simulation showed, subject to the limits of the relatively small sample size, that the "Reinforced Cue Detection Model" implemented in the form of asking the pilots situational awareness questions during the flight, can help to reduce pilot's complacency, increase situation awareness, and make automation a better team member. Pilots also found reinforced cues to be helpful in the event of unexpected system failure. The current research supports literature regarding pilots' opinions towards automated systems and indicates that there are benefits to be gained from improving the pilot automation integration. The Reinforced Cue Detection Model, albeit tested on a small sample size, supported improvement of the pilots' situation awareness.

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The most beautiful diamond is just a rock without a light reflecting its beauty…

Be the light, not the rock…

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NOMENCLATURE

ADM Aeronautical Decision Making

ADS-B Automatic Dependent Surveillance-Broadcast

AIC Automation Induced Complacency

ASAP Aviation Safety Action Program

ASRS Aviation Safety Reporting System

ATP Airline Transport Pilot

CAB Civil Aeronautics Board

CAST Commercial Aviation Safety Team

CDU Control Display Unit

CRM Crew Resource Management

EASA European Aviation Safety Agency

FAA Federal Aviation Administration

FCC Flight Control Computer

FDM Flight Data Monitoring

FMC Flight Management Computer

FOQA Flight Operational Quality Assurance

HART Human-Automation Relationship Taxonomy

HI-MI Human Intelligence-Machine Intelligence

IAN Integrated Approach Navigation

IRB Institutional Review Board

INS Inertial Reference System

LNAV Lateral Navigation

LOSA Line Operations Safety Audits

MJCA Multivariate Joint Correspondence Analysis

ND Navigation Display

NDM Naturalistic Decision Making

NTSB National Transportation Safety Board

ODU Old Dominion University

PARC Performance-Based Operations Aviation Rulemaking Committee

PFD Primary Flight Display

QRH Quick Reference Handbook

RCD Reinforced Cue Detection

RNP Required Navigation Performance

RPD *Recognition Primed Decision*

SA Situation Awareness

SOP Standard Operating Procedure

TO/GA Take-off/go around

VNAV Vertical Navigation

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CHAPTER I

INTRODUCTION

Pilots in early aviation continuously controlled the flight path of their aircraft by moving the yoke, rudder pedals, and throttles. This placed significant physical demands on pilots, but they benefitted from constant feedback through the controls exerting forces on their hands and feet. As aircraft designs and engine technology improved, pilots flew new planes with greater range and service ceilings. This increased flight times and the need for mechanical assistance to the pilot in order to maintain the desired flight path. Early automated systems helped to maintain a given heading and altitude, which not only reduced pilot fatigue but also reduced feedback from machine to human (Popular Science, 1930). The First and Second World Wars spurred rapid advances in airplane technology, and this included advances in autopilot and navigation systems (Clarke, 2004; Trueman, 2019). These allowed airplanes to fly more precisely when flying to targets. Ground based navigation aids using radio beacons were developed as well as the Inertial Navigation System (INS), and these were later tied to autopilot systems (Cutler, 2017). Aircraft automation improved operational precision and efficiency with each new generation.

The unrecognized trade off, however, was loss of aircraft state feedback to pilots as more of the flight path management duties were handled by the autopilot. Inevitably, pilots had less direct control over their aircraft. Edwards (1977) warned of potential problems with automated cockpits. He stated that modern cockpit technology requires pilots to use their psychomotor skills rarely, and they are mostly processing information and controlling automated systems with buttons and switches. Edwards stated that the development of cockpit automation was centered on engineering and economic study, rather than a systematic doctrine considering the role of humans in automated systems. His concerns have only been amplified over time. Exponential growth in computer technology in the 1960s and 1970s laid the groundwork for computerization of cockpits. By the late 1980s and early 1990s, very advanced flight management computers (FMC) were commonplace in commercial transport aircraft. Current generation commercial aircraft transports have 80% of their functionality enabled by software whereas aircraft from the 1960s had 10% (Marburger & Kvamme, 2007). These systems included the Flight Management System (FMS), navigation database, and position-determining sensors, such as INS, GPS, VOR, DME, and auto throttle controls. These were often developed in an ad hoc fashion without consideration of how sub-components interact and with little consideration for the principles of systems engineering (Chialastri, 2012). Degani and Wiener (1997) studied the airline cockpit as a complex human-machine system and discussed the impact of operational management of the organization on it. Airline organizations have developed detailed, voluminous procedures that pilots follow in order to carry out tasks based on operational management's expectations. The intent of these procedures has been to set forth a standardized means of achieving common flight tasks in a logical and efficient manner. Degani and Wiener's study found that in spite of this organizational doctrine, flight procedures carried out on a daily basis varied greatly in some cases from the mandates of the organization. They found fault in the way the procedures were developed but less so in pilots' actions. Standard operating procedures (SOP) have an important role in the cockpit. Overreliance on SOP's, however, can reduce the role of the human operator and thus reduce the benefit of one of the most valuable assets in the system; human judgment. They implored systems designers to be aware of these issues. Degani and Wiener's findings have become more relevant as the role of pilots has shifted more from that of direct controller to that of monitor of automated flight systems.

Accident and incident reports since early 1990s cite more problems with the human-machine interaction in these advanced aircraft and terms such as "automation surprises" (Sarter, Woods, & Billings, 1997) joined the aviation vernacular. Calls were made for changes to training protocols to better prepare pilots to use advanced automated systems. Cockpit automation had been given more autonomy and authority but not designed in such a way to provide adequate and unambiguous feedback to the human operator about intended actions relative to aircraft state. More or different training has failed to fully compensate for accidents related to human-automation interaction deficiencies. Accidents that cite pilot error do not always acknowledge that automated systems sometimes do not clearly relate their actions to the human crew. Humans and machines will never be infallible, but improved designs of cockpit automation systems can better reinforce situation awareness in pilot-automation interactions.

Theoretical and Applied Formulation

Major Commercial Aircraft Manufacturers

There are two primary manufacturers of commercial transport aircraft today. Consolidation in the US market over the last 20 years left Boeing as the primary manufacturer of commercial aircraft in North America. In Europe, the birth of Airbus in the early 1970s brought a strong competitor to Boeing. Automation related accidents and incidents have affected both manufacturers. Though each company uses automation in their aircraft, their design philosophies vary to such an extent that an analysis of the human-machine interface in each company's aircraft requires separate discussions in some cases. In both current designs, automation can override or resist the pilot at the outer limits of the flight envelope. Airbus has a marginally greater number of these override systems and they activate slightly sooner. Boeing and Airbus systems will both throttle back in an overspeed condition. The Boeing yoke uses a stick shaker when a stall is imminent and will push forward automatically in the event of a stall. The Airbus sidestick does not do this and when operating in normal law with no system failures, it will not let the pilot bring the plane into a stall condition. It does provide auditory alarms in a stall event that may occur after system failures. Airbus was an early adopter of fly-by-wire technology that removed the pilot from direct control of the aircraft and, also created a greater level of automation authority in the form of flight envelope protections. This arrangement is designed to limit pilot input during manual control if programmed rules regarding maximum pitch and roll attitude are violated by the pilot's actions. Significantly, in the event of several systems failures, most fly-by-wire protections are lost after the system goes into a mode known as alternate law. The hard control limits of the computer are removed, and this may create confusion if the pilot does not know alternate law has been activated. The Airbus sidesticks do not move when the autopilot is in control and hence provide less feedback than the Boeing design. They are also not slaved together and thus one pilot cannot know what inputs the other pilot is providing during manual flight. The Boeing yokes always move when automation is flying the plane or if one pilot is providing manual control input. In the Airbus design, if one pilot pushes the sidestick forward and the other pilot pulls the sidestick backwards, the computer takes the average of the two inputs. This scenario would be impossible in a Boeing plane as the yokes always move in tandem. The Airbus design has hard limits on pilot inputs that exceed airframe G limits. Generally, Boeing's approach to design is more pilot-centered. Boeing computer G limits are less restrictive in that it will let a pilot "bend" the plane but not break it as might be required to avoid hitting a mountain in an emergency.

Regulatory Environment

Regulators and operators of commercial aircraft have many specific requirements regarding the procedures and performance standards for the human operators of cockpit automation but much less so regarding the performance and design expectations of the automation itself. A Federal Aviation Administration (FAA) report published in 1996 (FAA Report, 1996) cited problems with automation designs, saying they did not reflect a human centered approach. The report also stated that existing regulations and guidance from the FAA to the manufacturers did not provide criteria that encouraged or mandated companies to adapt a flight deck design process that focuses on human performance considerations. Only workload considerations were formally addressed under the then current rules, and the FAA had no criteria or methods needed to conduct an evaluation of human performance issues associated with the design of automated cockpit systems. In reality, regulatory officials evaluate flight deck design late in the development cycle, typically during the testing phase, and it was often too late to make desirable design changes recommended during the evaluation. Pilot surveys published in 1995 and 1999 noted problems with governance relating to automated cockpits (Hutchins, Holder, & Hayward, 1999; Tenney, Rogers, & Pew, 1995). Pilots of the Airbus A320 expressed surprise that their plane did not notify them or intervene automatically when their aircraft descended below 10,000 feet at a speed higher than 250 knots. This might occur when the pilot selects airspeed higher than 250 knots and forgets to adjust this setting later. FAA regulation §91.117 specifies this speed rule, but automation is not required to comply. Indeed, the automated systems in commercial transport aircraft are not designed to conform to the official aviation rules of any particular country and thus fail to warn the pilot or intervene otherwise (Sarter & Woods, 1997). FAA regulations regarding flight guidance systems were updated in 2006 and are covered in §25.1329. Fourteen specific rules are laid out in the regulation and include requirements such as the need to have an autopilot disengagement control on the control yoke or equivalent for each pilot. Subsection (i) includes specific design requirements for automation as follows:

"The flight guidance system functions, controls, indications, and alerts must be designed to minimize flight crew errors and confusion concerning the behavior and operation of the flight guidance system. Means must be provided to indicate the current mode of operation, including any armed modes, transitions, and reversions. Selector switch position is not an acceptable means of indication. The controls and indications must be grouped and presented in a logical and consistent manner. The indications must be visible to each pilot under all expected lighting conditions" (FAA Regulation §25.1329). Line operation reports indicate this regulation does not adequately address the problems with human-machine collaboration in the cockpit (Geiselman, Johnson, & Buck, 2013).

Regulations for Crew

Crew Resource Management (CRM) was introduced decades ago in response to accident reports citing poor collaboration among pilot team members in the cockpit (Taylor, 2018). On December 28, 1978, United Airlines Flight 173 crashed 6 miles short of the runway. The crew had been circling the airport for one hour while they sorted out a landing gear anomaly. The First Officer and Flight Engineer repeatedly warned the Captain that their fuel was running low, but he was preoccupied with the landing gear warnings and the plane ran out of fuel. The National Transportation Safety Board (NTSB) assigned an aviation psychologist to the investigation, and his contribution to their report was the impetus for the creation of CRM (*Aircraft Accident Report* AAR-79-7, 1979). In 1998, the Commercial Aviation Safety Team (CAST) was formed with representatives from government organizations, industry leaders, and aerospace companies with two objectives: reduce the US commercial aviation fatal accident rate by 80 percent over a 10 year period ending in 2007 and work with airlines and international aviation organizations to reduce the global commercial aviation fatal accident rate.

Parasuraman and Miller (2004) stated automation systems should effectively communicate its intentions and limitations to the humans monitoring them. This is a basic tenet of CRM. In 2010, the FAA chartered the Performance-Based Operations Aviation Rulemaking Committee (PARC), which provides recommendations to the FAA to help globally harmonize and standardize technology in aviation. PARC and CAST later jointly formed the Flight Deck Automation Working Group. This group was charged with reviewing the operational use and training for flight path management systems in commercial transport aircraft. They also analyzed accident and incident data and develop recommended guidelines for operational use, training, design, policy, and procedures relating to cockpit automation. More recently, the aviation community has voiced their desire for cockpit automation to conform to the CRM principles pilots are expected to follow (Geiselman et al., 2013, Taylor; 2018).

Research Purpose and Objectives

This research aims to understand how pilots perceive and interact with current cockpit automation systems. Under the current CRM rules pilots must comply with many rules that automated systems do not need to follow. The initial phase of this research was to understand how pilots view automated systems when they are working with them. A survey was conducted in which questions included possible changes in the cockpit and how those changes could improve pilots' interaction with automated systems. The purpose of this was to identify commercial pilots' perceptions and expectations of current cockpit automation systems, and with this consideration, recommend guidance for the design of future cockpit automation systems. To explain these phenomena, an experiment with a limited number of participants was included in this research to determine if some minor changes can make a difference in pilots' situational awareness when they face failures during their flights. The goal of this prototype experiment was to demonstrate that without a total redesign, it is possible to make small changes to increase the pilots' vigilance and improve their situational awareness.

Statement of the Problem

Although the various shareholders view the issue through their own perspectives, there is a broad consensus among academics, regulators, designers, and operators of commercial transport aircraft that current cockpit automation systems are deficient in certain areas. While hundreds of academic papers, journal articles, books, conference papers, study group briefings, FAA studies, NTSB accident reports and operator protocols have been published since the 1980s, a general pattern of concern can be seen throughout this large set of publications. Their conclusions are supported by a vast amount of data gathered through various efforts to monitor flight safety. Some of these include Line Operations Safety Audits (LOSA), the Aviation Safety Action Program (ASAP), the Flight Operational Quality Assurance (FOQA)/Flight Data Monitoring (FDM) program, and the U.S. National Aeronautics and Space Administration's Aviation Safety Reporting System (ASRS). The ASRS database contains over 900,000 voluntary narrative reports regarding aviation safety incidents reported by pilots, mechanics, Air Traffic Control (ATC) personnel, and cabin crew. Several joint study ventures or working groups comprising most and often all major stakeholders arrive at similar conclusions regarding problems with cockpit automation. The core issues can be summarized as follows.

- Humans are poor monitors of highly reliable automated systems (Parasuraman, Molloy, & Singh, 1993)
- Pilot error is often the consequence of deeper issues with automation design (Dismukes, Berman, & Loukopoulos, 2007)
- Automation tends to degrade the manual flying skills of pilots (Gillen, 2008)
- The human is needed to maintain higher safety levels (Norman, 1990)
- More or different training is the most common stakeholder reaction to acknowledged problems with cockpit automation (Casner, 2003; *Pilot Training Compass*, 2013; Jones, 2011)
- Autopilot mode awareness confusion is a common factor in automation related accidents (Sumwalt, Morrison, Watson, & Taube, 1997)
- Future development of cockpit automation should take a human centered approach (Antonovich, 2008)
- The current regulatory model governing cockpit automation/pilot interaction is outdated, ad hoc, fragmented, and may inhibit advances needed to improve safety (Harris, 2011)
- Automation is not required to adhere to CRM rules (Taylor, 2018)

Even in light of these issues, pilots are considered the last line of defense when it comes to safety in commercial aviation (FAA, Advisory Circular, 2004), but they are required to interact with opaque complex automated components and sub-components whose interactions and interdependences are difficult or impossible for humans to comprehend (Dekker, Cilliers &

Hofmeyr, 2011). At the same time, automation has been designed with greater autonomy and authority, reducing the pilot's understanding of the current and intended aircraft state and negatively impacting the pilot's ability to intervene when automation fails and suddenly returns full control to the pilot. Cockpit automation has not been burdened correspondingly with the responsibility or liability that comes with being in charge. This has forced a reassessment of what is meant by pilot error.

Current designs of pilot-automation interaction for ensuring efficient and safe operation of highly automated aircraft have some deficiencies. Building an improved model of pilot-automation interaction in commercial transport is essential. It can be best realized through development of designs in which the automation better communicates its current and intended actions and alerts the pilot before it has reached its design limits or fails. A better model would contribute to the elimination or reduction of "automation surprises" by providing effective feedback from automation to the human operators. Additionally, it should not abruptly transfer full manual control to the pilot while providing little or no guidance to the pilot such as was seen and cited in the accident report for the Air France 447 crash in 2009 (*BEA Final Report AF447*, 2012). Current cockpit automation systems cannot operate without a human component. Automation designs are focused mostly on nominal conditions and may disengage when non-nominal conditions manifest. Several recent accidents indicate that when system failures occur, automation gives full authority to the pilots without providing aid regarding the last status of the aircraft. Most phases of flight are in a high state of autonomous operation, and this reduces the pilot's ability to intervene and take full control of the aircraft when needed. A wholesale redesign of automated cockpits is not expected in the near future but an incremental improvement may be possible to address interaction issues in the short and mid term. How can pilot-automation interaction be redesigned to provide better feedback to the pilot to increase situation awareness and mitigate the risk of accidents in emergency situations is becoming a critical question.

Pilots are the end users of these highly automated systems, and their input is usually not taken into consideration during the design phase. The aircraft industry and regulators often take a reactive approach after an accident occurs as seen in the Air Inter crash in 1992 and more recently in the Lion Air 2018 (Official Report of Air Inter Crash, 1993, Ostrower, 2018). Seeking pilots input regarding these systems and then making prototypes for validation is essential for the success of the industry as it works towards the greater automated environment known as NextGen and as air travel expands dramatically over the next twenty years. Pilots are rarely forced to suddenly take full manual control of their transport aircraft, but, if the enviable record of aviation safety is to be further improved, pilots need automated systems that behave as a better partner than what is currently available.

Purpose, Scope and Depth of the Research

This research intended to improve pilots' situational awareness under time constrained critical failure situations. Industry and pilots are already aware of them *being out of the loop* in normal flight conditions, especially on long haul flights, but there has not been much study done to reinforce or improve situation awareness. With that goal in mind, this research aims to help pilots stay in the loop by improving their vigilance using a proposed Reinforced Cue Detection (RCD) model.

For the survey phase of the research, the Qualtrics™ survey application allowed the survey to reach multinational regions via the internet, and made it possible to include a variety of pilots from different geographical regions. Seventy-seven pilots were recruited from North and South

America, Europe, and West Asia. Each held ATP licenses for various types of commercial transport aircraft from all the leading manufacturers. The goal of this research was to understand the pilots' perspectives of cockpit automation from a wide demographic range.

For the experimental phase of the research, a small-scale application of the Reinforced Cue Detection Model over naturalistic decision making was applied in a flight simulator to assess the effect of reinforcing cues on situation awareness. Due to many limitations explained later in the paper, the experiment did not include a sufficient sample size to allow generalization of the results, but this effort indicated the initial results justify a larger scale research effort that will allow quantitative analysis.

Significance of the Study

The survey included seventy-seven airline pilots who interact with automated systems in their daily work. The respondents were from a wide geography including Europe, West Asia, and North and South America. Findings of this research should be taken into the consideration for the future development of aircraft transport systems. This survey also solicited pilots' input regarding if any subtle changes can help improve their interaction in the human-automation collaborative systems such as applying CRM rules for the conduct of automated systems.

This study introduces a new approach whereby the survey was conducted, and the results were used to design a small preliminary flight simulation experiment to test the proposition that asking reinforcing cue questions over the course of a flight regarding their flight status could enhance pilot vigilance and increase situation awareness. Current cockpit automation designs make it difficult for pilots to intervene quickly when automation reaches its design limits or fails suddenly returning full aircraft control back to the pilot. Several case studies of different accidents show there is no transfer of last status from the automation before it disengages itself. Pilots are the last line of the defense for safety (Li, 2014), but the operation of automation can be opaque, which leads to the paradigm of "pilots not in the loop." This research proposes a new Reinforced Cue Detection Model to increase situation awareness over current naturalistic decision-making models.

Expected Research Contribution

Currently many engineering systems are designed by engineers with little input from the end users. While aircraft makers often use niche test pilots with highly atypical backgrounds for feedback and validation, the airline industry is lowering the bar on entry level training programs. An air carrier announced a training cycle for new pilots that is recruiting trainees with no flight experience whatsoever (Rizzo, 2017). A new generation of pilots is coming onboard that will have less manual flying experience than any generation of pilots that came before. Cockpit automation is highly reliable, but during a catastrophic failure pilots face many different challenges. These challenges can be expected only to increase with the new NextGen air traffic control system, which will significantly reduce separation distance and allow for simultaneous landings on parallel runways (NextGen portfolio, 2017). Line pilot opinions revealed in the survey portion of this research can guide further research projects toward improving the human-automation teaming and potentially justify small changes to current designs to improve pilot vigilance and reduce errors commonly cited in accident reports such as mode confusion.

In the survey, pilot input was obtained across five domains to better understand their perceptions of interacting with automation and if some changes might help reduce interface problems that have often been mentioned in the literature. Also, a prototype flight simulator experiment indicated some changes in the cockpit environment may be helpful by incorporating reinforcing cue questions to increase situation awareness. Pilots being out of the loop is not a new phenomenon, but there are a few efforts taken to address this issue. When failure occurs, the first response is to blame pilot error and require more training. After an accident, the common reaction from industry and regulators is to focus on human errors. An example for this situation was an accident that occurred under a cross wind landing in Poland (Report, A320-211, 1994). While the initial report focused on human error, after the Lufthansa pilot association conducted their investigation, it was revealed that Airbus design philosophy which limited the pilots' ability to intervene manually by deploying spoilers and reverse thrust was a contributing factor (Beveren, 1995).

While interviewing pilots who fly Boeing aircraft during the simulation experiments of this research, some pilots stated that recent Boeing models have a feature whereby if the pilot does not make any adjustments to the autopilot settings after a certain amount of time, the system will make a sound and the pilot only has to make some adjustment to the flight management system to satisfy the automation's requirement to remain engaged. They said, these adjustments required no cognitive work and were viewed by them as Pavlovian. This feature shows that Boeing is aware of the phenomenon of pilots being out of the loop, and they are taking some initiatives to address this issue. However, Boeing's approach requires little cognitive activity.

With this proposed model incorporating reinforcing cue questions, pilots' naturalistic decision-making process may improve their situation awareness. Thus, the proposed RCD model could lead to a larger scale research effort with benefits to the aircraft industry's design of cockpit automation systems.

Expected Research Limitation

This research is comprised of two components; a survey and a phenomenological approach (which explained in the methodology section) to evaluate flight simulator experiments. The survey tool was written in English, and some survey respondents used English as a second language. Their response for some of the questions may have been impacted by this fact. The survey was conducted following IRB regulations. Although it was clearly defined to the pilots that their information was anonymous, some may have not answered questions relating to their company's policies in a forthright manner.

The simulator was a proof of concept experiment that indicates a larger study would be worthy of the greater resources required to carry it out. The cost of paying pilot participants was the main constraint limiting the scope of the study. Material limitations in the flight simulator research included, no first officer, no air traffic control, and lack of a companies' dispatch system to provide guidance to test subject pilots.

Research Overview

The survey was designed to understand the pilots' perceptions of cockpit automated systems in which they use on their routine flights. As part of the consistency, only ATP license holding pilots were included. The survey measured pilots' perception about cockpit automation along five domains:

- Reliance/Trust in Automated Systems
- Monitoring Automated Systems
- Governance and Policies about Cockpit Automation and its use
- Training and Performance for Automated Systems

- Interface used by Automated Systems

Survey analysis results were used to define flight test scenarios used in the simulation.

A PC based flight simulation program, Prepare3D, was used to conduct simulated flights with the ATP test subject pilots to test the theory that reinforcing cues would increase their vigilance. Pilots were tested with and without the reinforced cues, and all their flights were recorded. At the end of the test session, their verbal inputs were solicited in a short interview to get their opinions if they felt reinforced cues made changes on their mental model, automation complacency, and vigilance.

CHAPTER II

LITERATURE REVIEW

A review and synopsis of the literature relating to cockpit automation provides a basis for understanding the evolution of cockpit automation and the major benefits and problems seen with each major revision. Airplane technology has mirrored general technological advances in society while also demonstrating rapid periods of development in times of war. The importance of aviation necessitated the establishment of regulatory bodies, accident investigative arms, airline companies, and personnel to design, build, fly, manage, and maintain hundreds and later thousands of aircraft. Many socio-technical components have also played important roles in the development, regulation, and operation of a commercial air transport system. Boeing and Airbus are the two primary makers of commercial airliners, and their approaches will be compared and contrasted. Crew Resource Management was developed to address various flight crew factors impacting flight safety. The role of the pilot and the level to which pilots control their aircrafts has evolved over time. The trend has been for less direct control although with no reduction in cognitive responsibility for the human operator. Several key publications from the existing body of research are presented, and research areas lacking sufficient study are discussed in support of this research.

History of Automation in Aviation

Early aircraft systems included a pilot who moved the controls, which changed the control surface positions, thus changing airflow and causing the plane to exhibit a response through flight path changes. This was a purely mechanical arrangement. Later early autopilot systems were introduced to assist the pilot in maintaining headings and altitude targets. This started the path toward reducing the pilot's direct control over the aircraft and placed a feedback barrier between the plane and its operator. A new danger was born as the autopilot might fly the plane into a mountain without human intervention. Later, controllers installed near the control surfaces were used to move them without pilot input to maintain more parameters of flight. Last, flight management computers were introduced that required the pilots to program waypoints along the planned flight path and enter performance data such as the amount of fuel loaded, local barometric pressure readings, runway length, and wind, etc. Flight management computers were later tied to auto throttle controls. With each new layer of automation the human operator lost more direct control of the plane and had more difficulties getting and interpreting feedback from the automation (Manningham, 1997).

Regulatory History

The US Army established a flying school near San Diego in 1912 and thus initiated the first organized oversight of aviation (Peck, 2006). After World War I, Congress started an innovative postal program known as the Contract Air Mail Act of 1925 that would later serve as a model for commercial air operations (Baltazar, 2013). President Franklin D. Roosevelt created the Civil Aeronautics Board (CAB) in 1940 and tasked it with safety rule making, investigation of accidents, and outlining the economic framework of airline operations. The CAB was later replaced by the FAA and a separate investigative arm, the National Transportation Safety Board (NTSB), was created to determine accident causation (FAA, 2015). The NTSB makes recommendations to the FAA regarding how to improve safety, but rulemaking has been solely in the domain of the FAA. The FAA also oversees a certification process for new aircraft models and related subcomponents to ensure safety. The 1978 Airline Deregulation Act was passed by

Congress to promote competitive market forces in the industry (Cong. Rec., 1978) and resulted in low cost carriers entering the market to challenge the legacy carriers such as American, United, Continental, Northwest, US Air, and Delta.

Aeronautical Decision Making and Risk Management

The FAA defines aeronautical decision-making (ADM) as the "Systematic approach to the mental process used by aircraft pilots to consistently determine the best course of action in response to a given set of circumstances" (Aeronautical Decision Making, 1991). The FAA places ADM in the broader context of risk management. Pilots are taught a simple framework to manage risk known as the 3-P model shown in Figure 1, taken from FAA Pamphlet (FAA Aeronautical Decision Making, 2008)

Perceive: the given set of circumstances for your flight
Process: by evaluating their impact on flight safety
Perform: by implementing the best course of action

Figure 1. FAA's 3-P Model from FAA "Aeronautical Decision Making" FAA-P-8740-69

Risk management is a decision-making approach created to identify hazards, determine the impact on risk, and make a judgment as to the best way to proceed. A hazard is something that could cause an unwanted event, and risk is the impact of a hazard that is not mitigated (FAA Aeronautical Decision Making, 2008). The level of risk created by a particular hazard is quantified by its severity and the likelihood that a hazard will cause some type of loss as illustrated in Figure 2.

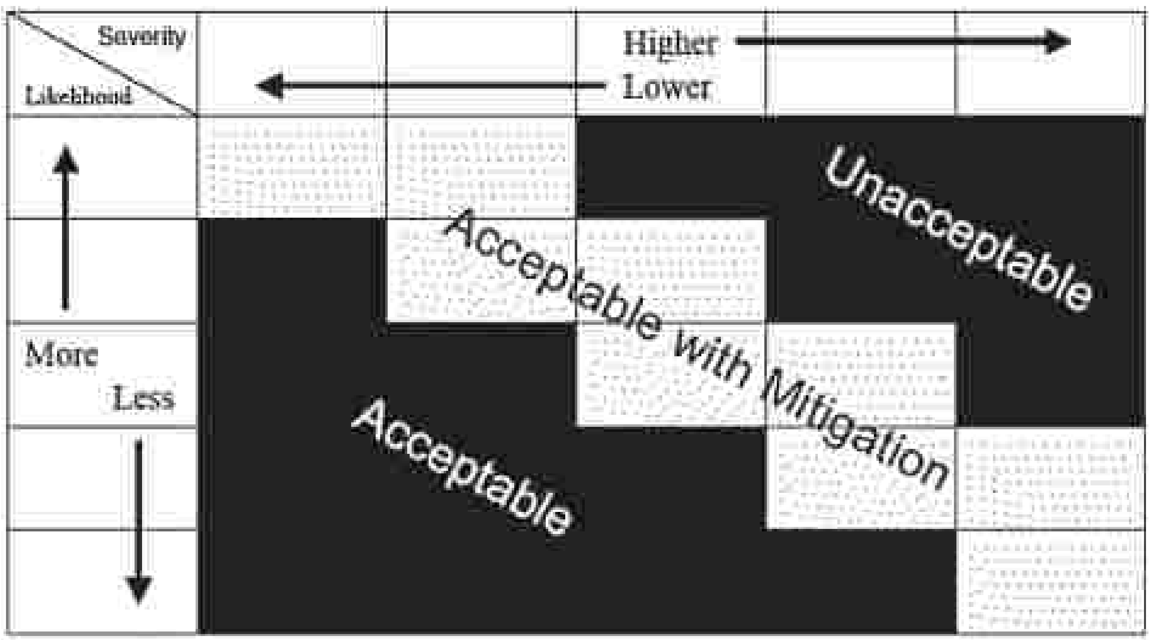

Figure 2. FAA's Risk Matrix from FAA "Aeronautical Decision Making" FAA-P-8740-69

Noyes, (2007) discussed the impact of complex automation on existing models of ADM. She stated "too much automation, and the human operator is not in the loop when failures and malfunctions occur. Making decisions thus becomes problematic as crew are not fully aware of the situation." She went on to state "the challenge for system design concerns the development of systems, which provide an appropriate level of automation for a particular situation at a given time." This view supports the development of adaptive automation in the cockpit.

Two Design Philosophies, Boeing vs. Airbus

Though Boeing and Airbus are not the only makers of large commercial transport aircraft, they play a dominant role, and their design choices have great influence over other makers and tend to set standards. In commercial aviation, the term “glass cockpit” refers to planes that replace analog gauges with computer displays, also utilize flight management computers (FMC), and utilize a programming hardware interface called a control display unit (CDU) (see Figure 3). Pilots look down at the CDU and push keys to program their flight plan and input performance data. When Boeing introduced the glass cockpit 757 and 767 in the early 1980’s, they firmly committed their company’s design approach to one in which analog gauges would have a role only in supporting legacy aircraft. At the same time, they eliminated the position of flight engineer and established the safety and efficiency of twin engine, extended range, commercial transports. After this, newer models of the 737 and 747 also utilized glass cockpits while their fly-by-wire 777 and 787 reflect the state of the art in Boing’s advanced cockpit technology. Boeing would later acquire McDonnell Douglas, a rival and pioneer in advanced cockpit avionics, which had produced variants of the MD-80 utilizing glass cockpits to compete with the 757 and 767.

Figure3. Boeing's Control Display Unit (CDU) from "Contribution of Flight Systems to Performance-Based Navigation" (Miller, 2009)

Aircraft could now navigate using satellites and on-board equipment. This design allowed performance-based navigation (PBN), which reduced average flight times, improved fuel efficiency, and is widely credited with reducing accident rates compared to air transports operating with only ground-based navigation aids for navigation guidance (Nakamura & Royce, 2008, Miller, 2009).

Airbus introduced the first fly-by-wire airliner in 1988 with their A320. The elimination of mechanical linkages from the cockpit to the control surfaces significantly reduced the airplane's weight. This design also allowed flight envelope protections programmed into the Flight Management Computer (FMC) to limit the pilot's input when such input places potentially damaging G forces on the airframe or would lead to an angle of attack that would cause a stall event. This technology has been in every Airbus model since the A320. Airbus also boasts of lowered maintenance costs and reduced training time when pilot's transition from one Airbus model to another (Airbus, 2019).

Boeing and Airbus have published automation philosophies. Their differences can be summarized by taking a key point from each company's policy.

- Airbus – Within the normal flight envelope, the automation must not work against operator inputs, except when absolutely necessary for safety
- Boing – The pilot is the final authority for the operation of the airplane. Apply automation as a tool to aid, not replace the pilot (Reidemar, 2012)

The approach of Airbus is illustrated in Figure 4 from their 2014 patent filing for an airliner design with no glass windows in the cockpit; the pilots instead using virtual displays to view outside their aircraft; U.S. Patent No.2014/0180508A1 (Zaneboni & Saint-Jalmes, 2014).

Figure 4. Airbus' new design to eliminate pilot's natural vision (U.S. Patent No.2014/0180508A1, 2014)

CRM and its Implications for Cockpit Automation

Crew resource management has been a core element of initial and recurrent pilot training for decades. It entails the crew working together as a team, not showing undue deference to a senior pilot, and being willing to speak up when one thinks standard operating procedures (SOP) are not being followed (Helmreich, Merritt, & Wilhelm, 1999). The opacity of automation and the lack of consistent feedback to the pilots have made it difficult to utilize CRM principles that include cockpit automation as part of the team. Pilots can have trouble recognizing and recovering from automation failures and trying to do so increases cognitive workload significantly. Studies and surveys have shown pilots are sometimes reluctant to challenge the autopilot's actions secondary to the rarity of automation failure (Cockpit automation concerns, 2015). In the 1990's the CRM programs of many carriers underwent a redesign in light of the increasing responsibility granted to flight deck automation. However, line operation reports indicate many pilots have not adopted CRM fully when interacting with automation (Helmreich et al., 1999).

Previous Studies into Cockpit Automation

Much research has been conducted relating to cockpit automation. Studies fall into a handful of categories. Notable research from each category is presented here. One common theme has been how automation impacts workload. The consensus is that automation reduces workload that is already low and increases it where it was already high as noted in the FAA report for operational use of flight path management systems (FAA-PARC, 2013). (This also has been confirmed by a survey completed by 77 airline pilots; 97% of the pilots who took the survey agreed that automation made their job easier during normal procedures).

This report from 2013 was the result of a joint effort involving the Performance-based Aviation Rulemaking Committee (PARC) and the Commercial Aviation Safety Team (CAST), which drew its members from representatives of manufacturing, government regulators, carriers, and academics as well as pilot associations. Workload during normal operations is reduced but during non-normal circumstances, such as a last-minute runway change from ATC, using the automated systems may increase task complexity and workload of the pilots. Another area of frequent study is how automation affects situation awareness (SA) of the human monitoring the automation. Pilots sometimes lose understanding of what the automation is doing and what it will do next, leading to a phenomenon known as automation surprise. Additionally, pilots can lose their cognitive model of what the plane is doing, and it is not uncommon to hear "I don't know what is happening" on cockpit voice recorders in the course of accident investigations (Sarter, Woods, & Billings, 1997; Chialastri, 2012). This SA problem is sometimes more narrowly focused in the literature as mode confusion referring to the myriad of possible mode configurations in the FMS. Degani, Shafto, and Kirlik (1996) created the diagram in Figure 5 that portrays the complexity in FMS mode options from the start of a flight until its end. The coefficients represent the relative frequency of using that particular mode configuration.

Another concern frequently noted in studies over the last 20 years is the loss of manual flying skills for pilots operating their aircraft at a high level of automation most of the flight. Casner, Geven, Recker, and Schooler (2014) found that when pilots who operate often in a high automation configuration were tasked to manually track their aircraft's position without access to a map display, their performance suffered. Notably, they stated, "the retention of cognitive skills needed for manual flying may depend on the degree to which pilots remain actively engaged in supervising the automation". How to improve training to help pilots better utilize automation is a topic of long standing, but more recently Geiselman et al. (2013), emphasize that better training is only a partial solution. They call for "a more context-aware automation design philosophy that promotes a more communicative and collaborative human-machine interface."

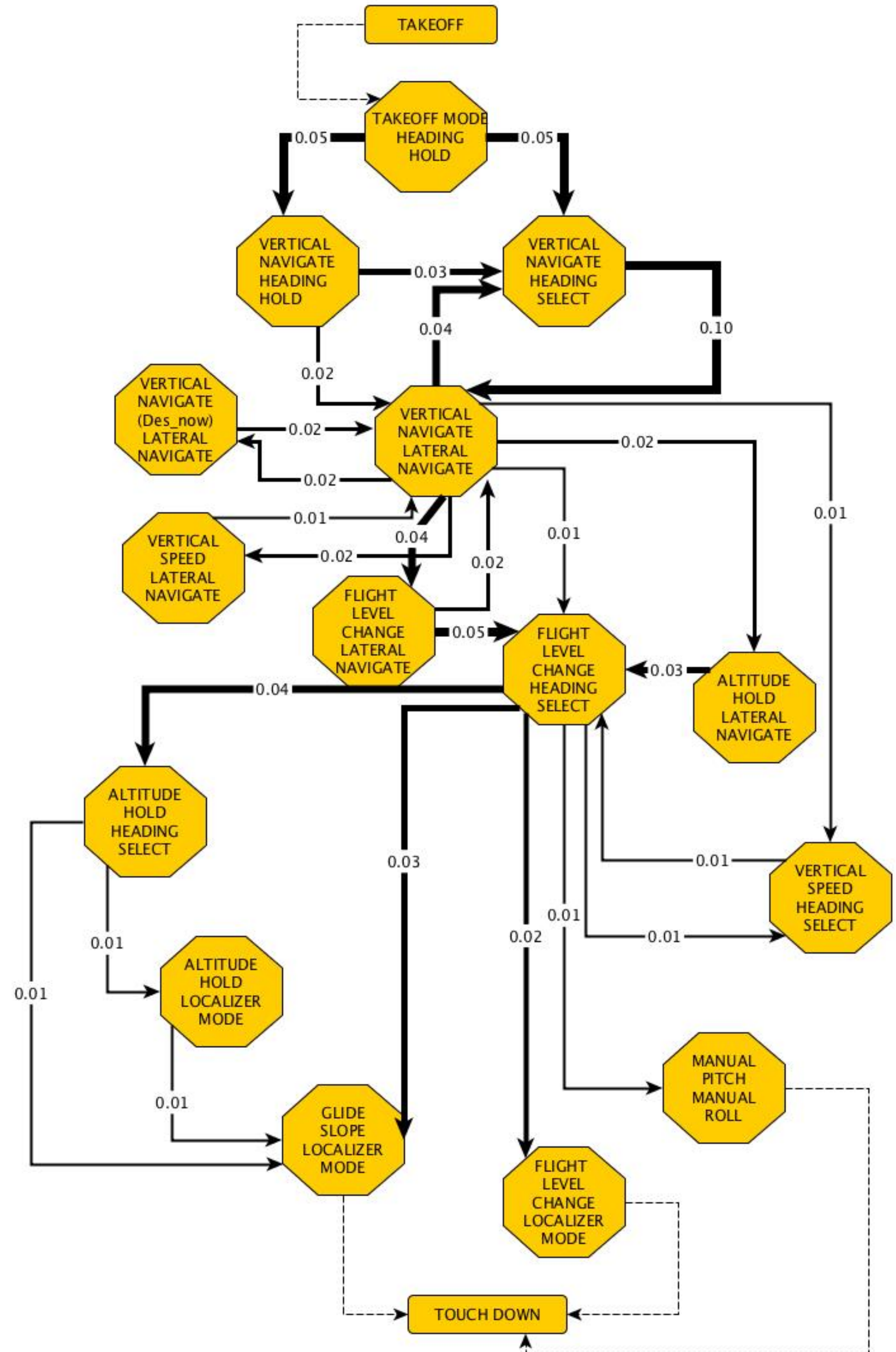

Figure 5. Diagram of various autopilot mode configurations over the course of a flight, (Adapted from, Degani, Shafto, & Kirlik, 1996).

Last, inadequate governance has been identified as an obstacle to improving safety in highly automated commercial transports. Reidemar (2012) highlighted the gap between operational policy and practices on the flight deck. She emphasized that the manufacturers automation philosophy is only about design and says little about operations. Poor guidance is being provided for training, procedures, and the division of labor. This makes it harder for pilots to manage situations where no SOP applies. She cites problems related to varying policies and cultures among different carriers and calls for a unified policy that "provides general principles for human-automation interaction in the cockpit and all other aspects of operation."

Previous Studies of Pilot Cognition and Decision Making

Decision-making is a process that leads to the selection of some action among available alternatives. This cognitive activity has been the subject of broad research for decades, and more recently it has been applied to vertical domains such as how pilots make decisions during a flight. The FAA and NTSB have long recognized pilot decision-making and risk management as essential skills that must be trained. These government agencies frequently produce policy papers and manuals that provide guidance and sometimes mandates in how pilots undergo primary and recurrent training relative to the cognitive process of decision-making. In 1987, the FAA released six manuals covering decision-making protocols for pilots with different ratings. Much of this material involves checklists for decision-making, bullet points, and rules of thumb when deciding to initiate a flight or make decisions when alternatives exist over the course of a flight. An example of this is shown below in the FAA's list of hazardous attitudes that can lead to poor decision making.

The Five Hazardous Attitudes

Anti-Authority: "Don't tell me."
This attitude is found in people who do not like anyone telling them what to do. In a sense, they are saying, "No one can tell me what to do." They may be resentful of having someone tell them what to do, or may regard rules, regulations, and procedures as silly or unnecessary. However, it is always your prerogative to question authority if you feel it is in error.

Impulsivity: "Do it quickly."
This is the attitude of people who frequently feel the need to do something, anything, immediately. They do not stop to think about what they are about to do; they do not select the best alternative, and they do the first thing that comes to mind.

Invulnerability: "It won't happen to me."
Many people falsely believe that accidents happen to others, but never to them. They know accidents can happen, and they know that anyone can be affected. However, they never really feel or believe that they will be personally involved. Pilots who think this way are more likely to take chances and increase risk.

Macho: "I can do it."
Pilots who are always trying to prove that they are better than anyone else think, "I can do it—I'll show them." Pilots with this type of attitude will try to prove themselves by taking risks in order to impress others. While this pattern is thought to be a male characteristic, women are equally susceptible.

Resignation: "What's the use?"
Pilots who think, "What's the use?" do not see themselves as being able to make a great deal of difference in what happens to them. When things go well, the pilot is apt to think that it is good luck. When things go badly, the pilot may feel that someone is out to get me, or attribute it to bad luck. The pilot will leave the action to others, for better or worse. Sometimes, such pilots will even go along with unreasonable requests just to be a "nice guy."

Figure 6. FAA. Aeronautical Decision-Making (ADM-FAA-P-8740-69, 2008)

This area of decision-making is called Aeronautical Decision-Making (ADM). Written doctrine produced by the FAA focuses little on the underlying core research conducted in a multitude of academic domains (ADM-FAA-P-8740-69, 2008), but instead focuses on actionable principles.

More recently Hunter (2005) has studied different scale formats to measure hazardous thoughts among pilots in an effort to overcome limitations in current research. Specifically, he wanted to address the problems with the ipsative scales where respondents chose one of two desirable options. Hunter examined the Likert type response scale where respondents select the score which best represents the degree to which they agree with a particular statement. He concluded the ipsative scale was suitable for training purposes but psychometrically inferior to any of the Likert scale attitude measuring protocols.

Many aviation accident reports cite poor pilot judgment as a causal factor in mishaps tied to pilot error (Wickens, Stokes, Barnett, & Hyman, 1993). Previous research concerning pilot cognition and decision making have provided some clues as to how pilots make decisions and what variables may help or hinder their ability to solve complex and sometimes novel problems under stress. Aeronautical decision-making (ADM) intersects with a broader constellation of related and ancillary disciplines. These include aviation psychology, human factors, situation awareness, and crew resource management (CRM). CRM is ADM for the multi-person cockpit found in commercial transports. The human factors professionals study the interactions between machines and the people who operate them, by applying of human sciences within a systems engineering context. Human factors specialists seek to design machines that can best utilize the capabilities of the people who will work with them. Additionally, they examine methods to select and most effectively train users of these systems. The priority is first making a system that reduces the need for training through better design and then selecting ideal users and developing training to compensate for any design short comings. Human factors researchers consider a myriad of physiological aspects that might impact user performance such as stress, age, and workload. Another domain they study involves cognitive areas such as decision-making and memory (Jensen, 1997).

Dynamic decision-making implies opacity, complexity, and dynamic situations (the dependence of the system's state on a previous state). External factors outside the control of the decision maker combine with actions taken by the decision maker (i.e. endogenous factors) and this results in an outcome. Complexity is related to how many interconnected sub-components exist in a system and increases as the number of sub-components rises. This can result in a system whose behavior is hard to predict. The decision maker's ability also impacts the complexity of the system. How much opacity a system has varies with the decision maker's knowledge of the system (Hardman, 2009). In a highly complex system such as commercial aviation, both hard and soft components exist. Human components of the aviation system are not only the operators in the cockpit but also designers, managers, regulators, and shareholders, etc. Each holds a particular worldview and often has differing priorities (Keating, Sousa-Poza, & Kovacic, 2005, Taylor, Keating, & Cotter, 2017).

One example is air carrier policies that mandate pilots fly using the automated systems most of the time in part to reduce fuel costs. This creates a certain mental model amongst the pilots to adhere to their company's policy and creates a predisposition in some aspects of their decision making. This can also lead to unintended consequences and conflict between human and machine. Billings (1997) cites an example of this regarding the use of automated vertical navigation where the computer determines the optimal point to begin descent which will reduce fuel costs. This point can be closer to the airport than the pilots may want and force them to work hard to slow the plane sufficiently in a short amount of time. Pilots have learned to "trick" the automation by inputting a false tailwind value, which causes the computer algorithm to begin descent earlier than it would otherwise. Humans have always adapted the tools available to suite their goals, but conflict between man and machine can increase workload and the chance for error.

Wickens et al. (1993) studied how anxiety might reduce the ability of pilots to make decisions leading to good outcomes. They cited the difficulty of using post-accident analysis to understand how accident crews make their decisions. The cloud of hindsight bias is difficult to neutralize. Though stress can be listed as a degrading factor, it is hard to establish a correlation between decisions that lead to undesirable outcomes and level of stress when conducting post-crash studies. That stress can harm decision-making is long established (Keinan, Friedland, &

Ben-Porath, 1987). Wickens et al.'s (1993) study used custom made software that displayed text and flight instruments to subject pilots and asked them to answer questions. The flight instruments were not tied to flight controls, and the display was static at certain times and dynamic at others. Pilot decisions (answers to questions) had the potential to change which of the predefined screens were presented as the experiment progressed. Time constraints and financial incentives were put in place to provide stress while giving incentives to complete the flight in an efficient and safe manner. When compared to the control group, the stressed pilots demonstrated a decline in decision-making ability. This work was significant because few prior experiments had shown a consistent pattern of stress related negative impacts specific to the aviation domain. These impacts were greater for tasks with large spatial demands but not for those requiring significant use of long-term memory or working memory.

Klein (1993) described the strategy to make fast decisions in dynamic environments as the recognition primed decision model (RPD). His study of experts working in high risk and time critical areas such as firefighting revealed they would recognize certain patterns and react correctly instead of comparing various options when engaging in high-risk scenarios.

Decision makers must have had previous training or experience in specific domains to make recognition primed decisions when later confronted with problem solving challenges in high-risk, high-workload circumstances. In a recent study, Gontar, Porstner, Hoermann, and Bengler (2015) analyzed pilots' decision-making in the context of naturalistic decision-making (NDM). They concluded that test subject pilots more often used analytical methods of decision-making rather than recognition-primed. This reflected an emphasis on checklists and SOP's during initial and recurrent pilot training. The authors raised concerns that this may mean pilots are less likely to make good decisions in ambiguous and novel situations and they suggested pilot training be updated to include more unlikely or unforeseen challenges.

Mosier (2002) suggested that new research recognize pilots' tasks as "cognitive work" and that new cognitive methods are needed to achieve the goals in this environment. Mosier stressed the need to determine if the automated cockpit is a mismatch for the pilot's cognition. Modern aircraft have shifted the task of pilots from looking out the cockpit window and manipulating controls to that of being automated systems managers, and thus the job became less about physical sensing of the aircraft's state and more about integrating information from multiple electronic systems and maintaining a cognitive model of aircraft's state. The correspondence of judgments relates to the accuracy of the decision and how the decision lines up with the facts. Sometimes pilots respond inappropriately to cues when they view all cues as having equal validity and reliability. The prominence of a cue can cause the pilot to sometimes give it inordinate value compared to other cues that are also present. It is thought that better pilot decision makers learn to use probabilistic cues more effectively which leads more often to accurate assessments and predictions on the part of the pilot (Mosier, 2002).

Coherence theories center on the rationality of the decision process. The focus of coherence theories is on how rational the decision process was (Mosier, 2002). The objective of coherence is to make judgments that are rational and consistent. Correspondence and coherence relate to the objectives of cognition and approaches used to complete these objectives. A pilot could use correspondence during visual flight rules operations by looking outside the cockpit and use a coherence strategy by checking the displays inside the cockpit and confirming that they are consistent with one another and match expectations for a given circumstance. Pilots use coherence competence when they scan their instruments and sub-systems indicators to confirm they cross check with consistent readings. Having coherence competence relates to someone's aptitude to sustain logical consistency in his or her judgments (Mosier, 2002, 2009). Since the 1970s much research on coherence has centered on how difficult it can be for humans to maintain coherence, and this approach to judgment research has focused on heuristics and biases. Studies typically compare human judgment that relies on heuristics in the decision-making process with models based on mathematics. Many of these studies concluded human decisions range from an approximate process down to an irrational one impacted by human bias. (Mosier, 2002). Parasuraman and Riley (1997) observed that pilots of modern aircraft may take short cuts and over rely on automation without comprehending its limitations and may fail to monitor automation's behavior.

The cognitive skills required of modern commercial pilots differ markedly from those in earlier eras of aviation. There has been a shift towards more analytical cognitive functions, as pilots must track large amounts of data. Mode confusion and misplacing a decimal point when programming a flight management computer can cause an accident. Pilots must understand the logic of a highly complex computer system with many interconnected parts that depend on sensors, which sometimes fail. When this happens, they may be required to take manual control of their aircraft with no observable horizon, little to no guidance from the automated systems, and often little time to determine which action on their part will prevent loss of control of their aircraft. Ground school training manuals require three-way call outs to transfer control of the aircraft and do not allow for sudden transfer to the pilot monitoring without confirmation (Pilot's handbook, 2008). This is not unlike what pilots experience when automation suddenly disengages and demonstrates a particular decision-making challenge for cockpit crews. (Mosier, 2002).

Woods (1996) noted that modern glass cockpits could appear straightforward to the pilots using them as these displays belie the deep complexity at work in the underlying avionic systems. When operators fail to monitor and analyze these systems correctly, small errors can rapidly grow into hazards impacting flight safety. Sarter and Woods (2000) observed that pilots are less likely to notice their errors from looking at cockpit displays and more likely to respond after noticing some "surprising" or unwanted action regarding the plane's flight path or configuration. This is reflected in many investigation reports citing interrogatives used by pilots in the accident flight:

- What is it doing now?
- What will it do next?
- How did I get into this mode?
- Why did it do this?
- I know there is some way to get it to do what I want.
- How do I stop this machine from doing this? (Wiener, 1989; Sarter & Woods, 2000; Mosier, 2002).

Woods (1996) stated that the modern cockpit can appear less complicated to the user than he or she realizes, and its complexity is better reflected in the cognitive processes demanded by the automated systems. He emphasized the need for an analytical approach when operating these systems, which are often counterintuitive in their design. The pilot's need to maintain cognitive coherence is challenged by the disparity between the mental requirements of using this equipment and how information is displayed to the user. This system opacity promotes pilot use of intuition while making analytical evaluations of system state difficult. The incongruence between the need to analyze what cockpit automation is doing in order to configure and monitor it and the urge to use intuition when a systems interface and feedback are inadequate must be addressed. (Mosier, 2002).

Research showing that people exert less effort towards a task when part of a group compared to performing the task individually has spurred interest in the question of how people's decision-making performance is impacted when they work collaboratively with automation. Social loafing and "slacking off" seen when people perform in groups also occurs when they share tasks with computers (Skitka, Mosier, & Burdick, 1999). They may defer to automated aids and feel less need or pressure to perform with all due diligence. Operators of automated systems may also show unwarranted deference to automated systems and consider them to have greater authority than they do. This has been observed when the human operator has access to raw data that contradicted what the automated decision aid was doing or suggested doing. This combination of influences have been linked to errors of omission and commission. A 1972 airliner crash outside of Miami occurred when the crew became pre-occupied with troubleshooting a landing gear indicator light. They had set the autopilot to maintain an altitude of 2000 feet while they sorted out the problem light. A nudge on the control stick disengaged the autopilot and they failed to notice they were losing altitude with each passing moment. They gave responsibility to maintain altitude to the automation and failed to monitor what it was or was not doing (Skitka et al., 1999).

NASA conducted an experiment during which test crews had to decide which engine to shut down due to a fire. The test crews using auto-sensing cues were much more likely to shut down the wrong engine as they ignored or failed to analyze basic data telling them which engine needed to be shut down. Test subject crews using traditional paper checklists with no autosensing equipment were much more likely to turn off the correct engine. They worked in the absence of an automation authority and this impacted their decision-making process (Skitka et al.,1999).

Automation bias can impact decision making when operators attribute greater authority to automated aids compared to other sources of information. This could be caused by the automatic cues being prominent and potentially drawing the user's attention from other important information that is not as salient. Automation is intended to improve efficiency and facilitate human decision-making, particularly in safety conscious domains like aviation. This can be realized only when used appropriately. (Parasuraman & Manzey, 2010)

In the context of everyday experience, human decision-making works by sequentially examining alternatives and selecting the first satisfactory one. This happens usually without consideration of all possible alternatives. This contrasts with the global models of rational choice in which every alternative is considered before a choice is made. In some cases, no satisfactory alternatives are found so more alternatives will need to be sought (Simon, 1955).

Decision makers will often act in a manner counter to the tenets of traditional normative theories. This was observed in psychology experiments. Researchers in the decision sciences who are primarily focused on normative models of decisions often dismiss empirical results as solely descriptive and therefore of little value (Weber & Coskunoglu, 1990).

People have various constraints on their ability to process data. When large amounts of information are provided, humans are unlikely to perceive all of it. Humans tend to process information in a sequential fashion to reduce the mental task load and this may not result in prime outcomes. Humans must rely on a memory system process known as reconstruction and, in contrast to computer memory, does not reference data in its original form. Recognition of these constraints underlie Simon's speculation of "bounded rationality" (Simon, 1955) being the basis for grading decision quality. People have developed techniques and protocols to overcome limitations in the mental processing of information. One of these involves the use of heuristics, i.e., using basic rules to process information and arrive at the correct choice in the majority of circumstances. The other involves reshaping the problem space. These approaches can become second nature over time and are often applied when it would be preferable to use formal procedures or when using heuristics can bias the choices made. As people gain experience and familiarity with an environment and its associated processes, they use heuristics when gauging the chance of an ambiguous event occurring. They look for similarities and apply old knowledge to new findings.

Klein, Calderwood and Clinton-Cirocco, (1986), determined that Fire Ground Commanders (FGC) seldom make decisions after considering the merits of every potential option. Their previous experience guides their response to the circumstances they encounter with each fire. The pros and cons of the available actions are not considered given the urgency of the situation. FGC's make decisions after recognizing features of the current fire that they had observed in previous events. They will also change their plan quickly when confronted with new facts (Klein, 1989).

Klein (2008) reported a history of studies supporting the notion that people approach decision-making based on the time available and will use more analytical methods when time affords but revert to using a process of recognizing and categorizing situations based on memories of earlier circumstances when scant time is available in a dynamic environment. People build up a catalogue of patterns over time and they can more rapidly identify the relevant factors in subsequent situations. This is central to the recognition-primed decision (RPD) making model. Seeing familiar patterns helps in choosing appropriate goals and leads one to match and employ a successful course of action. This method lends itself to rapid decision-making and implementation of responses but is predicated on having a rich set of prior experiences. This is not to say that analytical methods have no role. There is a continuum from intuitive to analytical approaches and adjusting to allow use of each as the situation allows will be ideal. Relying solely on intuition can cause one to follow a set of patterns to an improper action. Drawn out deliberations while a school building burns will negate the benefits of choosing the perfect solution after the building has already been lost. The model shown below in Figure 7 outlines the steps, information needed, and paths taken when using the RPD model.

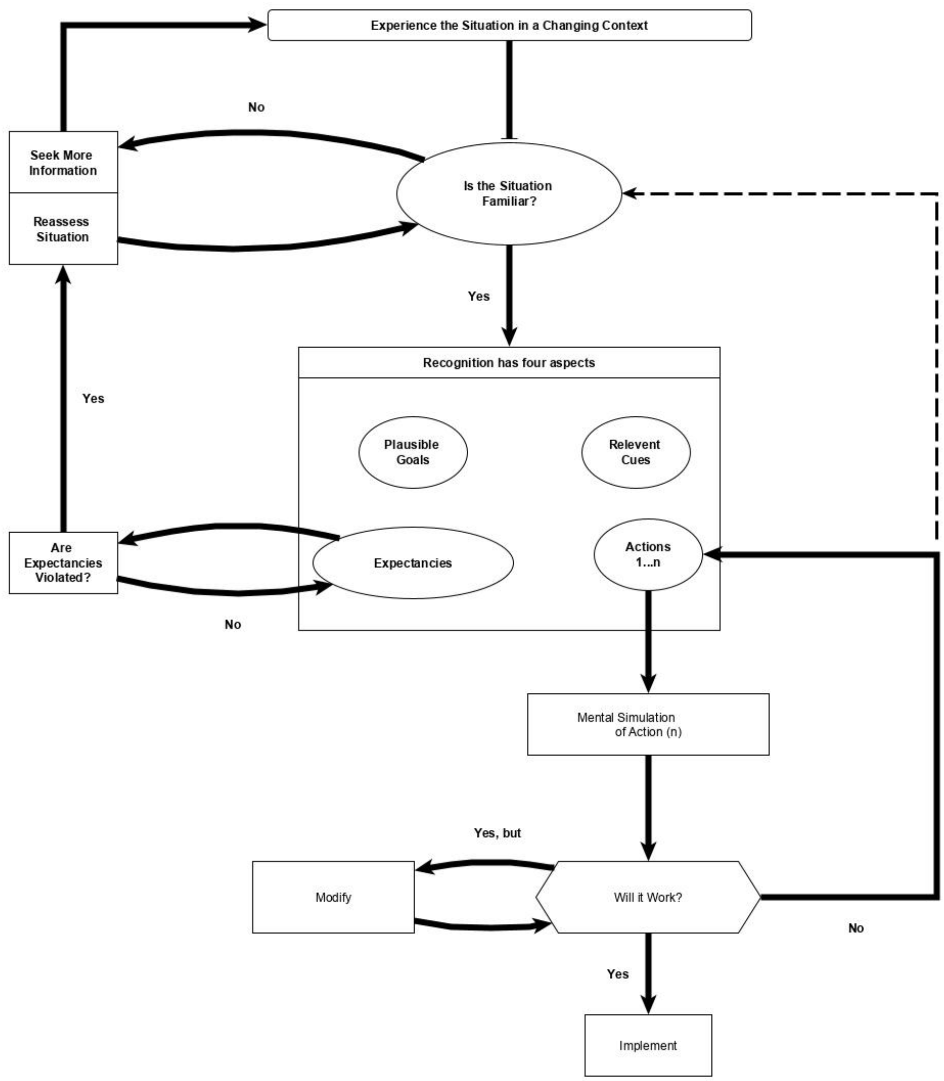

Figure 7. Model of recognition-primed decision making. (Adapted from Klein, 1993)

Naturalistic Decision Making (NDM) adherents consider intuition to be a manifestation of experience as people accumulate a set of experiences that help them quickly evaluate events and rapidly make choices without having to weigh many options (Klein, 2015). Without experience, one can potentially know all the options but have little basis to select one over the others. NDM researchers consider tacit knowledge a necessity when using intuition. Nonaka and Takeuchi (1995) exhaustively studied the value of tacit knowledge for organizations and how to increase tacit knowledge held by the organization's members. Klein (2015) suggested that increased situation awareness improves decision makers' ability to sort out the events unfolding before them. Pattern matching is not the limiting factor as much as understanding what is happening. In Klein's model for RPD above, when the decision maker does not have sufficient familiarity with the situation he or she will seek more cues to improve their cognitive model for that situation. The applicability for this model in aviation is not far from that seen in the FAA 3P model discussed in chapter 2. The 3P portrays a broad concept, and, in contrast, the RPD model provides depth in analysis for the decision-maker with analytical and intuitive approaches.

Highly automated control systems can make it difficult for human monitors/operators to take manual control when needed due to the inherent characteristics these control systems exhibit, such as machine autonomy and complexity. When the human in the system transitions from monitor to operator, they may have problems secondary to difficulties in tracking recent automation actions or understanding its planned actions. Thus, expecting operators to manage automated systems by intervening primarily when the automation reaches its design limits or fails in some way, has its pitfalls. (Woods, Johannesen, Cook, & Sarter, 1994). According to Billings (1991) pilots flying planes with highly reliable automated systems naturally come to rely on them, and this can change pilot behavior when compared to those operating planes with no or little automation. Previous research has shown people exert more effort when operating individually compared to operating as part of a team (Karau & Williams, 1993). Humans tend to become lazy when sharing tasks with other people or with automated systems (Nass, Fogg, & Moon, 1996). Modern commercial airliners may cause pilots to diffuse responsibility for tasks controlled by automation and may reduce their individual efforts and vigilance in the human/computer system (Skitka et al., 1999).

Endsley (1988) described situation awareness (SA) as perceiving aspects of the environment across a particular scope of time and location, understanding their meanings, and predicting their status in the immediate future. For pilots, SA requires they perceive critical features in their environment, process their meaning, and act accordingly to control their flight path in a safe and efficient manner. Remaining engaged in this manner helps pilots understand what will happen in the system in the proximal future. This engagement can be reduced by the automation of tasks formally performed by pilots. Broadly, system operators of automated machines have a reduced capacity to notice system errors and are less likely to successfully intervene manually when needed. A Northwest airliner crashed on take-off in 1987 when the pilots did not perceive that the configuration warning system had failed, thus denying them an automated warning that their aircraft configuration was incorrect for that particular take off. Their reliance on this system may have reduced their engagement with aircraft systems and impacted their vigilance in ensuring all take off settings were correct (Endsley, 1999). When pilots become out of the loop regarding their aircraft's state, they can be slower to detect problems and may require additional time to assess system parameters, diagnose the automation problem, and assume manual control to affect a solution. It has been hypothesized this happens because of the complacency that can accompany becoming a monitor of automated systems and from pilots passively receiving information rather than being active processors of information (Endsley & Kiris, 1995). Endsley and Kiris found that situation awareness decreases more during full automated phases versus partially automated phases (Endsley, 1999).

The issue of operator complacency caused by using reliable automated systems has been discussed in previous research dating from the 1970s. Wiener (1981) and Billings, Lauber, Funkhouser, and Huff (1976) described automation induced complacency (AIC) in terms of a psychological state with reduced suspicion resulting in reduced vigilance and a belief in system status without justification. Farrell and Lewandowsky (2000) described AIC by emphasizing the correlation between monitoring and manual control, implying that complacency refers to a decrease in performance seen when humans transition from carrying out a task themselves to being passive observers of automation. Many researchers describe how human behavior changes when they assume a supervisory role over highly reliable automated systems as seen in aviation, nuclear power plants, and medicine. Parasuraman, Molloy, and Singh, (1993) scrutinized previous studies and Aviation Safety Reporting System (ASRS) reports and found support for this idea. Accident reports have cited crew complacency in the past, and authors note that it has become more common as cockpit automation grows in sophistication, scope, and reliability (Casey, 1998). This has spurred research to better understand this problem and how best to prevent it. Parasuraman et al. (1993) advocated for the notion that overconfidence in automation leads to complacency. They observed that managers of automation often failed to detect automation errors when that automation only rarely failed. Others stated that an operator choosing to rely on automation could be impacted by the relationship of their level of confidence in the system, their confidence in their abilities, and other factors (Prinzel, 2002).

Some have contended that terms such as situation awareness and complacency are inappropriate for use in scientific domains (Dekker & Hollnagel, 2004) while others refute this opinion and point to the growing amount of literature supporting elements of both constructs (Parasuraman, Sheridan, & Wickens, 2008). Bagheri and Jamieson (2004) replicated an earlier study by Parasuraman et al. (1993) and found study subjects noticed more automation errors when the automated system had a low reliability rate than when it had a high reliability rate. Their results also supported Parasuraman et al.'s observation that a system with varying degrees of reliability resulted in system monitors finding more errors compared to when they worked with automated systems having fixed reliability (Parasuraman & Manzey, 2010**).**

While researchers differ with regard to the definition of AIC, it has been cited in fatal aviation accidents (Hurst & Hurst, 1982; NTSB 1973, 1988). These accidents often have factors in common. As automation assumes more control of a system, the supervisor of the system is less aware of the system state. Additionally, humans are ill suited to monitoring complex systems that rarely fail (Wiener and Curry, 1980). Thackray and Touchstone performed pioneering empirical research in complacency in 1989. Their experiment used a simulated ATC system and compared the performance of controllers with and without an automated aid. They observed no difference in the ability of two participant groups to detect deviations from ATC instructions. This conflicted with their hypothesis and they suggested this may have resulted from the experiment being too short. Research conducted by Parasuraman et al. in 1993 criticized previous research, and after several empirical studies they concluded that highly reliable automated systems may create overreliance for its operators therefore result in less monitoring (Bailey & Scerbo 2007).

Users sometimes fail to operate automated systems properly for various reasons including decision-making bias and inadequate monitoring. This phenomenon is not limited to new or poorly trained users. Seasoned users have sometimes placed trust in automation that is not warranted given the limitations and pitfalls of the systems they are directing. This is reflected in some ASRS reports as well as in previous research in which pilots cite failures in monitoring related to overreliance in automation (Parasuraman & Riley, 1997). Trust rapidly approaches 100% when users believe the system they operate does not fail as compared to the same users who suspect the system is not reliable (Bliss, Hunt, Rice, & Geels, 2013).

When people use automated systems, their role shifts from actively engaged operator to that of monitor and, their behavior can change. They are more likely to rely on heuristics and give the automation undue deference. The paradox is that in most situations, this will not result in failures or incidents, but in a very small number of scenarios leads to fatal accidents or significant material loss. Operators may miss a problem with the system if the automation does not provide a cue. Conversely, operators may act on erroneous information supplied by the automated system when they have no cognitive reference as to what the system status is as might be determined from consideration of raw data such as airspeed, angle of attack, and bank angle in the case of aircraft. When operators detect that raw data contradicts what the automation is doing, they may still fail to intervene secondary to habitual reliance on an automated system that has served them well most of the time. Research has shown that pilots substitute watching for automated cues in place of the traditional method of scanning for data and forming a cognitive model of what is happening (Parasuraman et al., 1997).

The RPD model is appropriate in complex scenarios with time constraints as seen in commercial aviation. Experienced users build a library of occurrences over time and use cues to match future problem situations with historical patterns in order to arrive at a workable response in a short amount of time (Klein 1998, Klein, Calderwood, & Clinton-Cirocco, 2010). One's emotional state while using the RPD model can impact cognitive activity. Negative and positive emotional states have both been shown to influence cognitive performance. The mechanism by which this occurs is not known (Jeon & Walker, 2011). Experienced users build a library of occurrences over time and use cues to match future problem situations with historical patterns in order to arrive at a workable response in a short amount of time (Klein 1998, Klein et al., 2010). One's emotional state while using the RPD model can impact cognitive activity. Negative and positive emotional states have both been shown to influence cognitive performance. The mechanism by which this occurs is not known (Jeon & Walker, 2011).

The Gap Analysis

The survey completed was the main instrument to understand automated systems' deficiencies from the users' perspective. Though the majority of the respondents believe automation is helpful, they also agreed many aspects of automated systems are lacking in some respect. The findings from the survey were used to develop the experiment.

Recommendation four from the *Operational Use of Flight Path Management Systems* (FAA-PARC, 2013) document states that "research should be conducted on new interface designs and technologies that support pilot tasks, strategies and processes, as opposed to machine or technology driven strategies". Other recommendations from the same report called for better validation and verification for equipment designs that target failures and failure effects secondary to the high integration of sub-components. Recommendation 12 called for designers to document their assumptions about how the equipment should be used in operation early in the design process.

Degani and Heymann (2000) criticized current techniques for designing and evaluating human-automation interaction as inadequate. These methods do a poor job of covering all possible pilot-automation interactions. They called for a more systematic approach when solving human-automation problems that accounts for how the automation behaves when operated by the end user.

The European Aviation Safety Agency (EASA) issued a policy brief in 2013 that outlines their automation policy by suggesting four steps to mitigating automation challenges (*EASA automation policy*, 2013):

- Identify and group crew-automation interaction challenges
- Bridge design and training principles
- Prioritize issues
- Assess risk mitigations in regulatory provisions

The Human-Automation Relationship Taxonomy (HART) project released a report in 2011 covering the current state of cockpit automation (Durso et al., 2011). They cited research indicating that some intermediate level of automation fosters better vigilance and engagement than full automation. Humans are better able to share control in an intermediate level of automation. They referred to research from Dao, Brandt, Battiste, Strybel, and Johnson (2009) that showed better pilot situation awareness in traffic conflict tasks if the pilots carried out the tasks interactively with the automation in contrast to full automation. A research gap exists for how humans and automation interact collaboratively for a better decision-making process and what type of design changes make this interaction better for human operators while they are making their decision in human intelligence-machine intelligence (HI-MI) collaborative environments.

Wiggins, Azar, and Loveday (2012) emphasized that utilization of cues relevant to the task is a critical factor in the progression toward decision making expertise. Not only is the utilization of cues important in developing decision-making expertise, but also, it is consistent with research findings from naturalistic decision making and the RPD model. Jeon and Walker (2011) found that decision making expertise must also encompass the ability to determine the critical cues to detect and why they are important. Additionally, Loveday, Wiggins and Searle (2014) found that decision making expertise must also include the ability to utilize cues as indicators for self and peer error management. They found that decision makers who utilized relatively higher levels of cue utilization for feedback and control were significantly more likely to engage in behaviors associated with expert decision making.

The literature review revealed problems with human-automated collaborative systems such as losing situation awareness due to over reliance on highly reliable systems. This was also confirmed by pilots who took the survey in the initial phase of this research. They said sometimes they are surprised by the actions automated systems take. Based on this information the simulation experiment was designed with the goal of increasing situation awareness through applying the Reinforced Cue Detection model to fulfill this gap by addressing this concern.

CHAPTER III

RESEARCH METHODOLOGY

The research methodology was based on a quantitative approach to analyze the participants' responses to the survey followed by a qualitative approach to design a prototype experiment used for understanding if minor changes had any impact on pilots' mental model by using the "phenomenology" method to have an overview about pilots' situation awareness by conducting interviews after each experiment.

Initially, each question under the survey was evaluated individually by exploratory data analysis followed by use of the Multivariate Joint Correspondence Analysis (MJCA) technique for detecting underlying structures in the survey. At the same time, the Spearman's rho analysis was used to understand if different demographics affect the answers participants provided. The survey plan and the experiment were reviewed and approved by the Old Dominion University (ODU) Institutional Review Board (IRB). The survey was conducted on active airline pilots to ascertain their opinions about various issues regarding the design, training for use, and operational use of cockpit automation. This information also helped to shape the design of experimental test scenarios using test subject pilots.

The survey was followed by a small study using a computer-based flight simulator for testing recognition primed decision making using reinforced cues model. Phenomenology was selected as the method to analyze the experiment results since this was an initial exploration of a new phenomenon under the naturalistic decision-making process and conducted with a limited number of participants. Pilots who participated in the experiment were interviewed after their experimental flight and their flight data and after flight interviews recorded.

Survey Methodology

The survey was conducted with airline pilots to ascertain their opinions on the design, training, and operational use of cockpit automation. The population consisted of all commercial pilots listed in the FAA Airmen Certification database who are certified to fly aircraft requiring a moderate to high degree of interaction with cockpit automation. The population included commercial airline pilots, commercial transport pilots, and private pilots with ATP (Airline Transport Pilot) certificate. Pilots for this survey were reached via electronic communication. All data sets are maintained off line for security. This information is stored on a CD and a USB memory stick for redundancy and secured by the researcher. The link to the online survey tool, Qualtrics™, was distributed by email or anonymous link provided by Qualtrics™, mostly via LinkedIn. Survey participants did not receive monetary compensation.

The survey presented every question with five response options, which ranged between strongly agree and strongly disagree. The survey tool allowed only one answer per question. Some questions were repeated in a negative form to verify response consistency.

Participants had the option to save their progress and return later and continue the survey. Also, they had the option to change their answers until they submitted their survey. The survey was held open until the response rate declined to zero. Four weeks after the last response was received, the survey was closed. Seventy-seven (77) surveys were completed.

The survey about cockpit automation was designed to measure five dimensions:

- Reliance/Trust in Automated Systems
- Monitoring Automated Systems
- Governance and Policies about Cockpit Automation and its use

- Training and Performance for Automated Systems
- Interface used by Automated Systems

Responses were analysed using exploratory frequency distribution analysis, Spearman's rho correlation analysis, and multivariate joint correspondence analysis methods.

Validity and Reliability of the Survey Instrument

For this research a questionnaire distributed as a survey was developed in Qualtrics™ and completed online by pilots holding ATP licenses. The survey respondents were taken directly from the target population being studied, and this supports the credibility of the study. It used the Likert format for structuring answers for the survey questions as this is well known and lends itself well to statistical analysis. The directions for completing the survey were clearly defined at the beginning of the survey. No problems were reported by the survey respondents to the researcher based on its use.

The validity of a survey also refers to how well this instrument measured what it is supposed to measure. This survey used questions with little or no ambiguity, as they were directed as a statement. The survey closed with two open ended questions giving the respondents the opportunity to provide feedback related to the automated systems in the cockpit. Some of the respondents gave detailed answers, and some respondents did not provide any input at all. Those questions are not included in the analysis since they were not in the Likert scale format. Those questions provided respondents the opportunity to bring their own concerns from their perspectives. None of the respondents provided feedback stating the questions were unclear. No concerns about ambiguity were relayed through the survey. A wide range of demographics by age, flight hours, carrier, nationality, and aircraft type were reflected in the survey pool.

Content Validity

The survey questions were structured around five domains identified in current literature related to cockpit automation and human interaction. All the questions in those domains were populated from research findings that try to explain the problems relating to human-automation interaction and were directed at line pilot participants who use automated aviation systems every workday.

Construct Validity

Survey questions should have a unifying theme known as a construct and this determines what is to be measured by the survey. A construct can be complex or simple and can vary greatly in how many questions are needed to form a picture about what is being measured. Constructs may involve several dimensions if the subject matter is more abstract. Careful design of the survey is needed to avoid answering the wrong question or gathering too little information about the construct (Dew 2008).

The construct validity of survey research qualifies how accurately it has measured what it claims to have measured. Survey results can be statistically analyzed to enhance their credibility and validity and support the researcher's claim to have measured what the survey was seeking to find. As an example, a simple analysis of this type could validate the responses given by various demographic segments (Lavrakas, 2008).

The construct developed in this survey was aimed at understanding pilot's perspectives in various dimensions. The dimensions were synthesized from literature findings and a few questions from previous surveys including the survey developed and published under the title "Rethinking Pilot Attitudes Toward Automation" (Hutchins, Holder, and Hayward, 1999). The survey construct was composed of five different dimensions; different categorical questions summed up those dimensions. As such, the survey's construct validity was established through discriminant validity across the five dimensions. Results were evaluated using various statistical approaches and the demonstrated dimensions were developed purposefully. In addition, demographics were analyzed under each dimension.

Reliability

Surveys can be evaluated for their reliability, which relates to their consistency as a measuring tool. Consistency is further broken down as falling into three types; test-retest reliability, internal consistency, and inter-rater reliability. Internal consistency reliability was established in this survey by randomly selecting three questions and stating the negative direction of the relationship. The results can be found in the consistency check section in Chapter 4.

Test-retest reliability could not be established in this survey, because the survey could not be administered with the same group of airline pilots. Further, it would be difficult to recreate the same demographics with another set of survey participants as that of the participants who took this survey. Since there was not any change for the pilots as to how automation is designed, it should be expected that a similar survey with a similar population would show similar results, but that is unproven.

Likert Scale for Rating the Answers

The Likert Scale came from the psychologist Rensis Likert in an effort to measure the attitudes towards certain proposed statements conveyed in a survey. (Likert, 1932). It has the advantage ~~to~~ of providing better resolution than surveys with only yes-no answers by providing more options, usually with a 1 to 5 or 1 to 7 scale ranging from strongly agree to strongly disagree with choices in between. It allows for a range of agreement or disagreement or even no opinion at all. Although there is not much difference in the analysis of the results of a 5 level Likert scale versus a 7-level scale, it is recommended to use the smaller option if the survey includes multiple questions (Sauro, 2010). Likert Scale is the most commonly used rating method for answers given in questionnaires such as the survey included in this research. Although it categorized the answers as rank order, a common misconception is to assume all the intervals are equivalent (Blaikie, 2003). The scale used in this research is based on the meanings of the attributes described in Table 1.

Table 1: Likert scale and its attributes.

Likert Scale	**Meaning**	**Detailed Description**
1	Strongly Agree	There is no hesitance about accepting the proposed statement
2	Agree	The respondent agrees but with some reluctance
3	Neither Agree Nor Disagree	Either they do not want to answer the question or do not have much idea about how to answer
4	Disagree	Respondent disagrees with some reluctance
5	Strongly Disagree	There is no hesitance about rejecting the proposed statement

Data Type and Structure

Data type includes both Excel workbook, CSV (Comma Separated Values) and tab delimited.

Data Acquisition, Integrity, and Quality

Acquisition – The survey tool Qualtrics™ allowed only one answer per question. Some questions were repeated in a negative form to verify response consistency.

Integrity – Data from Qualtrics™ were exported to an Excel workbook format and saved in a USB memory stick and a CD as a backup. Once the research and dissertation defense is completed, and publications are accepted, other researchers can obtain the data per their request from the author.

Quality – For cyber security purposes, data will not be kept on computer hard drive or cloud storage systems. It will be burned to write once, read many CD discs that cannot be changed once information is burned into the disc. These will also be archival type CD's manufactured by Kodak that are rated to last 300 years before any degradation of the media could be expected. Copies of these discs will be kept at multiple secure locations to guard against damage from fire or flood and the like. Data masters and backups will be periodically checked and verified for readability.

Privacy of Participants

To provide privacy and encourage forthrightness of the participants, personal data including the participants' race and nationality were not disclosed in the survey. Before the experimental study was initiated and before any pilots were recruited for the experiment, the IRB process was followed, and all the requirements requested by the ODU-IRB committee were met.

The only personal data collected was the age of the pilots. Their data records were stored and each pilot was assigned a code to identify them instead of using their name.

Phenomenology as Experimental Methodology for Reinforced Cue Detection Model

Phenomenology is an investigative approach to learn about what our life experiences mean. When the experiences of people are investigated and meanings applied to the phenomena of life, it falls under a research domain known as phenomenology (Bliss, 2016). Any experience can be investigated under the domain of phenomenology.

A longstanding theory that objects in the environment are independent was refuted by Husserl when he espoused the idea that people can only be certain about the things that are observed in their location that have entered their consciousness. This simplified view of the world and people's interactions with it comprise the phenomena studied using the phenomenological research methodology. Franz Bretano provided the foundation for phenomenology and influenced Husserl. Other philosophers made contributions to phenomenology including significant works from Merleau-Ponty and Sartre (Groenewald, 2004).

This approach was used to learn how the pilots perceived the situations they were placed in during their flight simulator trials by asking them open-ended questions during post flight interviews. The goal was to get sight of possible deeper issues regarding the interactions of pilots with their automated cockpit systems, and if the cues presented during some of the flights helped their decision making and vigilance versus their flights with no cues. Participants were assured anonymity and encouraged to speak freely. This method captures the feelings of a group of individuals and, while it is difficult to generalize from such information, can indicate if further study is warranted.

Experimental Design

Although prior studies have established the impediments to decision making by automation induced complacency in the cockpit and other studies within naturalistic decision making have established the importance of cues to decision making and error management, no studies have directly examined the application of automation cues to reinforce pilot decision making in the cockpit. This study seeks to advance and integrate prior work by examining the relationship between the effects of reinforcing cues within the RPD model of pilot decision making under normal and high-stressed, time-constrained failure situations. Insertion of reinforcing cues, however, requires modification of the basic RPD model to a RCD-RPD model as shown in Figure 8, because the inclusion of reinforcing cues modifies some of the assumptions underlying naturalistic decision making from which the RPD model was developed.

With the inclusion of reinforcing cues, the focus of the RPD model changes from “situation familiarity” to operational state awareness and from “recognition” to “engagement” as shown in the “Engagement aspects” box in Figure 8. Reinforcing cues force the creation of a real-time feedback loop between the pilot and the operational state of the aircraft through continual comparison of the actual operational state to plausible state goals. Klein’s recognition primed decision-making model is predicated on the belief that decision makers look for cues after arriving at the area that decisions need to be made such as fire fighters arriving at a burning building. The difference in this research is that pilots are already in the cockpit and they can potentially collect relevant cues necessary for them to make their decisions before a failure occurs. Due to the out of the loop phenomena (Endsley, 1999) especially during long haul flights, implementing the reinforced cue detection model could provide vial input for the pilots.

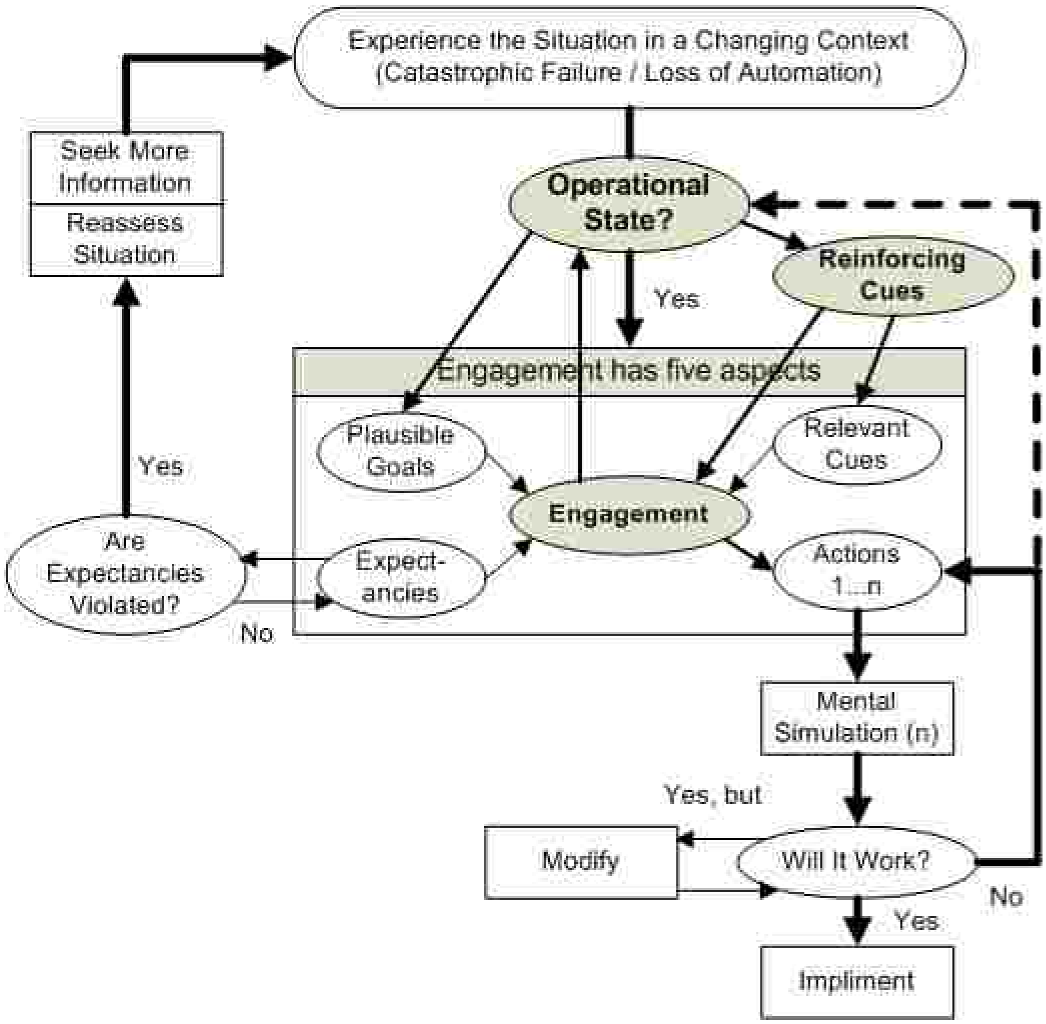

Figure 8. Reinforced Cue Detection – Recognition Primed Decision (RCD-RPD) model.

Setting up the Flight Simulator and the Experiment

The analysis of the survey demonstrated that pilots are sometimes surprised with the actions that automated systems take. These findings provided inspiration to develop a flight simulator experiment for ATP licensed pilots to test a novel method to help pilots maintain their vigilance and reduce their complacency during their flights. To test this, a flight simulation setup was assembled using the equipment and software listed below.

A personal computer was custom built for flight simulation of the Boeing 737-800; the most widely used single isle commercial transport aircraft. Hardware selection was based on optimization of frame rates as simulation software is more demanding of computing power than typical software applications. The PC consisted of the following parts.

- Gigabyte GA-X99-UD5 motherboard
- Intel Core i7-5820K Haswell-E 6 Core 3.3 GHz LGA 2011 microprocessor
- Intel 400 GB 750 Series solid state drive (NVMe) PCIE full height
- Zotac GeForce GTX 980 AMP! 4GB graphics card
- Corsair RM Series RM850 ATX12V Modular power supply
- G.Skill Ripjaws 4 Series 32GM RAM modules (4 x 8GB)
- Noctua NH-D15 CPU cooler
- Samsung 859 EVO 2.5" 250GB SSD drive
- LG 24X DVD burner
- Corsair Obsidian Series 450D Steel ATX Mid Tower case

Windows 8.1 was installed on the PC to serve as the operating system as it was the most compatible choice for the simulation software. The base simulation platform chosen was Lockheed Martin's Prepar3D. PMDG 737, an add on module, was installed to simulate the Boeing 737-800. A Samsung S34E790C 34-Inch Curved WQHD Cinema Wide monitor was used for the display. One iPad mini displayed the CDU using the iOS app Virtual CDU. Navigation data was maintained using a Navigraph subscription. Some flights were recorded using a dedicated software tool called Flight Data Recorder which allowed flight replay using Google Earth and for the display of black box parameters in Excel which can be referred to in future research.

Figure 9. Example virtual CDU screen on iPad (Virtual avionics store, 2018).

Flight simulator equipment used in the research appears in Figure 10 including mode control panel, yoke, CDU simulated on iPad mini, and throttle quadrant**.**

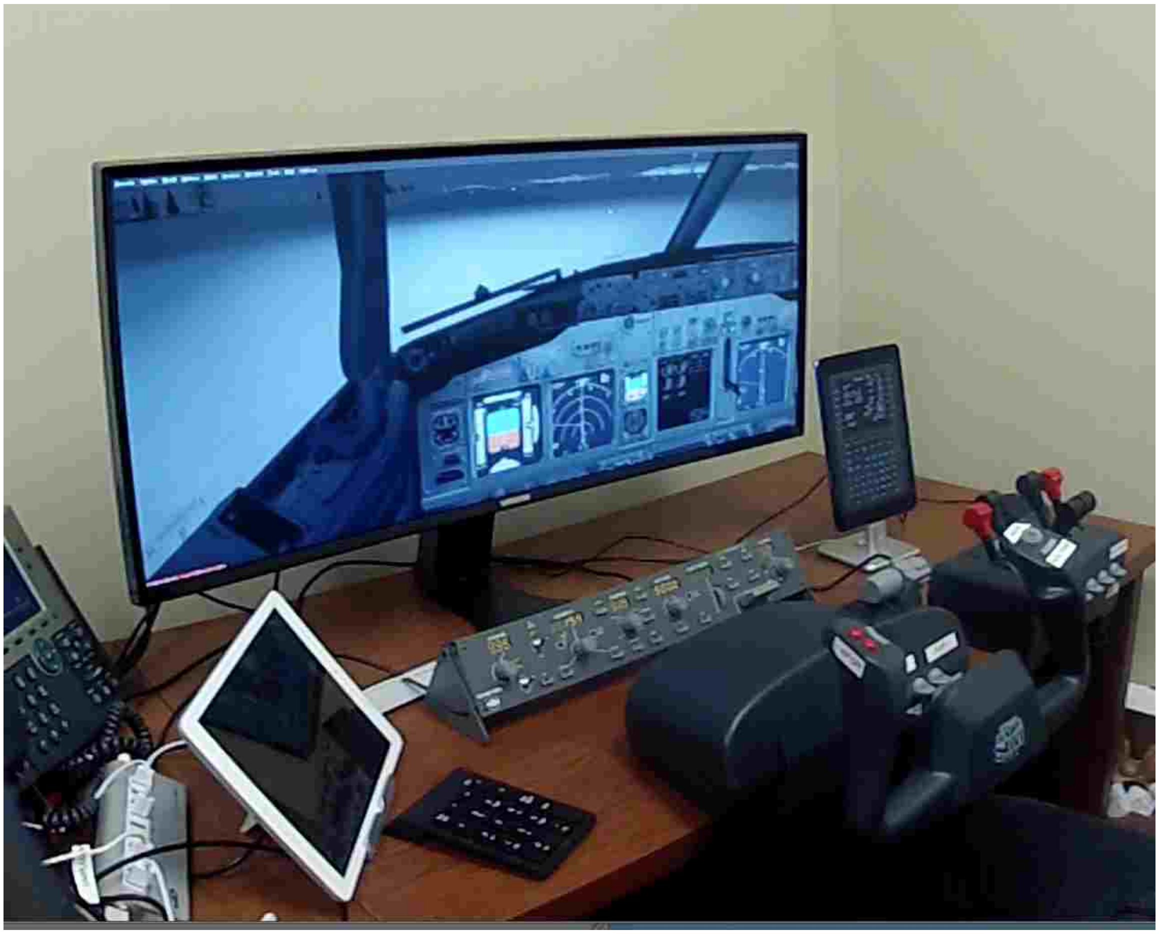

Figure 10: Flight simulator equipment used in the research

Before each experiment started, test subjects signed consent forms and provided basic demographic information. They were presented with an overview of the study and given an opportunity to review pre-flight paperwork as would be done before an actual flight. Pilots were briefed about the operation of the Prepare3D flight simulator and how to interact with an iPad Mini displaying a representation of the CDU. A hardware emulator of the B737 mode control panel was configured to work with the simulator. Test subject pilots were familiar with this device as it worked identically to what they use in the cockpit. The throttle quadrant hardware was adaptable to control either a 2 or 4 engine aircraft. The B737-800 uses two engines, and the middle two throttle levers were configured to control the port and starboard engines. The throttle quadrant also had switches that were configured to raise the gear, invoke thrust reversers, and activate throttle cut. The yoke had integral switches to provide elevator and rudder trim and raise or lower flaps. A TO/GA (take-off/go-around) button was located on the right yoke handle. Pilots used the system with ease as shown in Figure 11.

Figure 11: Test subject is adjusting the throttle before takeoff

Yoke configuration allowed pilots to take off as they would in real flight by pulling the yoke back for nose up and pushing it forward for nose down as shown in Figure 12. Rudder pedals were connected to the PC and operated as seen in actual aircraft.

Figure 12: Test Subject using the yoke to take off after V2 callout.

Nine pilots were recruited and each was put through three flight scenarios on the simulator. Test subject pilot recruitment efforts included; direct solicitation of pilots disembarking at Norfolk International Airport (ORF), placement of flyers in pilot lounges at ORF and Baltimore-Washington International (BWI) as well as recruitment of domestic and international pilots using their LinkedIn profiles and Twitter feeds. Pilot participants were encouraged to refer their colleagues and most participants were paid from personal funds as compensation for their time. During these simulated flights, they encountered different failure scenarios. At least one of the three flights included some questions posed to the test subject pilot relating to their flight. The purpose of this exercise was for pilot participants to answer the questions asked of them and while doing that pilots gathered more information regarding the status of their aircraft. All flights ended with some type of failure. Three failures (one per flight) were applied in a random order for the test scenarios for each pilot. Every pilot faced the same three failures but the particular flight in which a given failure occurred varied. Each flight lasted less than one hour. Among the limitations of the study were an absence of ATC, lack of a first officer, and no other air traffic. Budget constraints also limited the number of pilots who could be recruited.

The questions asked during one or a maximum two out of the three flights were intended to help the pilot gather up cues regarding their aircraft's status. The questions were asked in random order at random intervals included the following:

- What is the next waypoint?
- What is the speed of the aircraft? (They normally answered for both air speed and vertical speed)
- What is your divergent airport in case of emergency?
- What is your current altitude?
- What is the fuel flow?
- What is the distance to your final destination?

After the pilot's simulated flights were completed, they were interviewed about their experience using questions related to their flights and any implications regarding their situation awareness and vigilance level.

Validity of the Simulator.

The fidelity of the hardware and software used to conduct simulated flights reflects the validity of this experiment. The set up used a detailed simulation of the Boeing 737-800 developed by the software company PMDG. Their product was created with technical support from Boeing and the engine and flight modeling is within 5% of actual Boeing aircraft performance charts, including single engine operations. Virtual cockpit models and textures were created from Boeing engineering diagrams and thousands of photos from onboard actual aircraft. Sound accuracy was achieved through the recording of over 500 individual sounds from the real cockpit. The simulated weather radar is a working simulation of the Collins WXR-200 weather radar and depicts precipitation returns and also allows full control over tilt, gain, and radar mode including turbulence and windshear detection. The simulator's flight management computer (FMC) depicted Required Navigation Performance (RNP), Lateral Navigation (LNAV) leg bypasses, and highly accurate Vertical Navigation (VNAV) speed and altitude predictions. The set up featured Integrated Approach Navigation (IAN) and the full complement of scratchpad warning messages that a real crew could see. A senior Boeing 777 Captain and trainer from a major carrier flew the set up and verified it as an accurate simulation of this model aircraft. None of the pilots tested complained of inaccuracies in the simulation and only required a short familiarization flight to operate the simulator successfully. Three different failure scenarios were applied to each test subject in random order and random times. At least one or two of the three flights included reinforced cues.

Validity of the Experimental Flights

Test subject pilots were recruited online and at local airports using the distribution of hand fliers in pilot lounges. While all pilots held ATP licenses, they had a diverse background in terms of age, employer, experience level, and type rating. Pilots were "self" selected other than the requirement they hold a valid air transport license. Due to limited budget the number of airline pilots was less than needed to make statistically significant inference from the findings.

Unstructured Interviews for Evaluating the Phenomenology

Phenomenology is a research method focused on an individuals' experience in a particular environment i.e., for explaining the phenomenon those individuals are experiencing. From a phenomenological vantage point, interviews are part of the tradition of Theoretical Phenomenology (Marshall & Rossman, 1995). Under the domain of phenomenological research, interviews are also considered as the main tool to explore individuals' descriptions of their experience (Kvale, 1996). An unstructured interview can foster an exchange where the test subjects are more comfortable than they might be in a structured interview (Ramos, 1989).

Unstructured interviews are conducted without a formal template for asking questions. The interviewer asks broad questions of the test subject, and the exchange is not unlike an informal conversation. This differs from a structured interview as one would likely experience in a job interview. Unstructured interviews are not intended to evoke set answers and the interview is guided by the responses given by the interviewee. There is only a general theme in the make-up of the questions. This format is also known as unstandardized interviews and is predicated on the assumption that not much information exists about the topic of the interview, and this makes the use of predetermined questions inappropriate (Ryan, Coughlan, & Cronin, 2009).

This research already gathered sufficient information relating to how pilots feel about automated systems in the cockpit via the conducted survey, but an imagined experience can differ from a real experience. In the experimental part of this research, the goal was to understand whether the new phenomenon of reinforcing cues that pilots had never experienced before would make any difference in their opinions. This question could have been asked as part of the survey as well, but the reliability of the answers may not have been as strong compared to giving feedback immediately after they experienced it in a simulated flight. Unstructured interviews began by asking the pilots what they think about the reinforced cue detection model without referencing the model itself. They were asked if they felt the questions posed during their flight made a difference in their vigilance and situation awareness. Based on their answers, other questions were asked relating to the first answer; either asking them to elaborate on their first answer or continue with their comment to the first question. As an example, if a pilot referred to workload, the questioning continued as to how it affected the workload.

Why Unstructured Interviews

Unstructured or non-directive interviews differ from structured interviews in that they do not contain a set of prearranged questions. Reinforcing cues was a new experience that pilots had not been exposed to before, and it was decided not to limit their answers by using structured questions. Setting limiting boundaries for those questions could limit respondents' creativity, might bias their answers, and might prevent them from providing further recommendations to take into consideration. This interview structure is one where the answer to the first question leads to the second question. With this method the next question is structured according to the last answer they gave. Researchers cannot have the same knowledge on this subject that pilots have learned through their professional life. This fact limits the questions of the researchers using structured interviews. Unstructured interview methods, in contrast, allowed the researchers to learn more from the pilots since it gave them the freedom to elaborate on their ideas. At the same time, the researcher had the control to redirect the pilot if they started to wander far from the subject matter.

CHAPTER IV

RESULTS OF THE SURVEY AND REINFORCED CUE DETECTION MODEL

Exploratory Data Analysis of the Survey

The survey opened with a Yes/No consent question. If the pilot answered “Yes,” he or she continued to the survey questions but if the answer was “No” the survey terminated. The next twelve questions were demographic: (2) Age category ranging from 20 to 65 in 5-year increments plus a “65 and above” category; (3) Beginning year as a pilot; (4) Number of years flight experience; (5) Retired – Yes/No; (6) Current aircraft flown; (7) If retired, last aircraft flown; (8) Primary language spoken; (9) Seat – CAPT(1) or F/O(2); (10) Years/Months since completion of initial training in current aircraft; (11) Total flight time; (12) Total flight time in current aircraft; (13) Time in FMS equipped aircraft (other than your current aircraft) by type with the 15 most widely used FMS equipped aircraft listed plus and other category.

Questions 14 through 51 were Likert-style survey questions with anchors including, 1 – strongly agree, 2 – agree, 3 – neither agree nor disagree, 4 – disagree, to 5 – strongly disagree. Total of five domains are; Trust, Interface, Monitoring, Policies and Training-Performance, and were randomly selected for insertion of one negatively worded consistency question each to assess internal validity. The questions are listed in the Appendices section.

From an initial pool of 79 survey participants, two were eliminated since they did not answer 3 or more questions. If the pilot omitted only one or two answers, the rest of their answers were included and the missing answers were assigned option 3; the neither/nor option. For the seventy-seven (77) pilots who completed the survey, their demographics were as follows.

- Primary language: Turkish 26, English 18, Portuguese 13, German 5, Dutch 7, French 3, Danish 1, Italian 2, Spanish 1, and Hungarian 1. Thus, survey results may reflect the perceptions of primarily North and South American, European, and Middle Eastern pilots.
- Age categories count: 20-25 age 1; 26-30 age 12; 31-35 age 28; 36-40 age 11; 41-45 age 7; 46-50 age 11; 51-55 age 5; 56-60 age 1; and 61-65 age 1.
- Years flight experience: minimum = 3, median = 9, average = 14.1, and maximum = 45. Years flight experience by age group: 26-30 age 6.67 years; 31-35 age 10.0 years; 36-40 age 10.6 years; 41-45 age 20.4 years; 46-50 age 28.6 years; 51-55 age 33.5 years; 56-60 age 34.0 years; and 61-65 age 45.0 years.
- Flight time: minimum 250 hours, median 4,500 hours, average = 6,722, and maximum = 21,400 hours
- Seat 1(Captain) – 24 and seat 2(F/O) – 53.

Internal Consistency Reliability Check

The questions analysed for consistency are summarized in Table 2. Question 14, “automation in the cockpit made my job easier”, was checked for consistency by question 19, “automation in the cockpit made my job harder”. Responses were compared for two questions. When asked if “ automation made the pilots’ lives easier” a total of 75 out of 77 pilots agreed or strongly agreed their job got easier while 69 out of 77 disagreed or strongly disagreed that “automation made their lives harder”.

Question 34 was also cross checked by Question 37. Question 34 was “response to visual warnings are better than aural (sound) alerts, and Question 37 “response to aural (sound) alerts are better than visual warnings". While a total of 34 pilots disagreed or strongly disagreed that they respond to visual warnings better than sound alerts, a total of 37 pilots agreed or strongly agreed they respond to sound alerts better than visual alerts. This was one of the highest scored consistency checks which showed that most pilots prefer aural alerts over visual warnings.

Question 47's consistency was evaluated by Question 50. While Q47 stated, "difficulties in understanding automation can be overcome solely by training", Q50 stated "training is not the only answer for improving a pilot's ability to understand cockpit automation". A total of 56 pilots agreed or strongly agreed and a total of 15 pilots disagreed or strongly disagreed with Question 47. For question 50, a total of 47 pilots agreed/strongly agreed and a total of 17 pilots disagreed, strongly disagreed. Analysis of Kendall's tau correlations and consistency rates can be found in Table 3.

Table 2: Questions analysed for pilot response consistency.

Question	**St. Agr.**	**Agree**	**Neither**	**Disagree**	**St.Dis.**
Q14	37	38	1	1	0
Q19	0	5	3	42	27
Q34	2	14	27	32	2
Q37	7	30	26	14	0
Q47	16	40	6	14	1
Q50	7	40	13	13	4

Table 3. Confidence in pilot response consistency.

Question Pair	**Consistency Rate**	**Kendall's Tau**	**2_Sided p-value**
Q14-Q19	87.66%	-0.619	1.3153e-08
Q34-Q37	92.90%	-0.647	8.8317e-11
Q47-Q50	32.92%	-0.371	0.0001774

Explaining the Consistency Rates:

Q14-Q19:

(69/75)(144/154)+(1/5)(6/154)+(1/3)(4/154)=87.66%

Q34-Q37:

(14/16)(30/154)+(34/37)(71/154)+(26/27)(53/154)=92.9%

Q47-Q50:

(17/56)(73/154)+(15/47)(62/154)+(6/13)(19/154)=32.92%

Although the results for Q47-50 does not show significant consistency, having -0.371 Kendall's Tau value and 0.0001774 two-sided p value indicates statistical significance and it represents sufficient consistency.

Exploratory Frequency Analysis for the Survey

Table 4 presents the response percentage distributions by domain and question. Bold-italic percentages identify the modal class. Where two classes were within 5%, both are identified as modal classes.

In the Trust domain, there was strong agreement or agreement with questions Q14T automation makes job easier, Q15T automation increases engagement, Q16T rely on automation, Q17T automated flight planning and workload, Q20T comfort with VNAV and LNAV autopilot controls, Q21T confusing communications from automation, and Q22T rely on flight envelope protection. There was disagreement or strong disagreement for question Q18T *"I trust automation more than myself"*.

Table 4: Response percentage distributions by domain (***Bold-Italics*** = modal class).

Domain	Question	Strongly Agree	Agree	Neither/Nor	Disagree	Strongly Disagree
Trust	14T	**48.0519**	**49.3506**	1.2987	1.2987	0
	15T	16.8831	**40.2597**	31.1688	11.6883	0
	16T	11.6883	42.8571	28.5714	14.2857	2.5974
	17T	29.8701	**51.9480**	3.8961	2.5974	11.6883
	18T	1.2987	11.6883	18.1818	**33.7662**	**35.0649**
	20T	0	5.1948	7.7922	**54.5454**	32.4673
	21T	2.5974	12.9870	27.2727	**50.6493**	6.4935
	22T	5.1948	**31.1688**	20.7792	**28.5714**	14.2857
Monitoring	23M	31.1688	**50.6493**	11.6883	6.4935	0
	24M	**51.9480**	42.8571	2.5974	2.5974	0
	25M	24.6763	**55.8441**	15.5844	3.8961	0
	26M	1.2987	2.5974	18.1818	**57.1428**	20.7792
	27M	2.5974	35.0649	16.8831	**41.5584**	3.8961
	28M	1.2987	3.8961	11.6883	**54.5454**	28.5714
	29M	**46.7532**	**44.1558**	5.1948	2.5974	1.2987
	30M	0	6.4935	5.1948	**53.2467**	35.0649
	31M	12.9870	**76.6233**	10.3896	0	0
	32M	20.7792	**61.0389**	7.7922	10.3896	0
Interface	33I	2.5974	3.8961	16.8831	**57.1428**	19.4805
	35I	48.0519	**50.6493**	1.2987	0	0
	36I	19.4805	**63.6363**	10.3896	6.4935	0
	37I	9.0909	**38.9610**	33.7662	18.1818	0
	38I	0	12.9870	16.8831	**62.3376**	7.7922
Policies	39P	36.3636	**57.1428**	6.4935	0	0
	40P	18.1818	**66.2237**	5.1948	10.3896	0
	41P	15.5844	20.7792	19.4805	**25.9740**	18.1818
	42P	9.0909	**40.2597**	27.2727	22.0779	1.2987
	43P	33.7662	**63.6363**	2.5974	0	0
	44P	12.9870	**55.8441**	25.9740	5.1948	0
	45P	25.9740	**46.7532**	14.2857	10.3896	2.5974
Training/Perf.	46R	**49.3506**	31.1688	14.2857	3.8961	1.2987
	48R	**41.5584**	31.1688	12.9870	10.3896	3.8961
	49R	**46.7532**	**42.8571**	6.4935	3.8961	0
	50R	9.0909	**51.9480**	16.88311	16.88311	5.1948
	51R	12.9870	**77.9220**	5.1948	3.8961	0

Histogram for the Question 14 displayed below indicated majority of the pilots think automation in the cockpit made their lives easier.

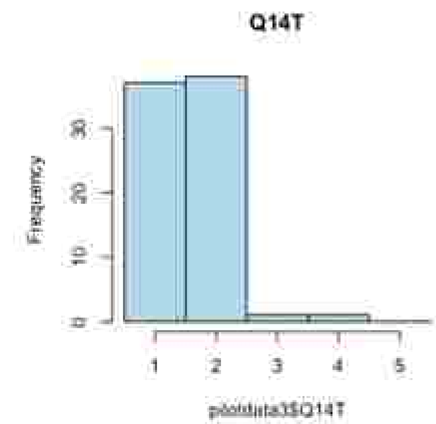

Figure 13: Answers for Q14

Answers for question 15 indicated more than 16% of the pilots strongly agreed and more than 40% of them agreed that automation kept them engaged throughout their flights; a good portion (31%) of the pilots were hesitant, neither agreeing nor disagreeing to this question.

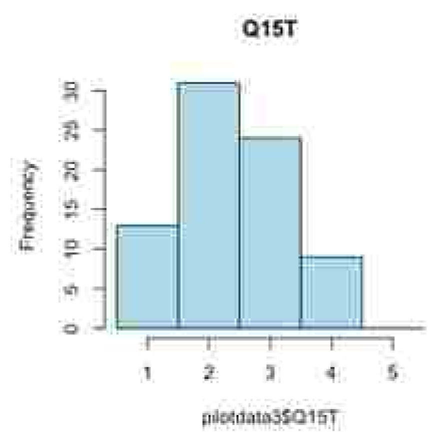

Figure 14: Answers for Q15

The majority of the pilots (43%) agreed that they rely on automation to keep them safe while 28% chose not to give a clear answer to this question by choosing neither to agree or disagree on Question 16.

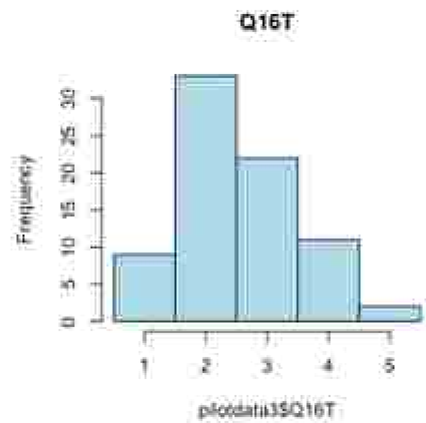

Figure 15: Answers for Q16

The answers given for Question 17 favored the use of automation with a majority of pilots strongly agreed or agreed that using flight management computers for flight planning lowered their workload. Almost 52% of them agreed on this with nearly 30% of the pilots strongly agreeing while almost 12% of the respondents strongly disagreeing. Results are illustrated by the histogram below.

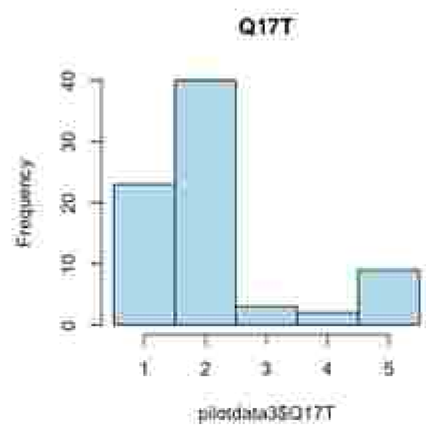

Figure 16: Answers for Q17

Up to this point although a majority of pilots agreed that automation is beneficial in many respects, they do not trust automation more than they trust themselves. Results are illustrated below for Question 18 as expressed "*I trust automation more than I trust myself*".

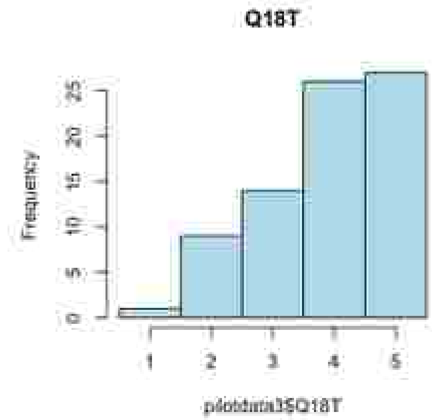

Figure 17: Answers for Q18

Question 19 was designed to check the consistency of participants' answers; we did not include those answers since it provided a consistency of 87.66%. Question 20 asked conversely as follows: *I don't feel comfortable when autopilot controls vertical and horizontal flight paths (VNAVs and LNAVs).* Results shown below. The majority of pilots disagreed or strongly disagreed to this statement and it reflects their overall positive attitude for these automated systems. A total of 87% of participants opposed the statement in this question.

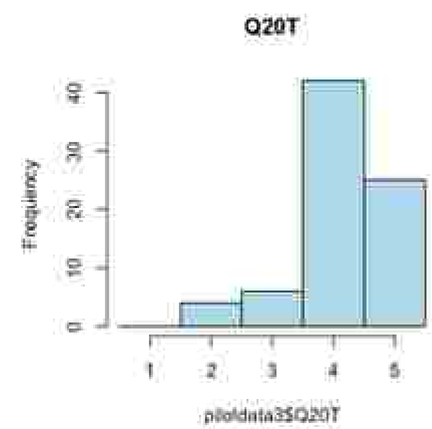

Figure 18: Answers for Q20

Question 21 stated "*The biggest obstacle to overall flight safety is ad-hoc and confusing communication from automated systems in the cockpit"* and again the majority of pilots (50.6%) disagreed and over 6% strongly disagreed however there was a large percentage of the pilots who chose the neither/nor option with over 27%.

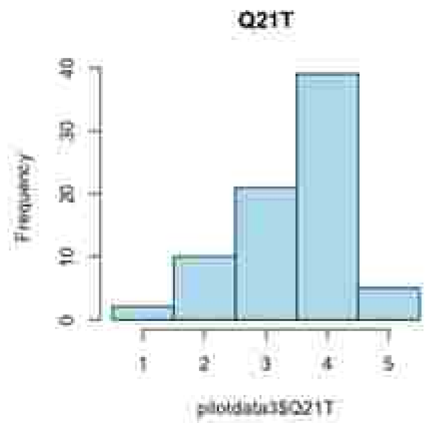

Figure 19: Answers for Q21

Question 22 indicated varying results, 31% of the pilots agreed while almost 28% of them disagreed in their response to this question, "*when equipped, I rely on flight envelope protection to protect my aircraft and passengers in case I make any mistake".* Mixed responses indicate contradictory feelings amongst the pilots regarding flight envelope protection on their aircraft. Results are displayed in Figure 20 below.

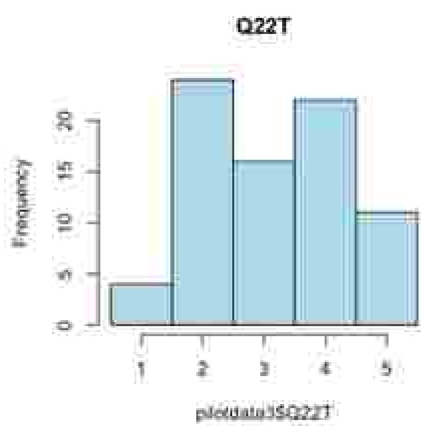

Figure 20: Answers for Q22

In summary, in the Trust domain of the survey, pilots reported that automation is beneficial, makes piloting easier, and increases their engagement with and reliance on automation, but pilots do not trust automation over their own judgment.

Questions between 23 and 32 were designed to understand pilots' attitude for cockpit automation regarding "Monitoring" of automated systems. The answers for Question 23 indicated great consensus amongst pilots as they agreed or strongly agreed that they always check their next waypoints and are aware of pending heading changes with a total of 81.8% as displayed by the histogram in Figure21.

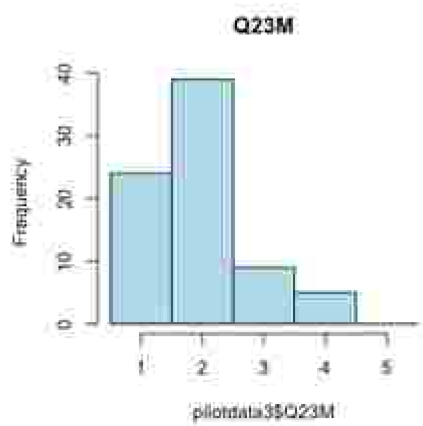

Figure 21: Answers for Q23

Question 24 about checking the primary flight display very often brought similar answers as shown below in Figure 22.

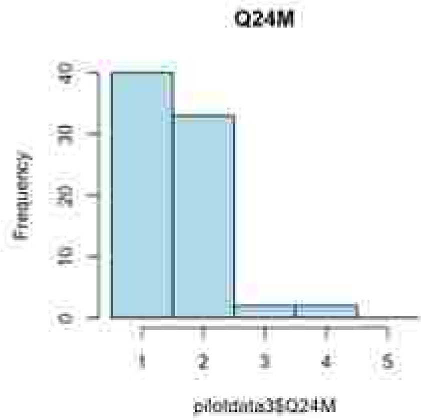

Figure 22: Answers for Q24

Most pilots agreed/strongly agreed again on question 25 which stated *"Information represented on the Control Display Unit (CDU) is clear and easy to understand"; almost* 56% of them agreed and nearly 25% strongly agreed on this statement.

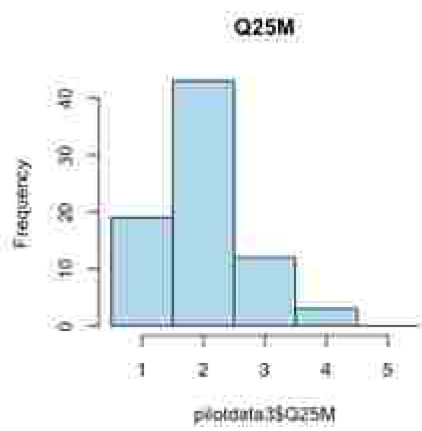

Figure 23: Answers for Q25

Question 26 projected a reverse attitude towards automation by stating "*Automation increased my workload, created more need to monitor*"; 57% disagreed and 20% strongly disagreed while 18% chose neither/nor option for this question. Again, pilots did not think automation increased their workload.

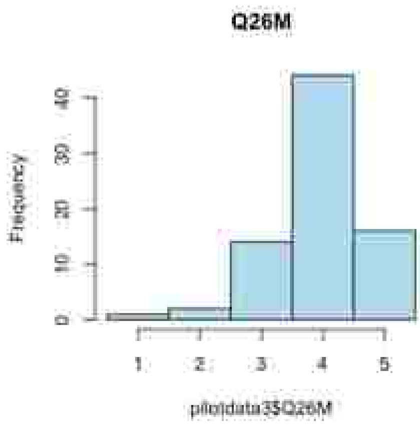

Figure 24: Answers for Q26

One the most interesting results came out of the answers for Question 27 which stated, "*During the automated flight phase, I am sometimes surprised by actions automation takes",* bimodal results indicated mixed feelings about "automation surprises", while 35% of the pilots stated they were sometimes surprised, 41 % of them disagreed with this statement.

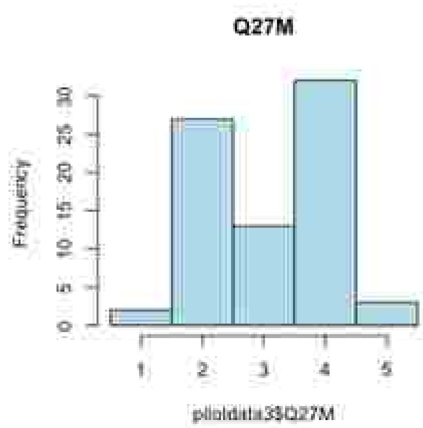

Figure 25: Answers for Q27

Question 28 was another reverse statement saying, "When I use autopilot to control HDG, SPD or ALT I feel automation creates distraction". As a consensus pilots disagreed or strongly disagreed about this with a total of more than 83% responses.

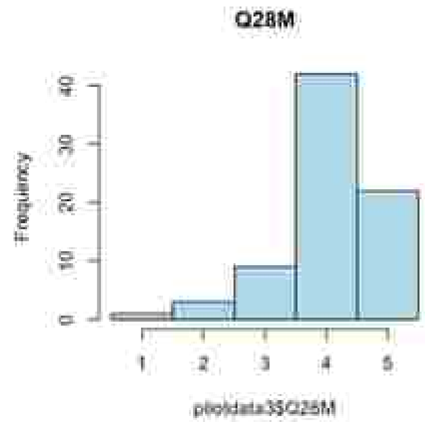

Figure 26: Answers for Q28

The majority of pilots agreed/strongly agreed that they check the flight mode annunciator often to understand the autopilot modes as asked in Question 29. Almost 47% of them strongly agreed, and 44% of them agreed. A total of 91% positive responses indicated that the majority of the pilots are diligent in checking autopilot modes.

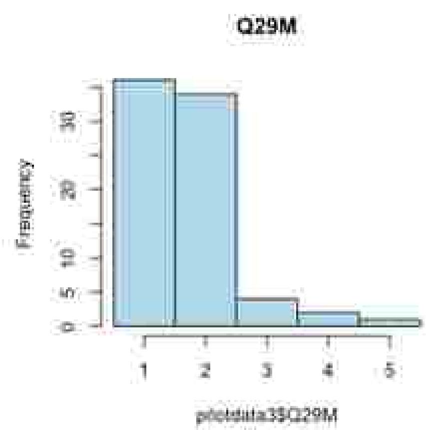

Figure 27: Answers for Q29

Question 30 was in the same direction as Question 28; statement made in a negative way to understand pilots' input towards the autopilot control modes. A total of 88% pilots disagreed or strongly disagreed to the statement "When I use autopilot to control HDG, SPD or ALT my understanding of the big picture diminishes". Once again pilots' answers were in support of automated systems. Results are shown in the Figure 28 below.

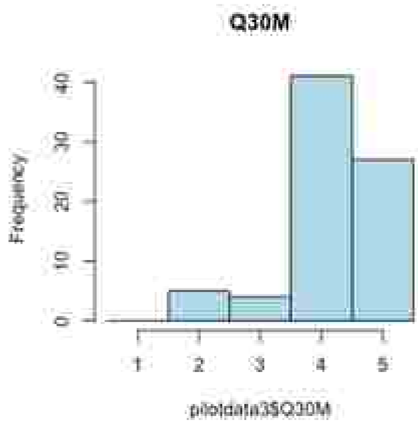

Figure 28: Answers for Q30

Pilots stated in Q31 (with 79% agreed and 13% strongly agreed) they could predict the behavior of the automation with ease; a histogram demonstrates the results in Figure 29.

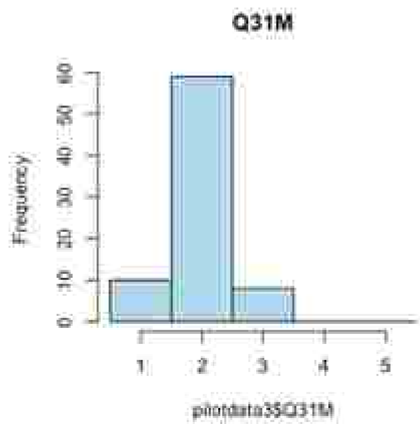

Figure 29: Answers for Q31

They also had a consensus in Q 32, using autopilot to control HDG, SPD or ALT their workload becomes lower with a total of 82% positive responses.

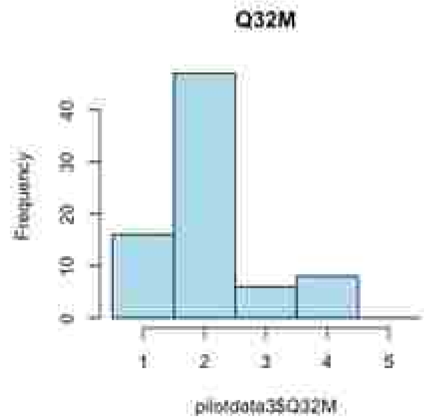

Figure 30: Answers for Q32

Questions between 33 and 38 were designed to understand pilots' attitude towards the cockpit automated systems' interface and how it relays information to the pilots. When the question 33 directed as "*overall information on the aircraft is too much"* almost 77% of the pilots disagreed or strongly disagreed.

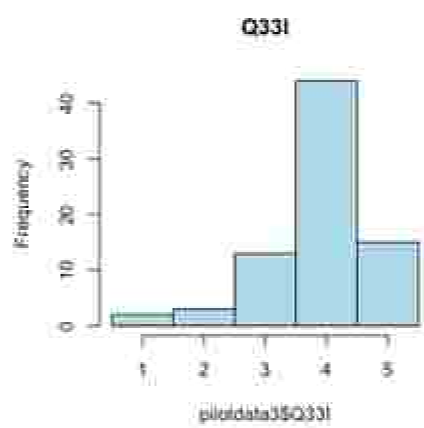

Figure 31: Answers for Q33

Question 34 and reverse question 37 for the consistency check provides insight about how pilots think auditory warnings are a lot more useful for them versus visual warnings. Since the consistency rate was very high with 92.9%. Kendall's Tau value was -0.647 with 8.8317e-11 two-sided p value. Q 34 was eliminated and only, Q37 will be analyzed in upcoming paragraphs.

Almost all the pilots confirmed that if a master caution alert occurs, it takes their attention immediately. Total of 98.7% of the respondents agreed or strongly agreed on this statement indicated by Q35.

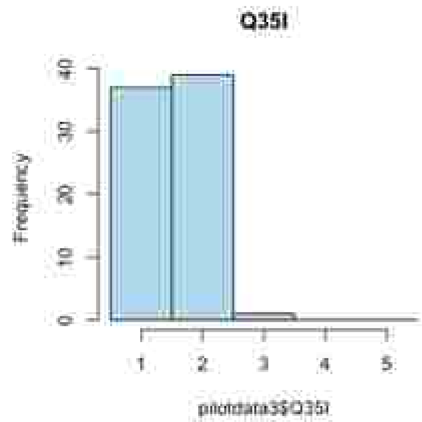

Figure 32: Answers for Q35

Question 36 was about pilots' trust for the master caution and warnings. Over 83% of the pilots agreed or strongly agreed that they believe the caution alerts are real, 10% chose not to give a specific answer, while 6.5 % stated they do not think all those alerts are real by choosing the disagree option on the survey.

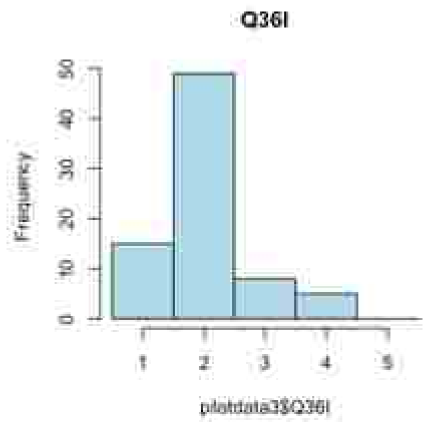

Figure 33: Answers for Q36

Question 37 is one of the benchmarks for this research and it needs to be considered for future designs of the flight deck and any other human machine collaborative systems. These answers also indicate great consistency when it was asked reversely in Q 34. Pilots want more auditory feedback versus visual. Histogram indicates the results for Q37 below in Figure 34.

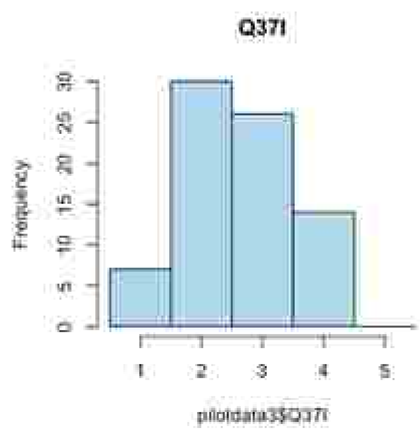

Figure 34: Answers for Q37

Answers for Q38 reversely asked as "*overall available information on the aircraft is not enough*"; over 70% of the respondents disagreed or strongly disagreed about this. Pilots do not think the information is not enough, and, also with Q33, they do not think the information is too much; the majority is satisfied with the amount of information displayed. Questions between 33 and 38 were designed to understand pilots' attitude towards the cockpit automated systems' interface and how it relays information to the pilots.

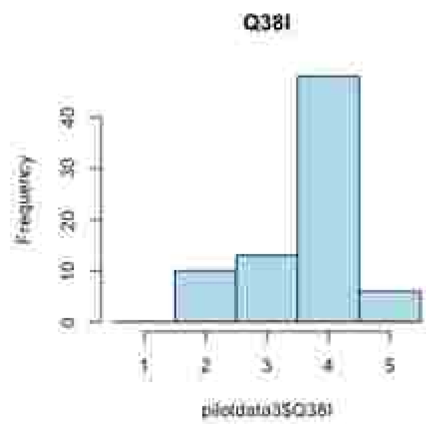

Figure 35: Answers for Q38

Questions between 39 and 45 were designed to understand pilots' attitude towards the policies applied by their companies and regulatory institutes. Almost all of the respondents, a total of 93.5% agreed or strongly agreed they always follow SOPs when they were facing a problem, indicated in Q39.

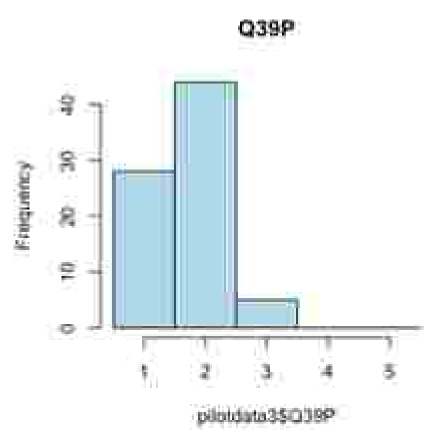

Figure 36: Answers for Q39

Majority of pilots agreed/strongly agreed that automation should prevent aircraft from exceeding its performance envelope as stated in Q40. Though 84.5% of the pilots agreed or strongly agreed on this question, over 10% disagreed.

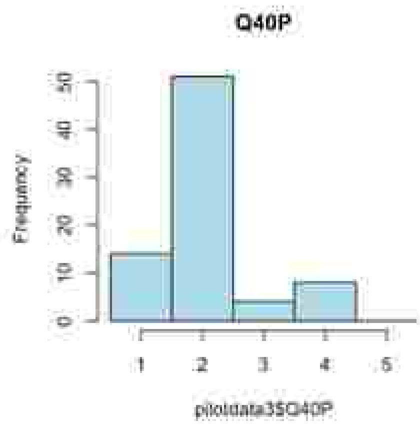

Figure 37: Answers for Q40

Question 41 was not an easy one to answer, although pilots' personal information is kept anonymous, they might still have some skepticism about this assurance, since almost 20% of the pilots chose neither/nor option; while 36% of the pilots agreed or strongly agreed, 44% of them disagreed/strongly disagreed when the question directed as:

> "*My airline doesn't allow me to fly manually; they force me to fly automated most or all of the time*".

The results indicate significant variety amongst the pilots, a large portion agreed, and another big portion disagreed, which could be the result of different cultures in different airlines from different countries. This might be related not only to their geographical culture but also a result of different companies following different rules and regulations. Also, this may be the result of a newer generation of pilots who are learning to fly with automation integrated into their routine training versus older pilots who learned how to fly manually first and then integrated automated systems into their flying routines. Results of this question are shown in figure 38.

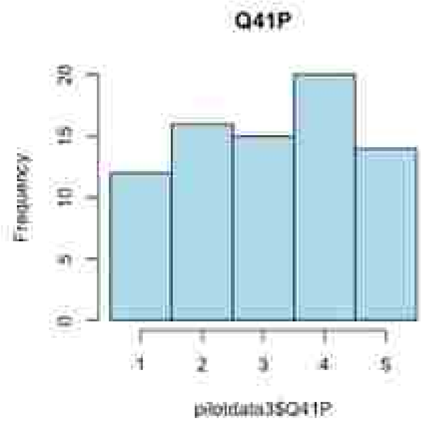

Figure 38: Answers for Q41

Many respondents, almost 50%, agreed or strongly agreed that they try to understand the bigger picture before following the SOP's when a problem develops in the cockpit as asked in question 42. Also notable in the responses of this question was the large number of pilots (27%) who did not want to answer this by choosing the neither/nor option; 23% disagreed or strongly disagreed on this.

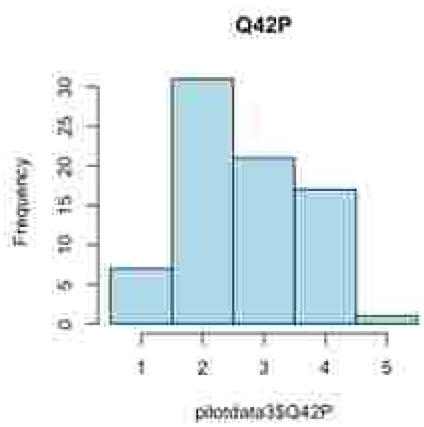

Figure 39: Answers for Q42

There was a great consensus on the answers for Q43. 97.5 % pilots agreed or strongly agreed saying they always adhere to CRM rules, only 2.5 % chose neither/nor option. No pilot chose the disagreed or strongly disagreed option.

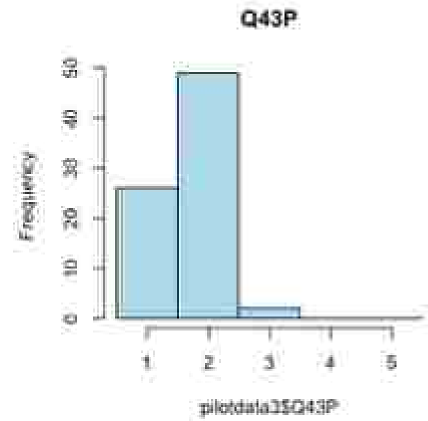

Figure 40: Answers for Q43

Question 44 was designed to understand pilots' view regarding if automation should comply with CRM rules and 69% agreed or strongly agreed, almost 26% chose neither/nor option, and just over 5 % of the pilots disagreed on this question. None of the pilots chose the strongly disagree option. This shows pilots believe automation in the cockpit should comply with CRM rules, as they are required to do.

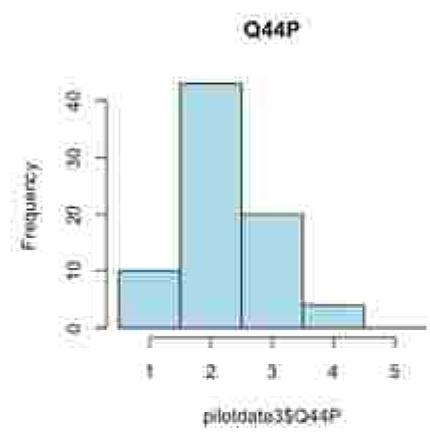

Figure 41: Answers for Q44

Question 45 stated that pilots should be warned when exceeding flight envelope protections but not have their control restricted. Answers for this question confirmed most of the pilots agreed/strongly agreed on it with 72%, while only 13% disagreed or strongly disagreed, and just over 14% of the respondents chose neither/nor option.

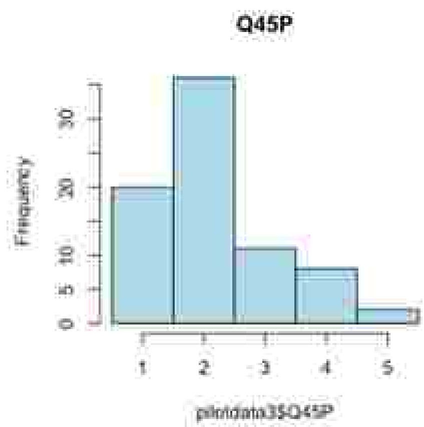

Figure 42: Answers for Q45

Questions between 46 and 51 were designed to understand pilots' concerns towards current training protocols required by their companies and rule makers such as FAA. Question 46 stated "*a high level of competency in manual flying skills would benefit the industry*", over 82% of the pilots agreed or strongly agreed about this, 13% disagreed or strongly disagreed, and 14% chose neither/nor option. Pilots' responses aligned with current literature and research that emphasizes the importance of keeping manual flight skills proficient.

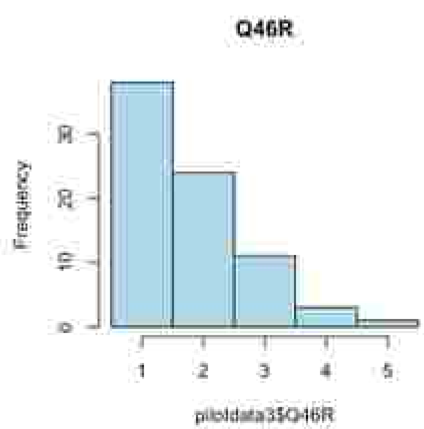

Figure 43: Answers for Q46

Question 47 designed to check consistency for the responses of Q50 and therefore the responses for 47 will not be included. Question 48 was an extension of the Q46. Over 72% of pilots believed that a number of recent airline accidents could have been avoided if pilots had been more proficient in manual flying skills, 13% disagreed or strongly disagreed, while 14% chose neither/nor.

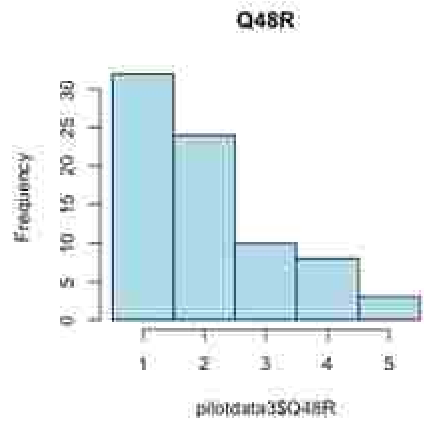

Figure 44: Answers for Q48

Question 49 gathered pilot's input regarding if airline companies should emphasize more training of manual flight skills to keep these skills current. Almost 90% of the pilots agreed or strongly agreed on this statement while only 3.9 disagreed. There was no strongly disagreed option chosen, and only 6.5 % of the respondents chose neither/nor option.

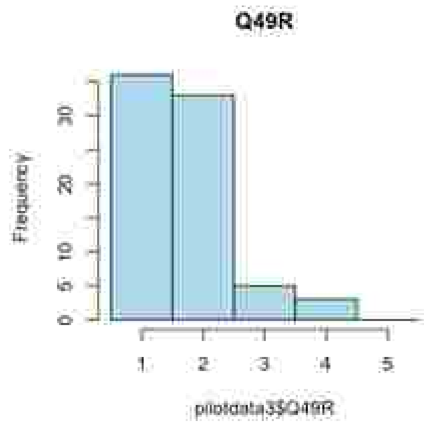

Figure 45: Answers for Q49

Question 50 was designed to check the consistency of the Q47. The question was written as "*training is not the only answer for improving a pilot's ability to understand cockpit automation*". A majority of the pilots, 61%, agreed or strongly agreed, and 21% of the pilots disagreed or strongly disagreed, while 16 % chose neither/nor option.

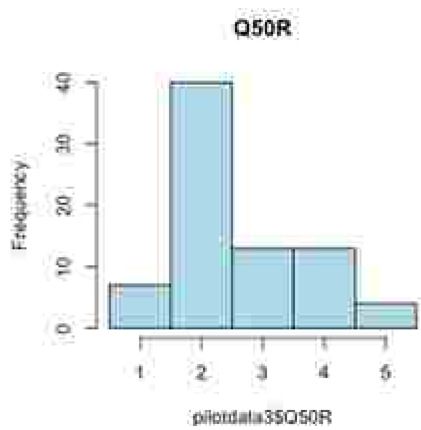

Figure 46: Answers for Q50

Question 51 was the last question of the survey in Likert scale and referred to pilots who trained in the last 15 years. It asked about learning the management of automation as an integral part of learning to fly an aircraft. Over 90 % of the pilots agreed or strongly agreed to this statement while less than 4 % disagreed. There was no strongly disagreed chosen for this question. The histogram presented below in Figure 47.

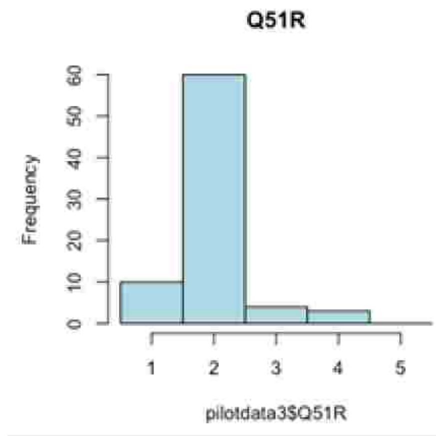

Figure 47: Answers for Q51

As of summary of exploratory data analysis; in the Trust domain, there was strong agreement or agreement with questions Q14T automation makes job easier, Q15T automation increases engagement, Q16T rely on automation, Q17T automated flight planning, Q20T comfort with VNAV and LNAV autopilot controls, Q21T clear and orderly automation communications, and Q22T rely on flight envelope protection. There was disagreement or strong disagreement for question Q18T, I trust automation more than myself. In summary, pilots reported that automation communication is beneficial, makes piloting easier, and increases their engagement with and reliance on automation, but pilots tend to not trust automation over their own judgment.

In the Monitoring domain, pilots were strongly agreed with Q24M checking primary flight display often and Q29M checking the flight mode annunciator often. Pilots agreed with Q23M always check next waypoint, Q25M control display information is clear, Q26M automation does not increase the workload (this question asked reversely), Q28M autopilot HDG, SPD, or ALT control does not create distraction (this question directed in the reverse way as well), Q30M autopilot HDG, SPD, and ALT control does not diminish their understanding (this was another reverse question directed as *"when I use autopilot to control HDG, SPD or ALT my understanding of the big picture diminishes"*), Q31M predict automation behaviour, and Q32M autopilot HDG, SPD, or ALT control reduces workload. Q27M, surprised by automation, was bi-modal with 35% agreeing and 41% disagreeing. These responses indicate that pilots interact with automation, believe they can predict its behaviour, think that autopilot and general automation control reduces their workload, increases understanding of their aircraft, and increases understanding of flight parameters. However, significant portion of the pilots are sometimes surprised by automation actions, which is consistent with current literature.

In the Interface domain, pilots' agreed with Q35M master caution alerts get their attention immediately and with Q36M to trust master caution and warning alerts. Pilots disagreed with Q33M available aircraft information is too much, and Q38M available aircraft information is not enough. Combining end-anchoring points Q33M and Q38M, on average pilots consider aircraft information about right. Pilots also disagreed with Q34M that they respond to visual warnings more than aural warnings and this was confirmed by their response to Q37M in which they agreed they react to aural alerts better than visual warnings.

In the Policy domain, pilots agreed with Q39P always follow SOP when facing problems, Q40P automation should prevent exceeding performance envelope, Q42P understand broader picture before following SOPs, Q43P adhere to CRM principles, Q44P regulations should require automation to adhere to CRM principles, and Q45P automation should warn of flight envelope exceedance but not restrict pilot control. From the uniformly distributed responses to Q41P, airlines are not consistent in their view of policies requiring automated versus manual flight control.

In the Training/Performance domain, pilots strongly agreed with Q46R high level of manual flying skills would be beneficial, Q48R recent accidents/incidence could have been avoided with more manual flying skills proficiency, and Q49R airlines should facilitate more training in manual flying skills. Pilots disagreed with Q47R sole training can overcome difficulties understanding automation and they agreed with Q51R pilots trained in last 15 years learn to manage automation as part of learning to fly an aircraft.

Correlations Between Answers and Demographics

A summary of the Spearman's rho analysis results is listed below in Table 5. This analysis was published earlier (Taylor & Cotter, 2017). The majority of the questions showed little correlation to demographics while some presented significant values as in question 41 with its correlations in all demographic metrics. Some other questions presented significant values when their correlation was analyzed with certain demographics.

Table 5. Spearman's rho Analysis Results of Correlations, (Taylor and Cotter 2017)

	AGE CORRELATION		FLIGHT TIME CORRELATION		SEAT CORRELATION	
Question	P Value	rho value	P Value	rho value	P Value	rho value
14T	0.4435	-0.09649845	0.3614	-0.1148596	0.3318	-0.1220778
15T	0.3202	0.1250285	0.04319*	0.2519175*	0.8869	-0.0179602
16T	0.5583	-0.0737674	0.8297	-0.0271408	0.7818	-0.0349471
17T	0.5853	-0.0687781	0.9951	0.00080337	0.03171*	-0.267215*
18T	0.5481	-0.0756889	0.4077	0.1042358	0.938	-0.0098359
20T	0.5592	0.07360259	0.8818	0.01876821	0.6101	-0.0642827
21T	0.5879	-0.0682990	0.9369	0.01000136	0.5361	-0.0779754
22T	0.4776	-0.0894496	0.5731	0.07103051	0.1678	-0.172994
23M	0.04345*	0.2516151*	0.6483	0.05750804	0.2598	-0.1415972
24M	0.5449	0.07630008	0.3147	-0.1264407	0.1452	-0.1825885
25M	0.2558	0.1427997	0.7	0.04859951	0.1564	-0.1777282
26M	0.3989	0.1061991	0.3101	0.1276432	0.05153	-0.2428171
27M	0.446	0.09597444	0.1787	0.1687076	0.6148	-0.0634507
28M	0.4317	-0.099004	0.7136	-0.0463009	0.9408	0.009394
29M	0.353	-0.116861	0.0577	-0.2368299	0.3799	-0.1105084
30M	0.1669	-0.1733567	0.02365*	-0.281050*	0.6862	-0.0509563
31M	0.03671*	0.260065*	0.2806	0.1356485	0.1892	-0.1647623
32M	0.1534	-0.1789733	0.1522	-0.1794904	0.9465	0.0084826
33I	0.6624	0.0550644	0.99	0.0015979	0.09948	-0.206118
34I	0.6101	-0.0642900	0.2133	-0.1562617	0.6852	0.0511191
35I	0.588	-0.0682904	0.7578	0.0388974	0.2837	-0.1347652
36I	0.9289	-0.0112800	0.7835	-0.0346698	0.9727	-0.0043356
37I	0.87	0.0206588	0.5206	-0.0809387	0.3691	0.1130216
38I	0.6135	0.0636755	0.6829	-0.0515121	0.4697	0.0910665
39P	0.4703	-0.0909405	0.2352	-0.1491154	1	0
40P	0.1731	-0.1708912	0.1959	-0.1623196	0.7852	0.0343832
41P	0.01108*	-0.314239*	0.03674*	-0.260028*	0.007595*	0.329557*
42P	0.3224	-0.1244548	0.5532	-0.0747318	0.9632	0.0058482
43P	0.959	-0.0065038	0.4221	0.1010808	0.297	-0.1311213
44P	0.09568	0.2084284	0.09762	0.2072422	0.188	-0.165213
45P	0.7993	-0.0320841	0.355	-0.1163816	0.3255	-0.1236797
46R	0.5701	-0.0715828	0.00345*	-0.359411*	0.3839	0.1095972
47R	0.05738	-0.2371291	0.2914	-0.1326616	0.7442	-0.0411555
48R	0.7875	-0.0340155	0.02281*	-0.282718*	0.339	0.1202913
49R	0.9436	0.0089371	0.08947	-0.2123669	0.1349	-0.1873406
50R	0.3504	0.1174969	0.9684	-0.0050142	0.2981	0.130825
51R	0.9168	0.0132042	0.639	0.0591495	0.4091	-0.1039135

Question 23M, "*I always check my next waypoint and I'm aware of pending heading changes*" was part of the Monitoring dimension and showed statistical significance when analyzed by age group. This question indicated correlation with 0.04345 p-value and 0.25161 rho value. Younger pilots more strongly agreed they always check their next waypoints and that they are aware of pending changes. Another statistical significance was revealed in Question 31. Younger pilots more strongly agreed they could foresee the behavior of automation when compared to older pilots. Though no survey respondents choose disagree or strongly disagree, there was a correlation between age and the remaining answers of strongly agree, agree, or neither nor. For these alternatives, 12% strongly agreed, 79% agreed, and 9% choose the neither/nor option. Advances in automation and the emphasis on its benefits without adequate consideration of its limitations have resulted in airline companies requiring their crews to use automated systems throughout most of their flights. The question broaching this issue brought the most variety of answers. Question 41 stated "*my airline doesn't allow me to fly manually, they force me to fly automated most or all of the time*" had variety of the answers selected. Results of this question indicated older pilots were more likely to agree that their companies do not allow them to fly manually when compared to younger pilots' responses. This could be a result of different training experiences for younger and older pilots regarding their interaction with cockpit automation. The newer generation of pilots had automation integrated in their training early while older pilots learned to fly manually first and later added automation. More recently trained pilots see flying with highly automated cockpit systems as an expected and normal routine. They usually have much less experience conducting flights manually (Taylor & Cotter, 2017).

Crew Resource Management is a critical element of the Aeronautical Decision Making (ADM) process and discourages pilots from acting macho or being too obedient and encourages them to speak up freely when needed regardless of seniority or cultural differences (*FAA Advisory Circular,* 2004). Complying with CRM by using standard call outs and sharing the work amongst the cabin crew is very important for any flight. During the student pilots' training they need to follow these procedures. A pilot flying cannot transfer the flight controls to the pilot monitoring without performing the necessary multi-way call-outs. Call-outs are very important in aviation to maintain situational awareness in the flight crew (Degani & Wiener, 1994). In contrast, the automated systems in the cockpit such as autopilot can disengage without these call-outs; a short sound from the autopilot and it assumes all the controls are transferred to the pilot (Taylor & Cotter, 2017). These are some of the known current problems with automation and human interaction. The survey question related to CRM and the pilot's responses is consistent with the current literature. Question 44 asked if *Regulations should require cockpit automation to adhere to the principles of CRM when feasible.* Majority of the participants agreed or strongly agreed, less than one fourth chose not to answer (neither agreed or disagreed) and only few pilots disagreed.

There was no correlation between the answers and age groups in this question regarding if automated systems should adhere to CRM principles, but this question is important for the governance aspect of the human-machine interaction in the cockpit (Taylor, 2017).

Question 15, "*automation keeps me engaged throughout the flight*", showed some statistical significance regarding the correlation between pilot answers and flight time. The results indicated pilots with less flight time were more likely to agree with the statement compared to pilots with more flight time. Pilots with fewer flying hours more strongly agreed that automation keeps them engaged with their flight compared to pilots with more flight time. A small percent of respondents strongly agreed while the largest block of them, agreed with this question. Surprisingly, one-third of the pilots taking the survey did not want to give a clear answer. Current literature emphasizes the tendency for automation to create complacency (Parasuraman & Manzey, 2010), which leads to pilots losing their situation awareness as seen in out of the loop phenomenon

(Endsley, 1999). This could explain why one-third of the participants did not want to answer this question. Only 12 % of them disagreed and there were no strongly disagreed answers.

Question 30 indicates statistical significance with a p-value of 0.02365. It demonstrates negative correlation between the flight time and respondent answers. Pilots with more flight time, did not strongly agreed with the statement "*…their understanding of the picture does not diminish when they use HDG, SPD or ALT as autopilot control inputs…"* versus pilots with less flight time. The majority of the answers were positive regarding the automated systems but 7% of the pilots agreed that their overall understanding of the big picture diminishes. Although 88% of pilots answered positively for automation, pilots with fewer flight hours placed more emphasis on automated systems in the cockpit.

Question 41 brought the most varied answers as discussed earlier. Pilots with more experience (flying years) agreed that their companies did not allow them to fly manually and are required to fly with automated systems most of their time in the air. This issue was brought up in the Department of Transportation's (DOT) January 2016 Audit Report, and their findings point out that pilots have few opportunities to practice their manual flying skills. The FAA only suggests maintaining manual flying skills by flying without automated systems when feasible, but they do not currently mandate any protocol for manual flight operation. Some pilots have difficulties when they must suddenly assume manual control when the autopilot disconnects unexpectedly. Currently no regulators mandate a specific protocol requiring airline pilots to have training in the monitoring of automation as well as how they should maintain manual flying skills. The FAA does not monitor air carriers regarding how much manual flight time their pilots are getting. There is a need for specific auditing programs to ensure airlines have sufficient training programs in place to develop and maintain manual flying skills for their pilots (*Office of Inspector General Audit Report*, 2016, Taylor & Cotter, 2017).

Question 46 stated, "*A high level of competency in manual flying skills would benefit the industry",* to which most respondents agreed with 49% of them strongly agreeing, 33% of them agreeing, 13% of them neither agreed or disagreed, whereas only 4% disagreed and 1% strongly disagreed. Spearman correlation analysis indicated that pilots with more flight time were more likely to answer *strongly agree* than the pilots with less flight time.

A similar result was seen in question 48 "*A number of recent airline accidents/incidents could have been avoided if the pilots had been more proficient in manual flying skills*", again, pilots with more flying hours more strongly agreed to this statement.

Current commercial airliners use a two-pilot cockpit crew. The captain, who has seniority for the aircraft they fly, and a first officer (F/O) who often has less flight time in that aircraft. In some situations, the captain and first officer have a close number of total flight hours but the F/O may have significantly fewer hours for that specific aircraft model.

In this survey during the analysis of the trust dimension, Question 17 stated "*Through use of FMC (Flight Management Computer) for automated flight planning (e.g. planning of route, waypoints etc.) my overall workload is lower*" a Spearman analysis indicated some significance with 0.03171 p-value, and the correlation was negatively related. Captains were less likely to agree that their workload is getting lower compared to first officers. There were not any significant correlations between seat positions and monitoring or interface and training dimensions but question 41 in the policies dimension indicated statistical significance with p value 0.007595. Question 41 stated, "… *my airline doesn't allow me to fly manually, they force me to fly automated* *most or all of the time."* First Officers more often agreed their companies do not allow them to fly manually versus Captains.

Multivariate Joint Correspondence Analysis

Based on the principle inertias (eigenvalues) the following data in Table 6 were extracted:

Table 6. Dimensions and eigenvalues

Dimension	Value	%	Cum%	Scree Plot
1	0.058953	27.3	27.3	********
2	0.022531	10.4	37.7	***
3	0.013277	6.1	43.8	**
4	0.012667	5.9	49.7	**

Questions related to the five domains were analyzed by Multivariate Joint Correspondence Analysis using the R software tool. The first 4 dimensions accounted for approximately 50% of the variation in the response data. Based on these four dimensions the results are presented as the relation between Dimension 1 and 2, Dimension 2 and 3, and Dimension 3 and 4. Some of the outliers came as a result of the first two-dimensional relation explained below. Q 14T:4, 17T:3, 24M:3, 26M:2, 42P:5, 45P:5, and 48R:5 were not within the 95% prediction interval. Their existence represented themselves on the X and Y axis, in Figure 48.

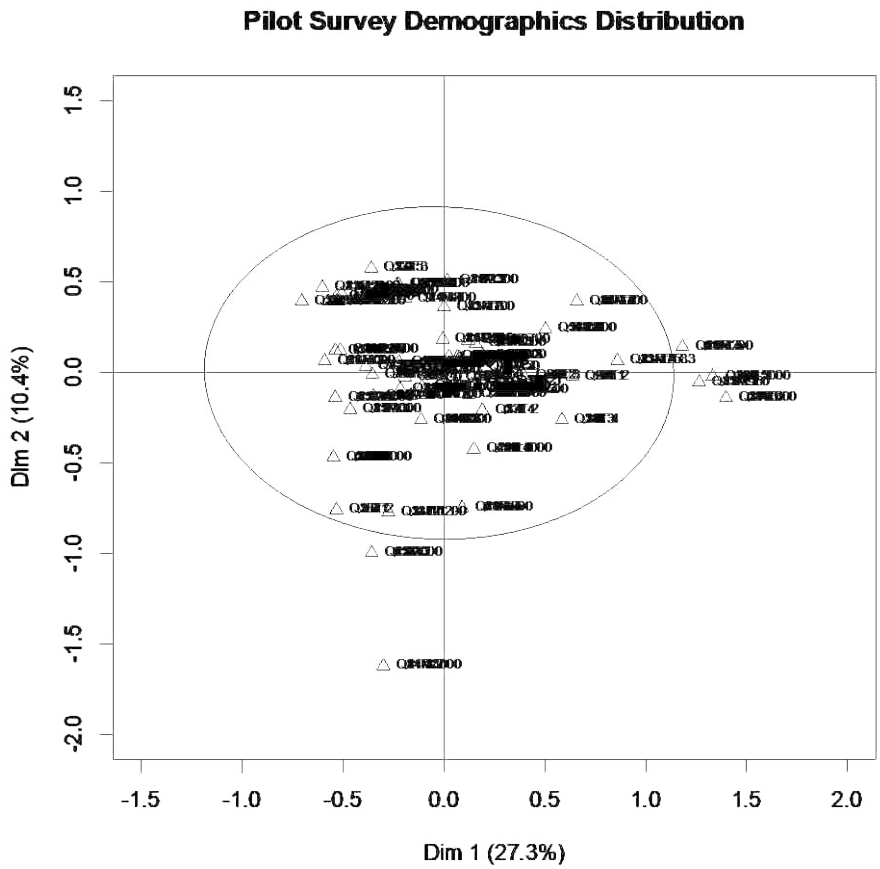

Figure 48: MJCA for Dimensions 1 and 2

The study of the MJCA and the histogram in Figure 13 revealed that the disagreed response (option 4) in Question 14T created noise and should be omitted. The resulting data supports a strong conclusion that the majority of pilots surveyed think automation in the cockpit made their job easier. The consensus increased to 98.6% from 97.4 %. Question 17T likewise suffered from noise created by the "disagreed" option and, when omitted, the strongly agreed/agreed option increased from 81.81% to 85%. Question 24M also had noise associated with the answers for option 3 (neither/nor) and a recalculation showed 97.3% of pilots agreed they are checking their PFD very often during their flight; an increase of 2.5% after the noise was omitted. MJCA of Q26 revealed that option 4 (agreed) created noise and its omission showed 79.99% of the pilots disagreed/strongly disagreed with the statement that automation increased pilots' workload and created more to monitor. This result was 77.92% previously. MJCA indicated in Question 42P, option 5 (strongly disagreed) is a very minor outlier that, once omitted (strongly disagreed), slightly changed the results from 49.34% to 49.99% as the percentage of pilots who follow their SOP's when a problem develops in the cockpit.

Figure 49 shows in Dimension-2-3 that data point 49R:4 was also an outlier. Option 4 (disagree) answers were noise. Its omission showed a stronger consensus that the majority of the pilots think that "*Airline companies should facilitate more training to ensure that manual flying skills are kept current*", with the percentage raising from 89.61% to 93.24%.

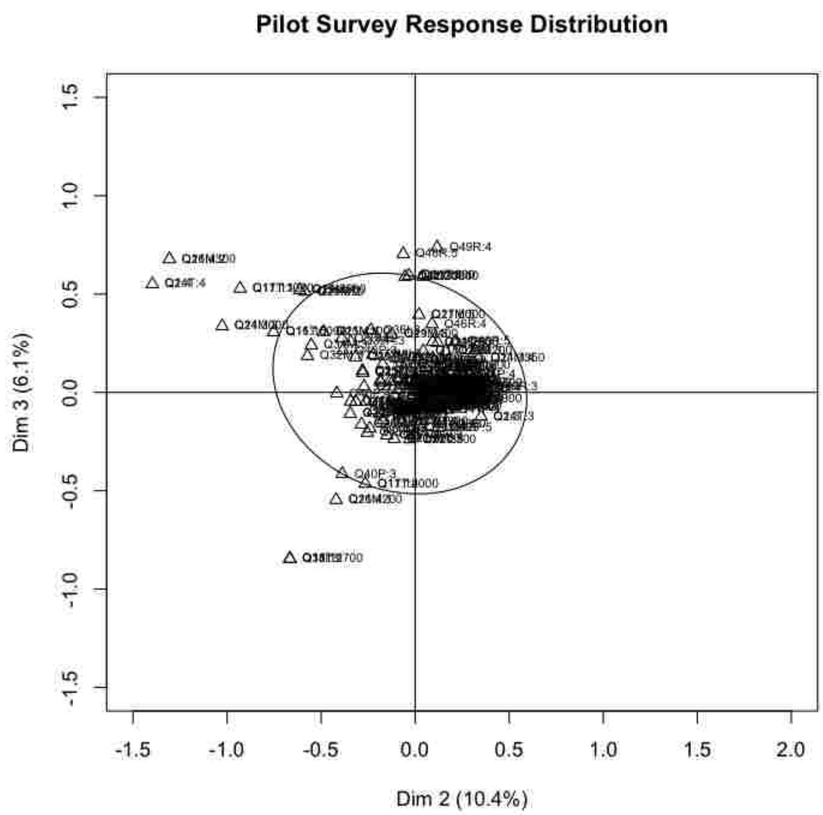

Figure 49: MJCA for Dimensions 2 and 3

MJCA results for dimension 3-4 are displayed below in Figure 50. Several question components were found to be outliers in the diagram and omitted. These included questions 22T and 33I, option 1 (strongly agreed) as well as question 43P option 3 (neither/nor option). After omission of option 1 for question 22T, the results changed to 33.63% for option 2 (agreed) where it had been 31.16% before. Answers for the strongly disagreed/disagreed option (option 4 and 5) increased from 42.85% to 45.2%. Regarding question 33I, once the answers for option 1 (strongly agreed) were omitted, the results for disagreed/strongly disagreed increased to 76.61% from 74.62%. A similar evaluation for question 43 produced the strongest consensus of the survey from the pilots for this question.

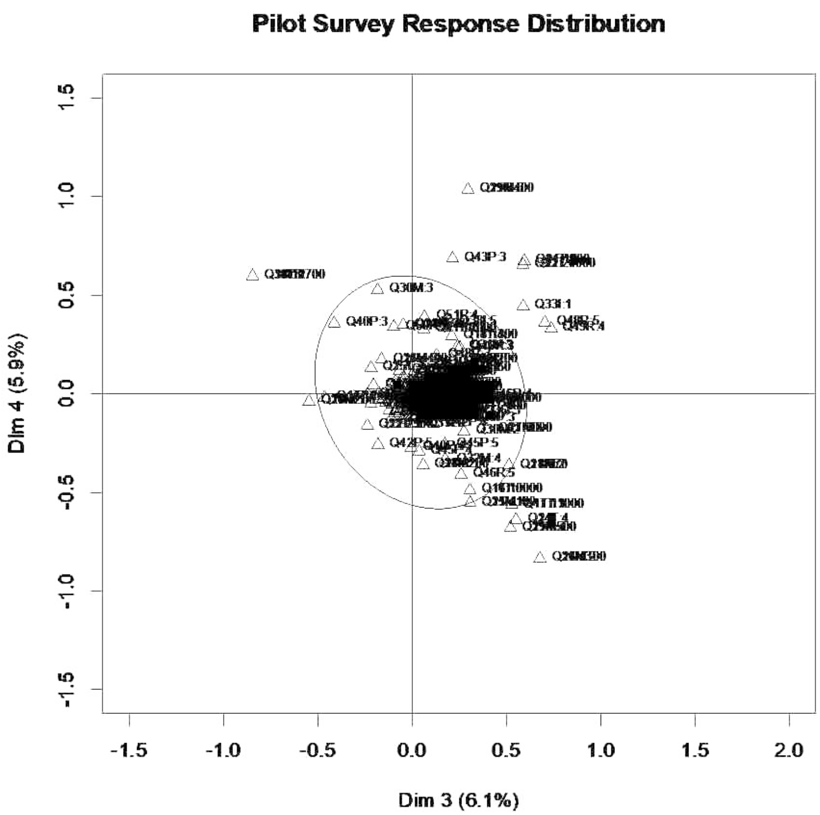

Figure 50: MJCA for Dimensions 3 and 4

Regarding question 33I, once the answers for option 1 (strongly agreed) were omitted, the results for disagreed/strongly disagreed increased to 76.61% from 74.62%. A similar evaluation for question 43 produced the strongest consensus of the survey from the pilots for this question. After eliminating answers for option 3 (neither nor), 100% of survey pilots agreed/strongly agreed to the statement "*I always adhere to the principles of Crew Resource Management (CRM)*".

Multiple joint correlation analysis results as included demographics displayed on Figure 51, Figure 52 and Figure 53. Results indicated few outliers and generally the survey responses indicated overall stability. From the responses a pilot with 300 hours flight time, another pilot with 5,600, one with 2,300, and another pilot with 1,700 flight hours demonstrated noise but this did not have a large impact on the analysis.

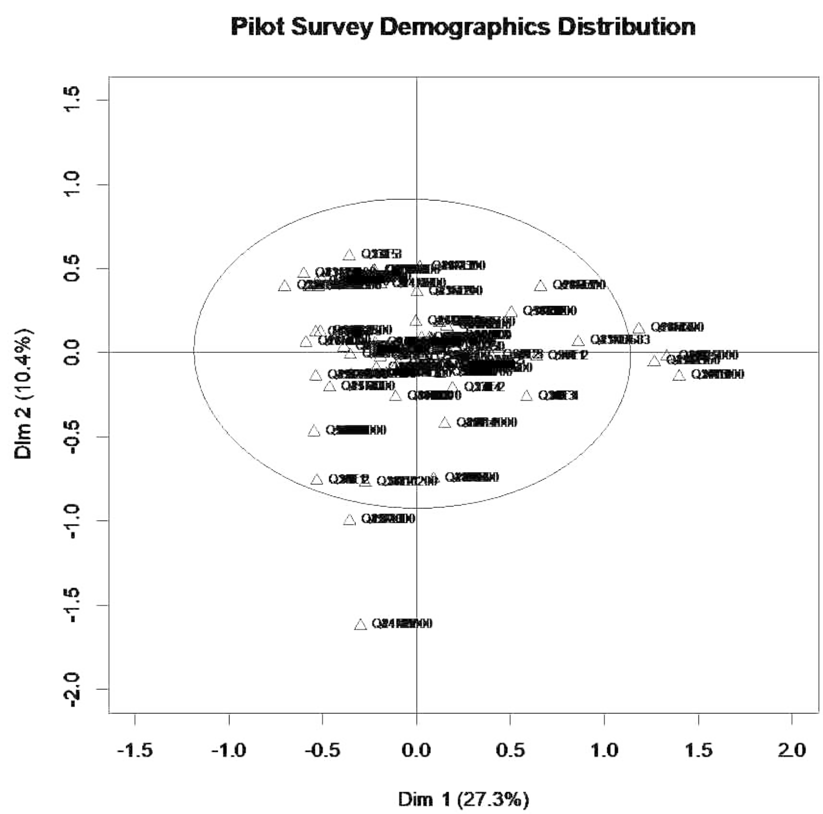

Figure 51: MJCA with Demographics for Dimensions 1 and 2

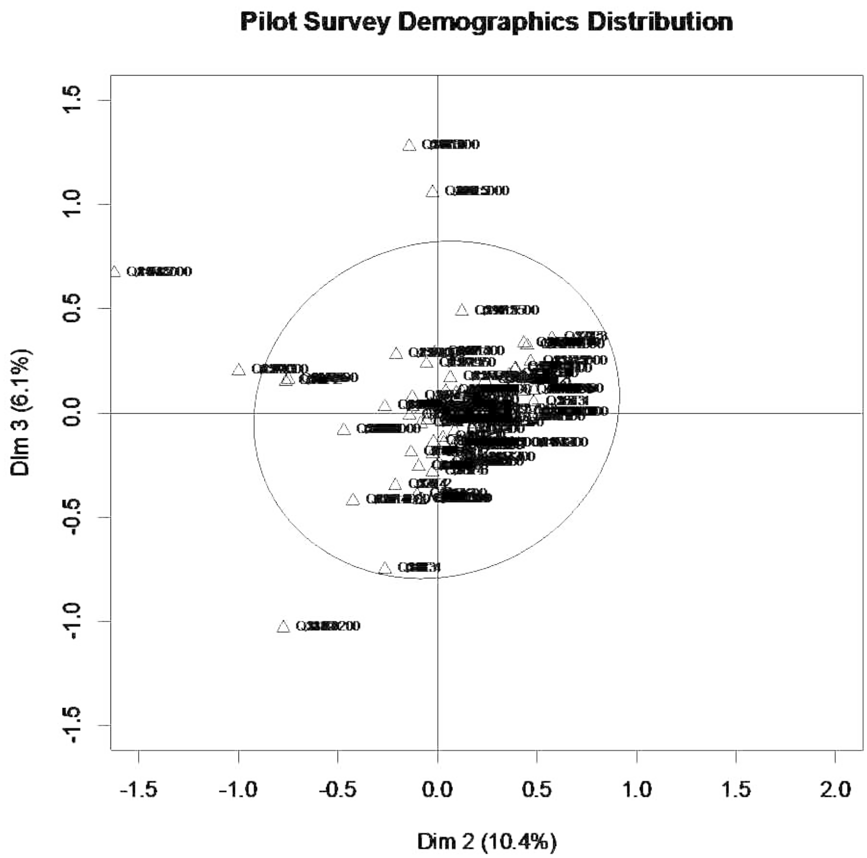

Figure 52: MJCA with Demographics for Dimensions 2 and 3

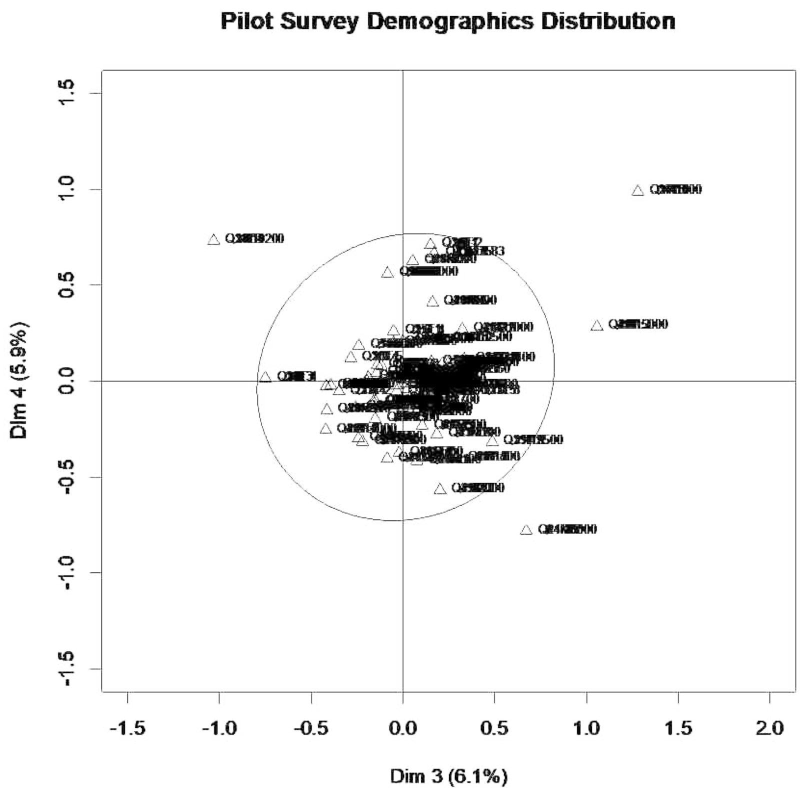

Figure 53: MJCA with Demographics for Dimensions 3 and 4

The raw data extracted with R software for MJCA is included in Appendices G and H.

Q52 and Q53 were optional open-ended questions designed to give the pilots a platform to speak freely about what they had to say relating to this subject. Their responses are presented as they provided with only some spelling error corrections and included in Appendix I.

Second Phase of the Research: Experiment to Test Reinforced Cue Detection (RCD) Model

Overview of the Experimental Design

The current survey showed that pilots sometimes observe cockpit automation taking actions that surprise them. Based on these findings, an experiment was designed using a PC based flight simulation system and working commercial airline pilots were recruited to test a new technique to increase vigilance while operating aircraft that are under automated control during the majority of their flight time.

Different equipment failures were presented to the test subject pilots in each of the three flights that each pilot undertook. Those three flights were different routes. The flight routes chosen for the experiment were 5 hours in duration on average to increase the risk that the pilots would lose situation awareness. Although longer flights could be more beneficial, the 737-800 operational range was a limitation. The CDU represented in the PMDG cockpit has a Failure menu that can be accessed, and different equipment can be programmed to fail after a certain amount of time. This failure panel screen is shown in Figure 54. One or two of the three flights also included questions for the pilot about the status of their flight parameters such as closest divergent airport. The questions were designed to prompt the pilot to gather more information regarding the progress of their flight. Every flight included some type of failure in the on-board navigation equipment. Each pilot responded to one system failure for each of the three flights they conducted. No flights lasted more than one hour. Only nine test subject pilots could be used.

Pilots participating in the study had an average age of 41.1 with a standard deviation of 6.22, minimum age of 33 with a maximum age of 50. The average flight hours logged of those pilots were 6,800; standard deviation was 5143 with a minimum flight time of 1,000 and a maximum of 16,000. There were eight male and one female pilot who participated.
The questions asked during one or a maximum two out of the three flights were intended to help the pilot gather up cues regarding their aircraft's status. The five questions that were asked in random order at random intervals included the following:

- What is the next waypoint?

- What is the speed of the aircraft? (They normally answered for both air speed and vertical speed)
- What is your divergent airport in case of emergency?
- What is your current altitude?
- What is the fuel flow?
- What is the distance to your final destination?

Figure 54. PMDG 737 software system failure option screen

Experiment Preparation

To create a flight with no visual references, a weather control add on software program was configured to limit visibility from the cockpit. All simulated flights took place at night. The room in which the simulation was set up was dark with a dim light used to allow the pilots to see their controls. The first flight for each pilot was a familiarization flight. The plane simulated was a 737-800 but not all pilots were rated on this aircraft, however they were shown how to access controls in the cockpit and use the yoke, rudder pedals, throttle quadrant, and mode control hardware.

Interviews with the Pilots who Participated in the Experiment

Pilot #919631: Three flights were simulated, the first being NYC to Panama City, Panama. The flight included questions to the pilot about his flight path, and state of his aircraft; he answered all questions. Both FMC's were failed using the PMDG failure control panel which can be accessed using the in-cockpit CDU. Care was taken to prevent the test subject pilot from knowing when a failure would occur or what the failure would be. He stayed on the flight plan by using the available data. Second flight, no cues applied, it was from LAX to ORF, both IRS's were failed. He stated that no communication with ATC was a limitation. Third flight was from Dubai to IST, cues were applied, both FCC's failed. He continued to fly and when asked if questions related to flight path improved his vigilance, he said it improved his situation awareness. Although the question was not specifically about situation awareness, he used that term to express his experience with the questions he had to answer. Pilot was male, 46 years old at time of experiment and had 16,000 + hours on FMC cockpits and flies as a captain.

Pilot #743170: The first flight was NYC to Panama City, Panama. Both IRS's were failed. He said he would use standby instrument to continue and ask ATC for vectors to closest airport. He looked at instruments to determine which airport was closest. Questions related to flight path were asked during the flight until the failure. Second flight was from LAX to ORF, both FMC's were failed. No cues applied. Third flight was Dubai to IST. Both FCC's were failed. No cues applied. Pilot stated questions gave him better situational awareness than he would have had. Pilot was male, 35 years old at time of experiment and had 7,000 hours on FMC cockpits and flies as a first officer.

Pilot #808571: The first flight was from NYC to Panama City, Panama. Questions were asked about flight status. Both FMC's were programmed to fail. He said he would get VOR's to determine which heading to fly to. He stated he would send a text message to dispatch that the FMC's failed. He said the questions asked of him during the flight related to flight path definitely helped his situation awareness (his own words). The second flight was LAX to ORF. Both the IRS's failed as planned. No cues were applied. The third flight was Dubai to IST, both FCC's were failed. Cues applied again. After the failure, pilot said he knows where he is and can hand fly although he might have an increased workload. When asked if questions helped, he said yes. Pilot was 37 years old and had 6000 hours on FMC cockpits and flies as a first officer.

Pilot #540385: The first flight was from LAX to ORF with no cues applied. Both FMC were failed. The second flight was from NYC to Panama City, Panama. No cues were applied. Both FCC's were failed. The third flight was from Dubai to IST. Questions related to flight path asked throughout the flight until the failure. He said questions created distraction and he had to perform multitasking, he said the questions posed increased his situation awareness and agreed that he was more alert when the failure was induced. Pilot was a 37 year old male with 9000 flight hours on FMC cockpits and was serving as a captain.

Pilot #801675: The first flight was NYC to Panama City, Panama, with no cues applied. Both FMC's were failed. The second flight was from LAX to ORF, no cues applied. Both FCC's were failed. The third flight was from Dubai to IST. Questions related to flight path asked up until the time of FCC failure. When asked if having questions asked on third flight compared to no questions on first two flights improved his vigilance, he said no but soon added he felt the alternate airport question may have helped because "I wasn't really thinking about an alternate airport". This particular pilot had experience with long haul flights, therefore a question was asked of him about longer flights; if he was flying long haul flights, would these questions increase his vigilance, he quickly said yes. Long haul flights have a much greater cruise period between top of climb and top of descent and it may be harder for pilots to remain engaged with their aircraft's status in this scenario. Pilot was 42 year old male with 13,000 hours on FMC cockpits and serving as a captain.

Pilot #259452: The first flight was NYC to Panama City, Panama. No cues were applied. Both FCC's were failed. The second flight was from LAX to ORF. No cues applied. Both IRS's failed. The third flight was Dubai to IST. Questions related to flight path were asked throughout the flight until failure. Both the FMC's failed. Pilot said she needs to check the non-normal checklist. She tried to re-engage autopilot then said it was not engaging. When questioned if the queries asked during the flight increased her vigilance, she said *probably not*. She said she normally would have a paper copy of the flight release and she would constantly go over that paper work. Follow up questions were asked about long haul flights and if cues would help in that situation. She said she would still have to check along the route and they plot the waypoints on a separate map. Pilot said she is always cross checking her plane's position and status of the flight. She keeps herself alert. When discussing about human dependence on automated systems and over reliance she said they could over rely. She asserted the worst flights for vigilance where 3-5 hour flights (not over water) that have a middle section with not as much to keep the crew busy. Operating in this flight scenario is harder to stay alert according to the pilot. Pilot was a 33 year old female with 5000 flight hours in FMC cockpit. She was currently on maternity leave during the experiment time. She had served as a first officer before going on leave.

Pilot #490817: First flight was NYC to Panama City, Panama. Both FMC's failed. Questions were asked over course of flight about flight path and aircraft status. After the failure he said he needs to obtain the frequencies for VOR and radar vectors back to JFK. Second flight was LAX to ORF. Both FCC's stopped working. No cues applied. Third flight was from Dubai to IST. Questions related to flight path asked over course of flight. Both IRS's failed. He recognized the navigation failure. Pilot said he would use standby instruments and descend to get out of the minimum separation standard required at high altitude. He said he would notify ATC of instrument failure and use radar vectors to the nearest airport. When asked if the questions during the flight helped his situation awareness at time of failure, he quickly said yes. He said ATC will clear other aircraft from his area and he would use ball compass and standby attitude indicator. He will leave reduced separation airspace. Pilot was a 50-year old male with 3100 hours in FMC cockpit, retired from military, and serving as first officer.

Pilot #783629: First flight was NYC to Panama City, Panama. Both FCC's malfunctioned. No cues applied. Second flight was from LAX to ORF. Both IRS's failed. Cues presented over the course of the flight. After failure, pilot said that he lost both navigation displays, noticed plane was climbing, and he moved the yoke to stop climb. He said he would tell first officer to inform

ATC we lost all autopilot functions. He then asked about using first officer display source to send data to his displays. Said he would ask first officer to tell ATC we are declaring an emergency. Lost primary navigation and attitude indicator and ask ATC for lower or higher altitude to meet separation requirements. He would ask ATC to clear traffic and ask ATC for a heading. He would send his company messages that we declared emergency and where they want us to go. Will look for a suitable airport. Would seek out visual meteorological conditions (VMC) to reduce his dependence on instruments. Third flight was from Dubai to IST. Both FMC's failed. Cues applied as before with questions asked along the route. He realized both FMC's failed at the time of failure. He was asked if questions about flight path posed earlier had any impact on his vigilance? He said he verified information asked in questions. It made him more aware and prompted him to look and verify. He said aviators should be checking all the time. Stated questions helped a little to maintain vigilance. Pilot said he does not fly long haul. He said when asked these questions, his first thought was "what am I missing?" Pilot was a 49-year old male, with 1100 hours on FMC cockpit and he flew as first officer. He also had 3800 hours flying a F-18 fighter. Made a statement that if he comes to a simulator at work, he is expecting to see some failures.

Pilot #555687: First flight was NYC to Panama City, Panama. Both FMC's failed. Questions asked over course of flight regarding flight status. He recognized he lost FMC. Stated he would give airplane to first officer and get out the checklist. He ascertained his location. Would talk to company if ACARS still works. Said he can navigate VOR to VOR. He may not get to final destination. He thinks he will not have a problem if he needs to land. Pilot stated he will not declare an emergency, but I would change my destination. Would check out max landing weight. Stated he would use checklist to check circuit breakers and the like. Pilot would get NAV data from his tablet. He said the questions might have helped him respond better when the emergency happened. He said he was already on alert as he expected failures while flying in a simulator. Second flight was from Dubai to IST, both IRS's failed. No cues applied. He started talking on his own, referencing questions asked during his previous flight and he said the question about the diversion airport made him think. At close to the end of his second flight, he started talking on his own. He was referring to talking to other pilots in the cockpit in order to keep their brain busy. Navy taught him about the curve regarding being under tasked or over tasked and the benefit of being in the middle of the curve. He needs other activities to do to engage himself such as talking to the other pilot. This helps keep the mind engaged he said. He spontaneously mentioned he needed something to keep him alert. Third flight was LAX to ORF. Both FCC's failed. No cues applied. Pilot was a 44-year old male, 1000 hours with FMC cockpit plus 2900 hours on F-18 in Navy.

Evaluating the Results of the Experiment Using the Constant Comparative Method

Glaser and Strauss (1967) laid the foundation of the constant comparative method (CCM) for qualitative types of analysis. Constant comparative methodology compounded by comparing data established during qualitative research and built categories. Glaser and Strauss's constant comparative analysis is appropriate not only for new data but also for previously collected data (Glaser & Strauss, 1967). Constant comparative analysis differs from analytic induction in that it can be used to build numerous categories relating to general problems. CCM is more likely to be used in the study of qualitative information such as interviews, observations, etc. CCM consists of four stages: "(1) comparing incidents applicable to each category, (2) integrating categories and their properties, (3) delimiting the theory, and (4) writing the theory" (Glaser & Strauss, 1967, p. 105).

According to Boeije (2002) there is little specific guidance as to how to carry out a constant comparison. She also stated that distinguishing between different types of comparison is not clearly explained in the literature. Boeije emphasized all data should be matched with other applicable data. Comparing data is a creative exercise and reflects the interaction between the researcher and the data over the course of data collection and interpretation (Strauss & Corbin, 1998; Corbin & Strauss, 2008). Interviews are transcribed and the data generated becomes input to support an analysis. The goal is to ascertain the meaning of the data and reveal the perspectives of the group being studied (Boeije, 2002).

After each simulated flight, test subject pilots were interviewed and their responses recorded. Every pilot had flown with and without reinforced cues. These interviews were transcribed and the data analyzed. Test subject pilot interviews were coded and placed in an Excel spreadsheet for pair-wise comparison of common theme agreement and theme disagreement between each pair of subjects. Definitions of terms that evolved from the themes defined below:

Communication (COM): When a failure occurred, pilots were encouraged to talk out loud to reveal their mental model regarding how they will address the problem. Some of them referenced talking to ATC immediately as they would like to gather as much information as is available outside the cockpit. When pilots refer to "talking to ATC", that action was coded as COM for communication. The flight simulation did not include a simulation of ATC.

Situation Awareness (SA): If the pilots referred Situation Awareness during or after flight simulation, the output was coded as SA.

Navigation (NAV): After a failure, if pilots spoke about navigating without using the automated systems, it was captured as an input for the analysis and coded as NAV.

Policy (P): If a pilot referenced communicating with his company's dispatcher for decision support, this was captured as an input for the analysis and coded as P.

Workload (WL): If a pilot referenced a change in his workload after a failure or anytime during the experiment this was captured as an input for the analysis and coded as WL. One important experiment constraint was the lack of a First Officer so the pilot flying also had the duties normally handled by the pilot monitoring. This naturally increased their workload.

Abnormality Checks (AC): If a pilot referred to a checklist (normal or non-normal), that information was used as input and coded as AC.

Cue Reinforcement (CR): If a pilot referenced the questions that were asked of them during the simulated flights with the goal of increasing their situation awareness, these comments were used as an input for the analysis with the code of CR.

Cue Distraction (CD): If a pilot commented that answering the questions under the reinforced cue detection model might create distraction it was captured as input for the analysis and coded as CD. Again, not having a First Officer could have an impact because the test subject pilot had to fly the aircraft while answering the questions and may have been distracted but not talked about feeling distracted.

Vigilance (V): If the pilots mentioned being vigilant during the interviews this data was recorded as input with the code of V.

Automation Dependency (AD): If the pilot discussed the issue of automation dependency during the interview this statement was considered an input and coded with AD.

Table 7 and Table 8 indicate and summarize theme agreement and disagreement frequencies.

Table 7: Thematic Agreement and Disagreement from Pilot Interviews.

Pilot	Theme 1	Theme 2	Theme 3	Theme 4	Flight Reinforcing Cues Beneficial	Between Two Comparison	Common Themes	Discriminating Themes
919631	COM	SA	V		Yes	743170	COM, SA	V
						808571	COM, SA	NAV, WL, V
						540385	SA	COM, CD, WL, V
						801675	SA	COM, CR, V
						259452	SA	COM, AC, NAV, AD, V
						490817	SA, COM	NAV, V
						783629	SA, COM	NAV, P, V
						555687	SA	COM, AC, NAV, P, V
743170	COM	SA			Yes	808571	COM, SA	NAV, WL
						540385	SA	CD, COM, WL
						801675	SA	COM, CR
						259452	SA	AC, COM, NAV, AD
						490817	SA, COM	NAV
						783629	SA, COM	NAV, P
						555687	SA	COM, AC, NAV, P
808571	NAV	COM	SA	WL	Yes	540385	SA, WL	CD, NAV, COM
						801675	SA	CR, COM, NAV, WL
						259452	NAV, SA	AC, COM, AD, WL
						490817	NAV,SA, COM	WL
						783629	NAV, COM, SA	P, WL
						555687	NAV, SA	AC, COM, P, WL
540385	CD	WL	SA		Yes	801675	SA	CD, CR, WL
						259452	SA	CD, AC, NAV, AD, WL
						490817	SA	CD, NAV, COM, WL
						783629	SA	CD, NAV, COM, P, WL
						555687	SA	CD, WL, AC, NAV, P

Table 7: Thematic Agreement and Disagreement from Pilot Interviews (continued).

Pilot	Theme 1	Theme 2	Theme 3	Theme 4	Flight Reinforcing Cues Beneficial	Between Two Comparison	Common Themes	Discriminating Themes
801675	CR	SA			Yes	259452	SA	NAV, AD, CR, AC
						490817	SA	CR, NAV, COM
						783629	SA	CR, NAV, COM, P
						555687	SA	CR, AC, NAV, P
259452	AC	NAV	SA	AD	Yes	490817	NAV, SA	AC, COM, AD
						783629	NAV, SA	AC, COM, P, AD
						555687	AC, NAV, SA	P, AD
490817	NAV	COM	SA		Yes	783629	NAV, COM, SA	P
						555687	NAV, SA	AC, COM, P
783629	NAV	COM	P	SA	Yes	555687	NAV, P, SA	AC, COM
555687	AC	NAV	P	SA	Yes	555687		

Table 8: Summary of Common/Discriminating Themes.

Total	Common Themes	Discriminating Themes
SA	36	0
COM	10	20
NAV	10	20
P	1	14
WL	1	14
AC	1	14
V	0	8
AD	0	8
CD	0	8
CR	0	8

Interpretation

A key finding from the survey results was that pilots are sometimes surprised by automation's actions. This could be because they are not able to follow the actions of automation due to its design or whenever automation fails or reaches its design limits, pilots were already out of the loop due to their complacency to those systems. Survey results framed the design of this experiment and input from the pilots participating in the flight simulations was consistent with the survey results. It shows they believe they sometimes have a hard time following the automated systems' actions. They think it is especially difficult during long flights. This supports the idea that the cue detection model could be useful.

Using the phenomenological approach, the goal of this experimental design was limited to understanding the test subject pilots' experiences when flying with and without the cue detection model. For this reason, rather than asking a broad spectrum of questions, they were only interviewed regarding their experience with this additional model. Overall, the results indicated that the majority of study pilots found the new model (asking them questions related to their flight), increased their situation awareness. They were more aware about the status of their aircraft when a failure was induced. Generally, this new model helped them to remain engaged by increasing their vigilance. CCM analysis indicated pilots are particularly concerned with SA since all pilots in the experiment referenced the need to maintain SA in some way. Some of the pilots spontaneously mentioned there is a need to keep them alert while they are flying. Some of them discussed their own solutions such as chatting with the other pilot in the cockpit. Some of the pilots said the cue detection model was not needed, because they are expected to be aware of the status of their aircraft at all times. However, when interviewed about long haul flights over land, the same pilot said more effort is required to stay alert in that scenario. The consensus of all pilots who contributed to this research as a test subject was that long-haul flights require more effort to remain alert. The Reinforced Cue Detection Model worked for its intended purpose. Since this was a small-scale research, it could only be interpreted as an initial indication of the benefits of the cue detection model, and it should be expanded to a larger scale research to allow for quantitative analysis. This research should be viewed as reflecting pilots' preference and not pilot performance.

Pareto analysis of common theme agreement indicates that situation awareness (SA) was the most common with 36 pair-wise instances, followed by communication and navigation each with 10 pair-wise agreement instances each. However, there were 20 pair-wise disagreements where pilots did not refer to communication or navigation as part of their information gathering and decision-making process. Other information-gathering and decision-making pair-wise disagreements were policy, workload and abnormality checks with 14 each, vigilance, automation dependency, cue reinforcement, and cue distraction with 8 each. Interestingly, there were 8 pair-wise theme disagreements on the effects of cue reinforcement and cue distraction for maintenance of situation awareness. The 8 pair-wise agreements and disagreement arose from two test pilot subjects. One stated that cues were distracting, but the other indicted that cues helped maintain situation awareness. However, when directly questioned about the usefulness reinforcing cues during flight to help maintain situation awareness upon encountering failures, all nine pilots replied that cues were useful in increasing decision-making vigilance under failure.

In summary, all test subject pilots gathered information to maintain situation awareness for decision making; however, they varied in their approaches and techniques. This observation agrees with finding in survey questions 23, checking waypoints, and 24, checking primary flight displays often, as part of information gathering for situation awareness. Such variation strongly suggests that differences in natural cognitive processes and prior training contribute to how pilots gather information and apply it in flight and failure situation decision-making. The disagreement on cue reinforcement, one test subject pilot, versus cue distraction, one test subject pilot, reflect the differences in responses to survey question 37, response to auditory warnings are better than to visual warnings. For question 37, 47% agreed or strongly agreed, 33.8% were neither, and 18.2% disagreed. This strongly suggests that cue reinforcement must be designed to accommodate information gathering preferences.

CHAPTER V

ANALYSIS AND SUMMARY OF THE RESULTS

Overview of Findings

The survey indicated pilots favored automated cockpit systems and believe their job is made easier through their use. Most also think their workload was lowered with the help of automated systems, but, when asked, they reported that they do not trust automated systems more than they trust themselves. They also gave some divergent responses when they indicated they are sometimes surprised by actions that automation takes. This finding aligns with the literature. They think the information displayed is neither too much nor too little. One of the important findings from the survey was pilot agreement that they respond to aural feedback better than visual feedback. This should be taken into consideration when designing future cockpits; pairing visual alerts with sound alerts. The "Bitchin Betty" warning system model from the Navy might be applicable for commercial air transports.

Another controversial result came from the question if their airline does not allow them to fly manually, i.e., they are forced to fly using automated systems most or all the time. A large percentage of survey takers agreed or strongly agreed while another large percentage disagreed or strongly disagreed. This could be the result of several factors, one of them being concerned about stating they are rarely allowed to fly manually and possibly upsetting their employer despite the anonymity assured them in the consent form. Another factor could be cultural differences found in different nations as well as the culture of the company they are flying with and varying company policies. For instance, during the flight simulation research it was observed that some of the regional airline pilots prefer to fly manually and they stated their companies allow them to fly manually if they chose to. Another factor for these controversial answers could be the fact that the younger generation of pilots are learning how to fly with automation since the beginning of their training. They might not feel they are being forced by their companies, or it could be their preferred method to fly with automated systems most of the time.

One of the major findings of this research was how to take advantage of crew resource management (CRM) and apply it in a broader context whereby automated systems are expected to conform to CRM rules, as human pilots are required to do. CRM has become a key method to resolve issues in the cockpit. CRM was developed as a reaction to several accidents where crewmembers did not work collaboratively, and bad outcomes resulted. Every student pilot in ground school is taught to comply with CRM rules. Currently, CRM rules apply only to human crews. Development of automated systems in the cockpit over the last 30 years has made those systems more independent and capable and has raised concerns about the human-automation team as reflected in the literature over the same time frame. As autonomous systems were developed, those systems became more human like, started making their own decisions, and sometimes overrode human decisions. Autonomous automation systems are acting more human-like, but they are not complying with the requirements specified in CRM rules. Survey questions were directed to line pilots, who are the end users and work with those systems routinely. Only 5% of the survey participant pilots disagreed that automation should comply with CRM rules. This should be an indication in the future development of autonomous automation systems. Specifically, they should have the same responsibility if they are acting as a team member. Currently, automated systems have great authority but are lacking responsibility.

Pilots also emphasized that keeping manual flight skills current is very important. They are also aware that, over last few decades, pilots are learning how to fly with automation as an integral part of their flight training. Pilots are sometimes surprised by the actions taken by automated systems, and this implies they do not understand every action taken by automation.

Research Implications

Current literature of "pilots being out of the loop", "automation complacency", and "overreliance on automated systems", as well as their direct feedback in this survey supports a need to continue the research on how to help pilots when they are working with those automated systems. With the equipment explained above in the methodology section, a simulator was constructed with adequate fidelity to emulate a flight similar to the test subject pilots' routine flight experience. This research strove to develop a solution to reduce, if not eliminate, the being out of the loop situation for the pilots. Over the long term the overarching goals should be to create a new cockpit design that communicates to its human partner as they take actions and make decisions. Generating a whole new cockpit design is costly, and it is not practical to retrofit the large number of planes in use with new cockpits. This research aimed to see if a small addition such as reinforced cue detection model will make a difference for the pilots when they face a failure after being out of the loop. Pilots are more likely to get out of the loop during long haul flights. The budget constraint prevented bringing a pilot for testing multiple times in this study. Rather, they had to fly three different scenarios back to back over one session. Nonetheless, this research indicates that future research could measure pilot performance based on the reinforced cue detection model in a larger scale and that could be beneficial for the industry. Human pilots are usually left as the authority for the final decision making when a failure happens, and, when they are making those decisions under time constraints, they use their own knowledge based on their experience employing the first best solution that comes to mind. Because pilots will be the final decision making authority, providing them some support should be emphasized, and this could be beneficial for the pilots and for industry. Future research should include a simulation set up using the same pilots making several flights in different dates. In addition to having a small number of pilot participants, the research flight runs made it apparent the test subject pilots would frequently look to ATC and dispatch services to aid them in their decision making. The lack of ATC was a significant limitation to the simulation research.

Research Limitations

Pilot responses to the survey questions may have been affected by their company's culture and indoctrination. This impact is hard to measure.

Air Traffic Control (ATC) is an integral part of the civil aviation system. Ground based controllers monitor and provide guidance regarding the movement of aircraft in the air as well as on the ground. The ATC system is made up of different control centers that pass control of aircraft as they progress through their flight, from the loading gateway to the disembarking gateway. The types of ATC include tower, approach and departure, and en route controllers. Takeoff and landing instructions are conveyed to pilots, and ATC informs the cockpit crews of updates involving weather, runway conditions and closures, and any other information that could impact the safety of a flight or its efficiency (Bureau of Labor Statistics, 2018).

Increases in air traffic have inspired upgrades in the technology used in ATC. One new technology is known as Automatic Dependent Surveillance-Broadcast (ADS-B) will semi-automate some aspects of aircraft separation, allow for narrower minimum vertical separation requirements, and allow two planes to land on parallel runways simultaneously among other changes. The ability for aircraft to "self-separate" without direct guidance from ATC is a significant milestone in aviation development (Safety Management System FAA, 2013). ADS-B will be a change from radar-based surveillance to a satellite based global positioning system, and it will increase flight crew awareness of other traffic on the ground and in the air (Richards, O'Brien, & Miller, 2010).

Commercial airline flight crews utilize support from ATC in routine flights and often contact ATC when a malfunction of equipment occurs. Communication with ATC could be a mundane matter or something impacting safety. When onboard navigation systems fail, crews will quickly contact ATC to ask for the space around them to be cleared of traffic and for frequent updates as to their position. Planes flying at high altitude may need to descend to a lower altitude because of the requirements to use automated altitude control equipment at high altitude. It is difficult to maintain the required separation margin when manually flying an airliner. Descending to a lower altitude reduces efficiency because of air density and associated increases in drag and thus fuel management issues may require the plane to land before it reaches its destination airport. Depending on the severity of the emergency, a crew may ask for vectors to the closest alternate airport and for emergency vehicles to be made ready.

Test subject pilots were made aware before the experimental flights that no simulation of ATC would be provided. There are some simulated ATC environments such as PilotEdge in use among PC flight simulator hobbyist, but this was not practical to employ in the simulator setup. Use of these systems implies the presence of traffic in the airspace the test subject pilots would be flying in and this would have undoubtedly raised the fidelity of the experiment but at increased cost and complexity in terms of managing the experimental flights. One alternative would have been to have ATC "light" with a dedicated controller managing only the test subject flight but able to interact with the pilot in real time and in a manner for which they are trained. There are also some add on software products for Prepar3D that use artificial intelligence to simulate ATC interaction. These options could be explored in future research. Eight pieces of software were needed to manage each flight in a Microsoft Windows environment and one concern was stability of the software as crashes of component parts or "blue screens of death" could have ruined a test flight. As it was, all test flights were completed without any software failures.

Lack of ATC did impact the flight simulation experiments and results should be considered with this in mind. Test subject pilots would vocalize their intent to contact ATC and describe how an ATC interaction might go and how this would impact their decision-making process. They frequently referred to ATC after an equipment failure and described the information they would be seeking and specific assistance they would request. Lacking this information from ATC, they could not respond to the situation in the same manner as they might on an actual flight. Modern airliners have redundancy in navigation methods, but they require maps, VOR frequencies, and reference charts that were not available to them and, thus, using ground-based navigation aids was problematic. This is not to say the experiments lack validity. Adding ATC would have increased the complexity of the design greatly and added to the cost. One benefit of the absence of ATC is the pilots "thought out loud" more concerning their decision making and this may have revealed more about their thought processes than might have been observed otherwise.

The aircraft simulated in the experiment normally operates with two pilots but in the research only one pilot could be tested, and this increased their workload. To adjust for this the test subject pilots verbalized what their instructions to a copilot would have been and expressed their mental model of how they would have reacted in an actual flight.

Budget constraints required each test subject to conduct all flights in one session instead of over multiple days. No flights without failure could be run in this circumstance and flight times were also shorter than they would have been otherwise. Lack of no failure flights increased their conditioning in that they expected a failure on each flight.

CHAPTER VI

CONCLUSIONS

Primary Contributions of This Study

The survey in this research aligned with the majority of the findings in the literature. The major contribution of the survey was how pilots perceive automated systems relative to CRM requirements. This question was never considered before from the pilots' perspective in terms of including the automated systems as a team member who will comply with CRM rules. Many accident investigations cite pilot error as the primary causal factor. With automated systems becoming more autonomous and making their own decisions while sometimes limiting human decisions, it should be regarded as a powerful team member with important input in the decision-making process. CRM currently only refers to interactions among human crewmembers. Autonomous systems have grown in sophistication over the last few decades, giving them greater authority but not commensurate responsibility, and this created an imbalance in the decision equation. Industry and regulators should consider a fresh approach for including automated systems as part of CRM rules.

Another significant finding of the survey was that there is a consensus among pilots that aural warnings are needed more than visual warnings. This input should be considered by the industry when designing cockpit automation systems. Aircraft designers might consider pairing more visual warnings with aural warnings. Pilots not only agreed with this as part of survey Likert scale questions but also spontaneously mentioned this when answering the survey open ended questions. They said that when they are overwhelmed with many other tasks, they are more likely to miss visual cues, but, if visual warnings are paired with aural alerts, they stated that they will more likely pay attention to those warnings.

The major contribution of this research is trying to find a solution for mitigating pilot complacency by increasing situation awareness. Many accidents that involve impact with terrain happen within minutes of the first indication of a failure. In this case, pilots do not have a lot of time to review the Quick Reference Handbook (QRH) and find a solution that they can reference from a SOP. Some of the accidents cannot be described in a SOP, because they are novel, and no SOP exists yet. In these cases, pilots have to improvise a novel solution for the problem. Pilots are ultimately responsible for finding a solution for these catastrophic events. Having pilots out of the loop is not a new phenomenon, but it has not been addressed specifically. The usual approach was more training or more automation (on a path to eliminating the pilot). Until the air transport system reaches a full autonomous level, we should explore how to maximize the benefits of both parties, human and automation. Since pilots often have a very limited time to make their decision to prevent a crash, keeping their vigilance high throughout the flight is important. Klein's naturalistic decision-making model refers to making decisions under time constraints and most pilots apply this model if they don't have any SOP's from their memory. That is why this research tries to strengthen human decision-making under time pressure by supporting their naturalistic decision making with collecting cues. These research interviews indicated reinforcing cues could be beneficial.

Generalizability of the Research

Raja Parasuraman was a prominent researcher in the area of human factors with automated systems and published a paper in 1997 stating:

> *"System designers, regulators, and operators should recognize that overreliance happens and should understand its antecedent conditions and consequences. Factors that may lead to overreliance should be countered"* (Parasuraman & Riley, 1997).

So far the aviation industry's response has not taken the pilots out of the button pusher mode. Boeing recognized this problem and programmed some of their aircraft such as B777, B787, and newer models of B737 to prompt the pilots to touch a button or knob if a certain amount of time passes with no interaction with the control systems. Pilots are a vital and unique asset in the cockpit and their contribution to safe flight should not be as a lab animal responding to a bell. Pilots have acknowledged that it can be difficult to stay cognizant of their aircraft's status and have developed their own coping mechanisms, however the aircraft industry should work to design a system that helps them focus on maintaining situation awareness while still providing the benefits of automation. As an industrial leader Boeing has a philosophy that supports pilots and their initiative to help them remain engaged. This initiative should be recognized, but the solution should be more function oriented.

Automation complacency is not limited to aircraft pilots. Any highly-reliable automated systems, such as nuclear power plants, highly automated trains, and highly automated cars using driver assist technology, etc., create complacency. A 2016 report from the NTSB regarding a fatal crash in Florida of a Tesla automobile cited the driver's overreliance on vehicle automation as a contributing factor to the accident (NTSB, 2017). If an operator is managing a system for long periods of time, such as a 3 to 5 hour shift, it is more likely he or she will get out of the loop and become a less effective monitor of the automated systems. Other industries that use highly reliable automated systems can use the proposed reinforced cue detection model over the naturalistic decision making to help their operators when they face unexpected events with time constraints.

Future Research

This research used a small number of pilots due to budget constraints. This model should be re-tested with larger sample size. As previously noted, the pilot's inability to communicate with ATC in the event of a failure inhibited the realism of the cockpit simulation. Future research should include ATC and dispatch in the simulation. This will increase the fidelity, and, therefore, results could be measured quantitatively. The small sample size of only nine pilots in the cockpit simulation may have limited the scope and depth of the test of reinforcing cues. A larger sample of pilots in the simulated tests would yield more reliable inferences. The time limitation necessitating three test flights in a single experimental setting may have affected experimental results. A staggered test schedule with several days or weeks in between test flights for every pilot, four flights per pilot, longer flights of 3-5 hours each, and the inclusion of "non-failure" flights would be more realistic. With a sufficient amount of funding, this research would be more beneficial for the industry. A full time, high level subject matter expert (ATP license holder) that could help in the development of test flight failure scenarios and verify their applicability to the research would be beneficial. This expert could also help evaluate the actions of the test subject pilots and help in post flight interviews.

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Zaneboni, J., & Saint-Jalmes, B. (2014). *U.S. Patent No. 2014/0180508A1*. Washington, DC: U.S. Patent and Trademark Office.

APPENDICES

APPENDIX A. Survey Research-Exempt from IRB Review

OLD DOMINION UNIVERSITY

OFFICE OF THE VICE PRESIDENT FOR RESEARCH

aaalac INTERNATIONAL
PROUDLY, AN AAALAC ACCREDITED PROGRAM

Physical Address
4111 Monarch Way, Suite 203
Norfolk, Virginia 23508
Mailing Address
Office of Research
1 Old Dominion University
Norfolk, Virginia 23529
Phone(757) 683-3460
Fax(757) 683-5902

DATE: October 29, 2015

TO: Teddy Cotter, PhD, MS, MBA, BS
FROM: Old Dominion University Engineering Human Subjects Review Committee

PROJECT TITLE: [783306-4] HUMAN-MACHINE INTERACTION GOVERNANCE IN THE COCKPIT AND APPLICABLE DESIGN CHANGES TOWARDS BETTER COLLABORATION
REFERENCE #: ENGN-15-09
SUBMISSION TYPE: Amendment/Modification

ACTION: DETERMINATION OF EXEMPT STATUS
DECISION DATE: October 29, 2015

REVIEW CATEGORY: Exemption category # *6.2*

Thank you for your submission of Amendment/Modification materials for this project. The Old Dominion University Engineering Human Subjects Review Committee has determined this project is EXEMPT FROM IRB REVIEW according to federal regulations.

We will retain a copy of this correspondence within our records.

If you have any questions, please contact Stacie Ringleb at 757-683-6363 or sringleb@odu.edu. Please include your project title and reference number in all correspondence with this committee.

This letter has been electronically signed in accordance with all applicable regulations, and a copy is retained within Old Dominion University Engineering Human Subjects Review Committee's records.

APPENDIX B. Application for Human Subject Research

IRB Identifier:____________
(To Be Assigned by the IRB)

OLD DOMINION UNIVERSITY
HUMAN SUBJECT RESEARCH REVIEW APPLICATION FORM

Responsible Project Investigator (RPI)		
Responsible Project Investigator: The RPI must be a member of ODU faculty or staff who will serve as the project supervisor and be held accountable for all aspects of the project. Students cannot be listed as RPIs.		
First Name: Teddy	**Middle Initial: S.**	**Last Name: Cotter**
Telephone: 757-683-3758	**Fax Number:**	**E-mail: tcotter@odu.edu**
Office Address: 2101I Engineering Systems Building		
City: Norfolk	**State: VA**	**Zip: 23529**
Department: Engineering Management & Systems Eng.	**College: Batten College of Engineering & Technology**	
Complete Title of Research Project: HUMAN-MACHINE INTERACTION DECISION MAKING IN THE COCKPIT WITH REINFORCED CUE DETECTION MODEL	**Code Name (one word): Cockpit**	
Investigators If more investigators exist than lines provide, please attach a separate list.		
Investigator(s): Individuals who are directly responsible for any of the following: the project's design, implementation, consent process, data collection, and/or data analysis.		
First Name: Aysen	**Middle Initial: K.**	**Last Name: Taylor**
Telephone: 757-683-2577	**Fax Number:**	**Email: aktaylor@odu.edu**
Office Address: 2100 Engineering Systems Building		
City: Norfolk	**State: VA**	**Zip: 23529**
Department: Engineering Management & Systems Eng.	**College: Batten College of Engineering & Technology**	
Affiliation: __Faculty __Staff	X Graduate Student __Other__________________	__ Undergraduate Student
First Name:	**Middle Initial:**	**Last Name:**
Telephone:	**Fax Number:**	**Email:**
Office Address:		
City:	**State:**	**Zip:**
Department: Engineering Management & Systems Eng.	**College: Batten College of Engineering & Technology**	
Affiliation: __Faculty __Staff	__Graduate Student __Other__________________	__ Undergraduate Student
List all information for additional investigators on attachment and check here: __		

Revised 9/14

APPENDIX C. IRB Approval

OLD DOMINION UNIVERSITY

OFFICE OF THE VICE PRESIDENT FOR RESEARCH

Physical Address
4111 Monarch Way, Suite 203
Norfolk, Virginia 23508
Mailing Address
Office of Research
1 Old Dominion University
Norfolk, Virginia 23529
Phone(757) 683-3460
Fax(757) 683-5902

DATE:	July 28, 2016
TO:	Teddy Cotter, Phd; MS; MBA; BS
FROM:	Old Dominion University Institutional Review Board
PROJECT TITLE:	[905373-2] Human-Machine Interaction Decision Making in the Cockpit with Reinforced Cue Detection Model
REFERENCE #:	16-103
SUBMISSION TYPE:	New Project
ACTION:	APPROVED
APPROVAL DATE:	July 28, 2016
EXPIRATION DATE:	June 23, 2017
REVIEW TYPE:	Full Committee Review

Thank you for your submission of New Project materials for this project. The Old Dominion University Institutional Review Board has APPROVED your submission. This approval is based on an appropriate risk/benefit ratio and a project design wherein the risks have been minimized. All research must be conducted in accordance with this approved submission.

This submission has received Full Committee Review based on the applicable federal regulation.

Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding followed by a signed consent form. Informed consent must continue throughout the project via a dialogue between the researcher and research participant. Federal regulations require each participant receive a copy of the signed consent document.

Please note that any revision to previously approved materials must be approved by this office prior to initiation. Please use the appropriate revision forms for this procedure.

All UNANTICIPATED PROBLEMS involving risks to subjects or others (UPIRSOs) and SERIOUS and UNEXPECTED adverse events must be reported promptly to this committee. Please use the appropriate reporting forms for this procedure. All FDA and sponsor reporting requirements should also be followed.

APPENDIX D. Amendment on Previous IRB Approval

OLD DOMINION UNIVERSITY
IDEA FUSION

OLD DOMINION UNIVERSITY
HUMAN SUBJECT RESEARCH AMENDMENT FORM

Responsible Project Investigator (RPI)		
Responsible Project Investigator: The RPI must be a member of ODU faculty or staff who will serve as the project supervisor and be held accountable for all aspects of the project. Students cannot be listed as RPIs.		
First Name: Teddy	**Middle Initial: S**	**Last Name: Cotter**
Telephone: 757-683-3758	**Fax Number:**	**E-mail: tcotter@odu.edu**
Office Address: 2101I Engineering Systems Building		
City: Norfolk	**State: VA**	**Zip: 23529**
Department: Engineering Management & Systems Engineering	**College: Batten College of Engineering & Technology**	
Complete Title of Research Project:		

Type of Amendment Request (Check all changes that apply)	
☐ **Study Design/Methodology**	☐ **Informed Consent Process/Form**
☐ **Data Collection Tools**	☒ **Subject Recruitment Methods or Materials**
☐ **Number of Subjects**	☐ **Inclusion/Exclusion Criteria**
☐ **Personnel Changes**	☒ **Other, describe:**

Amendment Description:

Provide a description of all changes and the justification/rationale for changes below.
(Attach new or revised document(s) with your amendment request).
NOTE: You must upload any new or revised document(s) (application, consent form, recruitment materials, etc.) to IRBnet that are affected by the change.

Subject recruitment - Clause 12b. "Are there any other forms of compensation that may by used? (e.g., Money) Change from "No" to "Yes." Provide nominal compensation comparable to the median $106 per hour (source US BLS*, median annual pilot salary $105,720 limited to 1,000 flight hours per year) to attract more participants. Change compensation to $200 up to first three (3) hours participation plus $100 for additional two (2) hours participation.

* https://www.bls.gov/ooh/transportation-and-material-moving/airline-and-commercial-pilots.htm

Other - IRB Application, July 2016, clause 4, "Where will the experiment be conducted?" On Campus, change Building and Room Number from Engineering Systems Building, Room 2123H to Engineering Systems Building, Room 2123E.

APPENDIX E. Pilot-Automation Interaction Questionnaire

Q1 Your personal information will not be associated with the answers that you give in this survey. Your personal information will be protected by the regulations of IRB Process. Will you consent for this survey?

- ❍ Yes (1)
- ❍ No (2)

If No Is Selected, Then Skip To End of Survey

Q2 Your age bracket

- ❍ 20-25
- ❍ 26-30
- ❍ 31-35
- ❍ 36-40
- ❍ 41-45
- ❍ 45-50
- ❍ 51-55
- ❍ 56-60
- ❍ 61-65
- ❍ 65 and above

Q3 Year you started to fly as a pilot

Q4 Number of years you're flying

Q5 Are you currently retired?

- ❍ Yes (1)
- ❍ No (2)

Q6 Current Aircraft

Q7 If retired, last aircraft flown

Q8 Primary language spoken

Q9 Seat (choose one)

- ❍ CAPT (1)
- ❍ F/O (2)

Q10 Years/Months since completion of initial training in current aircraft

Q11 Total Flight Time

Q12 Total Flight Time in your "current" aircraft

Q13 Time in FMS (Flight Management System) equipped aircraft (other than your current aircraft) by type

- ❑ B737-400 (1) ____________________
- ❑ B737-800 (2) ____________________
- ❑ B737--900 (3) ____________________
- ❑ B747-400 (4) ____________________
- ❑ B777 (5) ____________________
- ❑ MD 80-88 (6) ____________________
- ❑ MD 11 (7) ____________________
- ❑ A 320 (8) ____________________
- ❑ A 330 (9) ____________________
- ❑ A 340 (10) ____________________
- ❑ A 350 (11) ____________________
- ❑ A 380 (12) ____________________
- ❑ ERJs' (13) ____________________
- ❑ ATR 42-72 (14) ____________________
- ❑ Dash 8 (15) ____________________
- ❑ Other (16) ____________________

Q14 Automation in the cockpit made my job easier

- ❍ Strongly Agree (1)
- ❍ Agree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Disagree (4)
- ❍ Strongly Disagree (5)

Q15 Automation keeps me to engaged throughout the flight

- ❑ Strongly Agree (1)
- ❑ Agree (2)
- ❑ Neither Agree nor Disagree (3)
- ❑ Disagree (4)
- ❑ Strongly Disagree (5)

Q16 I rely on automation to keep me safe
- ❍ Strongly Agree (1)
- ❍ Agree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Disagree (4)
- ❍ Strongly Disagree (5)

Q17 Through use of the FMC (Flight Management Computer) for automated flight planning (e.g. planning of route, waypoints etc) my overall workload is lower.
- ❑ Strongly Disagree (1)
- ❑ Disagree (2)
- ❑ Neither Agree nor Disagree (3)
- ❑ Agree (4)
- ❑ Strongly Agree (5)

Q18 I trust in automation more than I trust in myself
- ❑ Strongly Disagree (1)
- ❑ Disagree (2)
- ❑ Neither Agree nor Disagree (3)
- ❑ Agree (4)
- ❑ Strongly Agree (5)

Q19 Automation in the cockpit made my job harder
- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q20 I don't feel comfortable when autopilot controls vertical and horizontal flight paths (VNAVs and LNAVs)
- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q21 The biggest obstacle to overall flight safety is ad-hoc and confusing communication from automated systems in the cockpit.

- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q22 When equipped, I rely on flight envelope protection to protect my aircraft and passengers in case I make any mistake

- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q23 I always check my next waypoint and I‘m aware of pending heading changes

- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q24 I check my primary flight display very often throughout the flight

- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q25 Information represented on the Control Display Unit (CDU) is clear and easy to understand

- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q26 Automation increased my workload, created more need to monitor
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q27 During the automated flight phase, I am sometimes surprised by actions automation takes
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q28 When I use autopilot to control HDG, SPD or ALT I feel automation creates distraction.
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q29 I check the flight mode annunciator very often to understand which mode the autopilot flight director system is in (what autopilot is doing)
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q30 When I use autopilot to control HDG, SPD or ALT my understanding of the big picture diminishes
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q31 I can predict the behavior of the automation with ease
- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q32 When I use autopilot to control HDG, SPD or ALT my workload gets lower.
- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q33 I think the overall amount of information available on my aircraft is too much.
- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q34 My response to visual warnings is better than aural (sound) alerts
- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q35 When a master caution and warning alert occurs; it gets my attention immediately
- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q36 When a master caution and warning alert occurs; I trust the alert signals are a real event
- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q37 My response to aural (sound) alerts is better than visual warnings
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q38 I think the overall amount of information available on my aircraft is not enough
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q39 When I face a problem in the cockpit I always follow the SOP's (Standard Operating Procedure) before trying another approach to solve the problem
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q40 In most cases an automatic system should prevent the aircraft from exceeding its performance envelope
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q41 My airline doesn't allow me to fly manually; they force me to fly automated most or all of the time.
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q42 When a problem develops in the cockpit, I always try to understand the broader picture before I follow the SOP's.
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q43 I always adhere to the principles of Crew Resource Management (CRM)
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q44 Regulations should require cockpit automation to adhere to the principles of CRM when feasible.
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q45 In most cases an automatic system should warn the crew of flight envelope exceedance but not restrict pilots' control
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q46 A high level of competency in manual flying skills would benefit the industry
- Strongly Disagree (1)
- Disagree (2)
- Neither Agree nor Disagree (3)
- Agree (4)
- Strongly Agree (5)

Q47 Difficulties in understanding automation can be overcome solely by training
- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q48 A number of recent airline accidents/incidents could have been avoided if the pilots had been more proficient in manual flying skills.
- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q49 Airline companies should facilitate more training to ensure that manual flying skills are kept current.
- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q50 Training is not the only answer for improving a pilot's ability to understand cockpit automation
- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

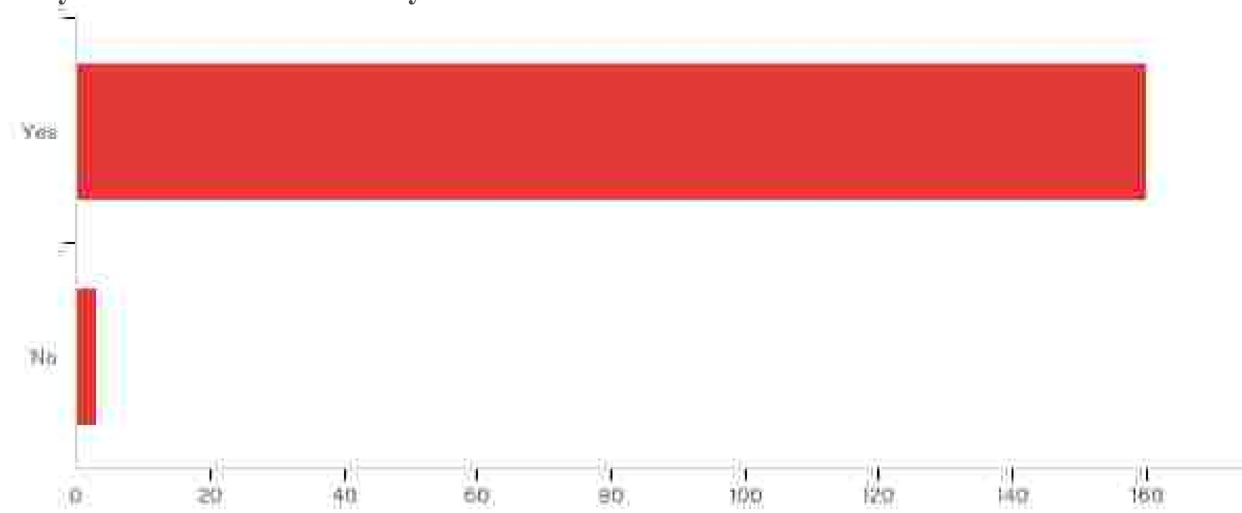
Q51 Most pilots trained in the last 15 years learn the management of automation as in integral part of learning to fly an aircraft.
- ❍ Strongly Disagree (1)
- ❍ Disagree (2)
- ❍ Neither Agree nor Disagree (3)
- ❍ Agree (4)
- ❍ Strongly Agree (5)

Q52 Please describe your overall experience with automated systems in the cockpit and how it affects your piloting skills.

Q53 What design improvements would you recommend to enhance the communication between automation and the pilots to increase flight safety?

APPENDIX F. Survey Questionnaire-Results Using the Survey Tool Qualtrics™ (Raw Data, As Is At The Moment Of Extraction)

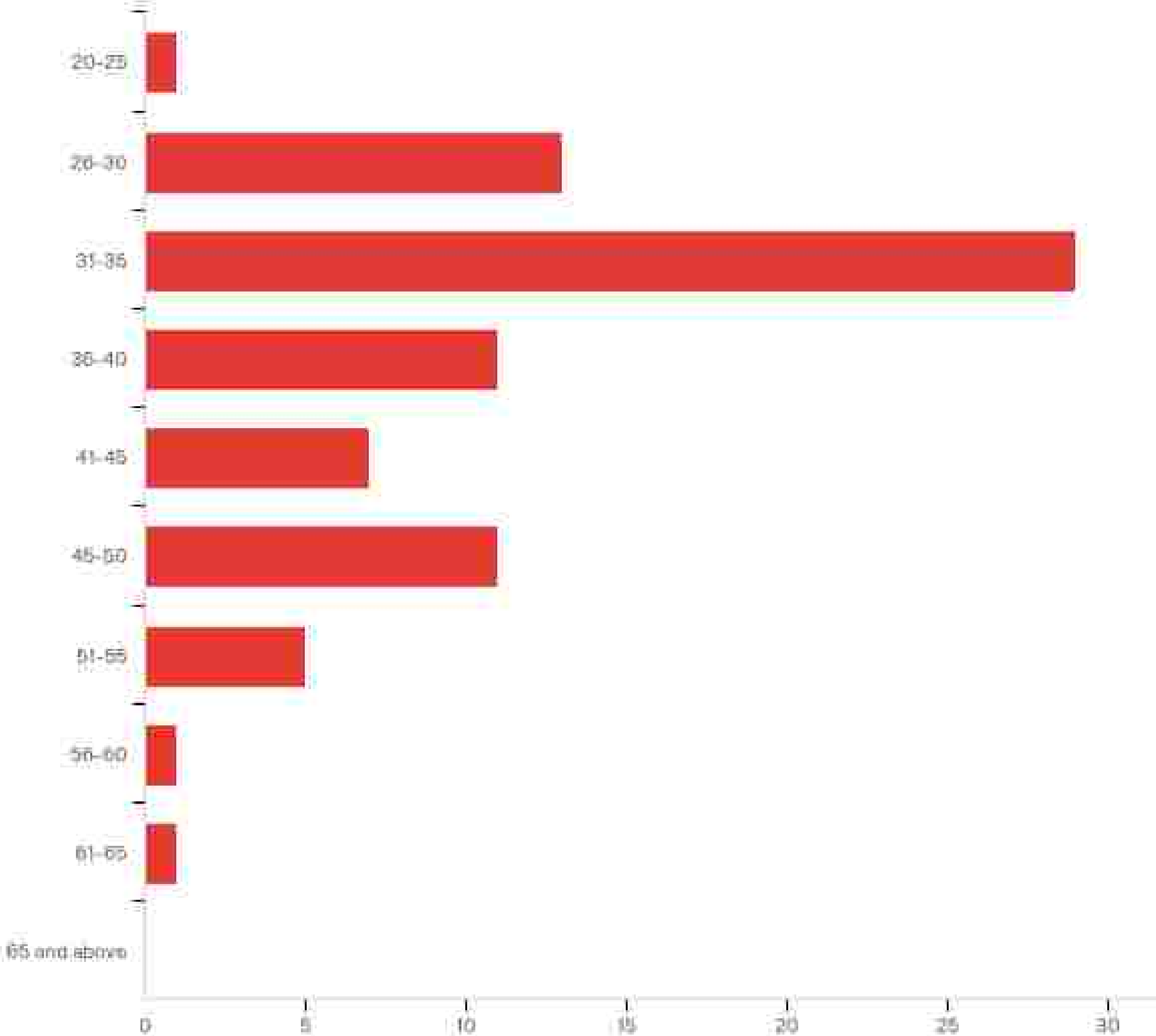
Q1 - Your personal information will not be associated with the answers that you give in this survey. Your personal information will be protected by the regulations of IRB Process. Will you consent for this survey?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Your personal information will not be associated with the answers that you give in this survey. Your personal information will be protected by the regulations of IRB Process. Will you consent for this survey	1.00	2.00	1.02	0.13	0.02	163

#	Answer	%	Count
1	Yes	98.16%	160
2	No	1.84%	3
	Total	100%	163

Q2 - Your age bracket



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Your age bracket	1.00	9.00	3.94	1.69	2.87	79

#	Answer	%	Count
1	20-25	1.27%	1
2	26-30	16.46%	13
3	31-35	36.71%	29

4	36-40	13.92%	11
5	41-45	8.86%	7
6	45-50	13.92%	11
7	51-55	6.33%	5
8	56-60	1.27%	1
9	61-65	1.27%	1
10	65 and above	0.00%	0
	Total	100%	79

Q3 - Year you started to fly as a pilot

Year you started to fly as a pilot
1997
2012
1985
2011
1998
2009
.2010
2000
2010
1999
2007
2006
1991
2011
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1979

Q4 - Number of years you're flying

Number of years you're flying
19
4
30
5
17
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16
6
16
8
9
24
5
7
5
9
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7.5
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19
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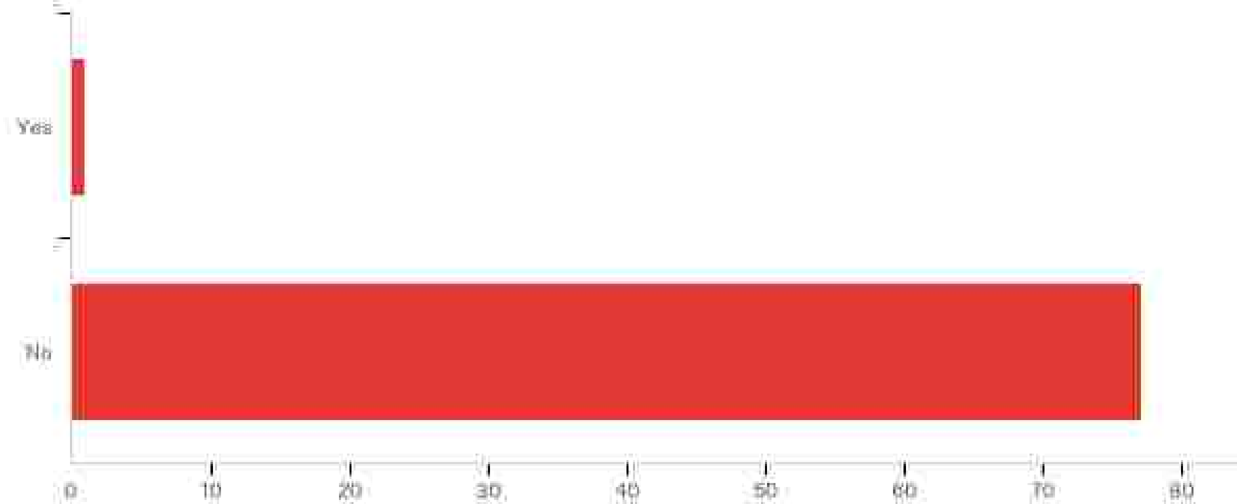
36

Q5 - Are you currently retired?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Are you currently retired?	1.00	2.00	1.99	0.11	0.01	78

#	Answer	%	Count
1	Yes	1.28%	1
2	No	98.72%	77
	Total	100%	78

Q6 - Current Aircraft

Current Aircraft
B738
Boeing777
A-320
B777
B777
B737-800
B777
AIRBUS 330
B777
B777
B777
Boeing 777
MD-88
B777
Boeing 777
Boeing 777
B777
B777
B 777
777
B777
777
b777
BOEING 777
B77W

B777
B777
Boeing 777
737
B777
B777/300ER
B777
Boeing 777
B767
777
Boeing 777
Boeing777
77W
B777
B777
A320
B777/300ER
Boeing 737 -300/-500/-700/-800
Boeing 737-700/800/900
B-777
Boeing 737
Airbus 320
A330
Airbus A320
A-330
Airbus 330
C-130H
757/767

B777
MD-88, MD-90
A320
B737
P210
A-320
Boeing 737
Boeing 777
Boeing 777
A-320
Dual qualified on A340-600 and A330-300
C-152
Kingair C90
B737-800
B737NG, Gulfstream GIV
ATR 72-600
B737NG
C172
B737
B737NG
B 737
737-300
C-172
b757
B737; PA46T

Q7 - If retired, last aircraft flown

If retired, last aircraft flown
NA
/
Na
-
Nil
I retired form the Army Aviation, but continue flying with the Airline
-
Na
N/A
-

Q8 - Primary language spoken

Primary language spoken
Turkish
Turkish
Turkish
PORTUGUESE
Hungarian
Dutch
Turkish
TURKISH
Turkish
German
Dutch
Turkish
English
Turkish
Turkish
Dutch
German
Danish, English, Turkish
Turkish
FR
French
portuguese
dutch
TURKISH
Turkish

French
German
Turkish
Turkish
Dutch
Italian
Dutch
Turkish
Turkish
English
English
Turkish
English
Turkish
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German
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english
Turkish
Turkish
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turkish
Turkish
turkish
Turkish, English
Turkish
English

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german
Portuguese
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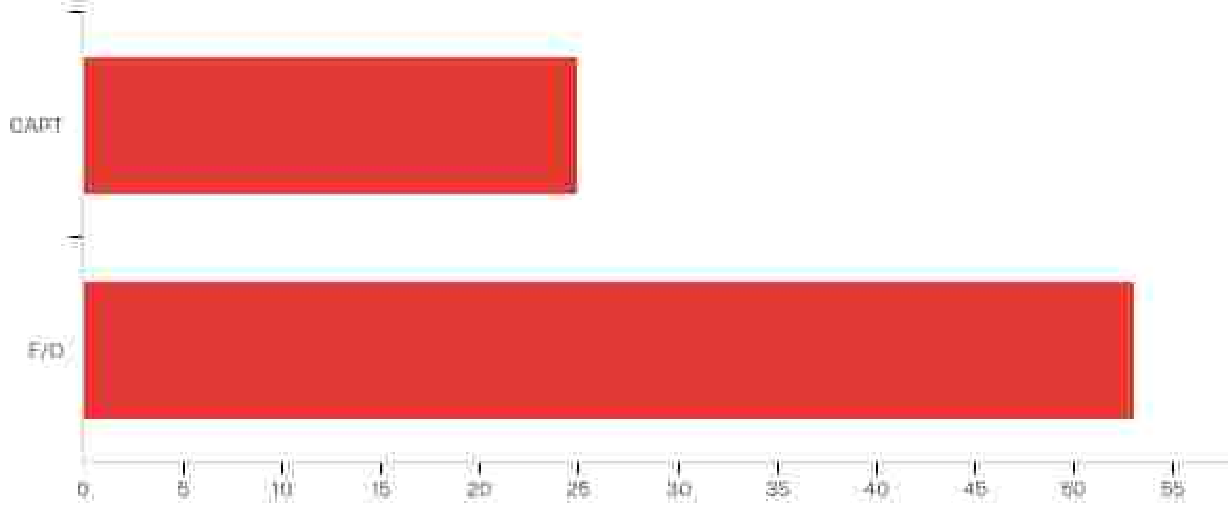
Q9 - Seat (choose one)



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Seat (choose one)	1.00	2.00	1.68	0.47	0.22	78

#	Answer	%	Count
1	CAPT	32.05%	25
2	F/O	67.95%	53
	Total	100%	78

Q10 - Years/Months since completion of initial training in current aircraft

Years/Months since completion of initial training in current aircraft
8
1 year
8 years
18 MONTHS
1,5 years
4
2
2015 DEC
2,5
1.5 years
1.5 years
6 years
14
2014/9
4 years 8 months
1 year / 3 months
5 Years and 6 Month
1 year 2 months
2 years
2
2 years 1 month
2 years
2years 1 month
2Y6M
3 years 6 months

3 years
2 years
4.5 years
30
2,5
2003/05
2 years
5
2
3
2 years
3 years
2
1
3
2 Years
03/2014
5 yrs 3 months
20
3/6
6,5 years
5/7
2014
28 months
2015/8
2 and a half year
2012/06
6

0/5
4
13, 6
3/7
22 years 10 months
14 months
4 years
8
2 years, 5 months
3 years 10 months
2 years
A340 21 years, A330 3 years.
2011
6
4
12
2 years
3 years
7
2004
5
November/1997
7
30
10
10; 4

Q11 - Total Flight Time

Total Flight Time
7400
1700 hr
11000
2800
9400
250hr
+10000
4500
8000
4000
5600
8500
2400
4400
2960
6700
4500
2300
5000
3500
3000
3350
4000
4200
6200

4500h
4600
1500
3000
12700
3700
5800
3500
5000
4300
6000
1800
4100
8500
1300
15,000+
17583
3000
18000
6000
1000
12.500
670
3500 hours with A-330 and 5000 hours with the helicopters
2500
300
~2500 hrs
7200

19,700
21000
21,400
1400
15000
7900
8200
10500 hours
12.000
Aprox 20,000 hrs
200
2.500
4500
15,000+
2000
12000
600
10.000
2074
19.000
6000
4000 hours
10200
14000

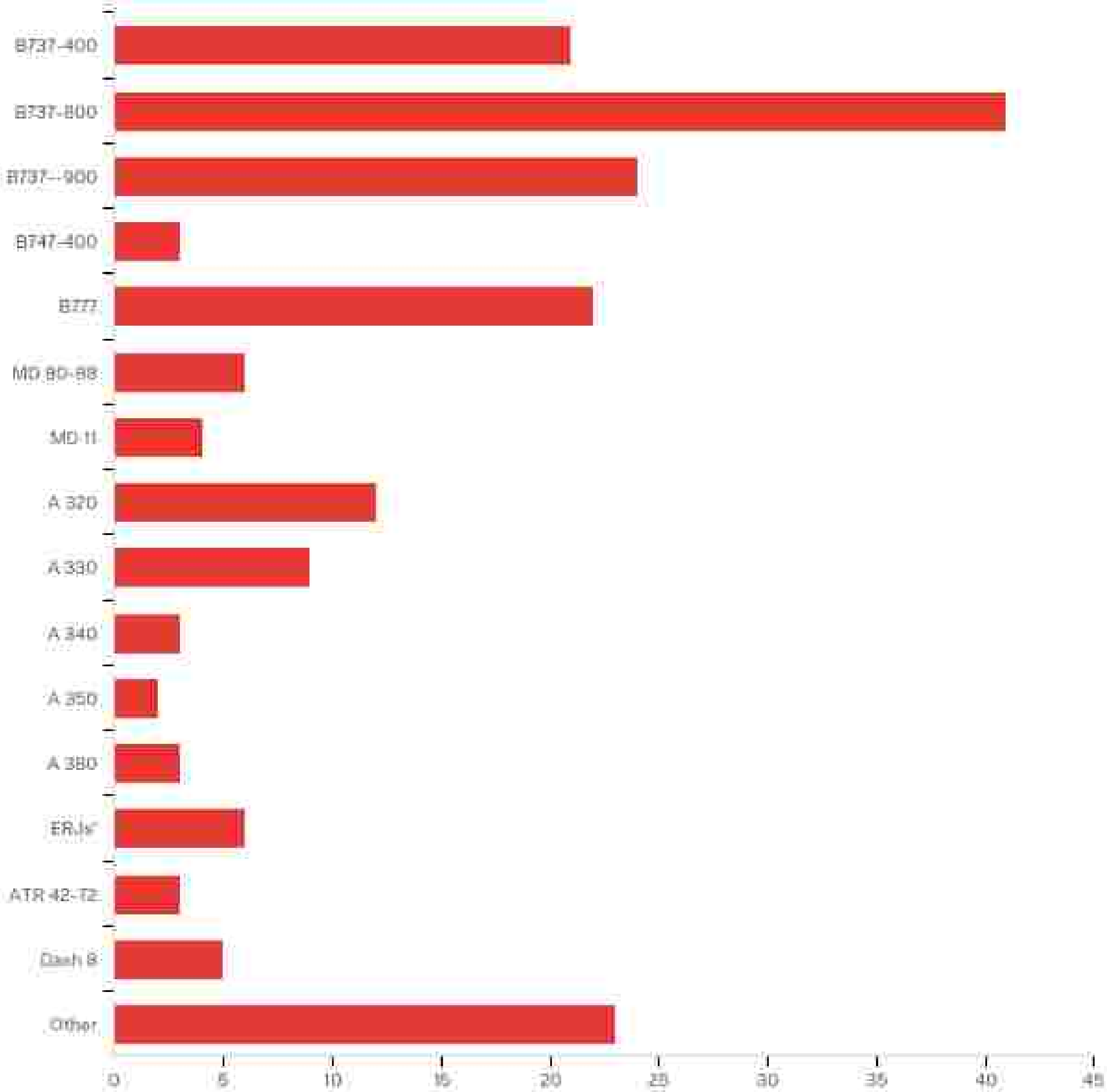
Q12 - Total Flight Time in your "current" aircraft

Total Flight Time in your "current" aircraft
6000
700hr
6000
800
700
40hr
1500
200
2000
1000
1000
4800
6000
1300
3800
700
4300
700
1250
200
1250
800
1100
1800
2900

1800
1200
3900
1500
1100
9700
1200
3900
4500
1100
1200
2400
2000
700
2500
1000
600
5000
12117
2700
5500
4500
700
1.800
370
Almost 2000 hours
1800
100

~200 hours
3000
9,600
1000
15,900
100
700
5900
1680
3800 hoirs
1.500
Aprox 16,000 hrs
1.500
1300
4,600+
700
1800
585
4.600
1173
12.000
3000
500 hours
5500

Q13 - Time in FMS (Flight Management System) equipped aircraft (other than your current aircraft) by type



#	Answer	%	Count
1	B737-400	11.23%	21
2	B737-800	21.93%	41
3	B737--900	12.83%	24
4	B747-400	1.60%	3

5	B777	11.76%	22
6	MD 80-88	3.21%	6
7	MD 11	2.14%	4
8	A 320	6.42%	12
9	A 330	4.81%	9
10	A 340	1.60%	3
11	A 350	1.07%	2
12	A 380	1.60%	3
13	ERJs'	3.21%	6
14	ATR 42-72	1.60%	3
15	Dash 8	2.67%	5
16	Other	12.30%	23
	Total	100%	187

B737-400

B737-400 - Text
40
100
50
/
1600
300
2200
50
400
300
100 hours
100

0
3.600
2100
100
2 years
-
4.600
11.000
3000

B737-800

B737-800 - Text
6000
1000 hr
7500
900
1900
1700
600
450
650
/
1900
750
2000
1500
1950
1900

1300
1500
3300
500 hours
1000
100
1900
700
3800
1200
1000
1300
3500
150
700 hours
500
0
760
0
1800
1173
1000

B737--900

B737--900 - Text
3 YEARS
500
100

300
300
1600
/
160
300
100
500
1800
2500
1300
300
350
100
200 hours
100
0
0
-

B747-400

B747-400 - Text
/
0
-

B777

B777 - Text
700 hr
1.5 YEARS
1500
2000
4800
700
4300
770
1250
1250
1100
2900
1800
1700
1100
1200
2400
0
800
-

MD 80-88

MD 80-88 - Text
6000
/
0
3700

-

MD 11

MD 11 - Text

/

2500

0

5200

A 320

A 320 - Text

6000

/

3000

600

6 yrs

5 years

700

4000

0

1050

-

A 330

A 330 - Text

HONEYWELL

/

1.800

2000 hours

1800

0

1150

-

A 340

A 340 - Text

/

0

-

A 350

A 350 - Text

0

-

A 380

A 380 - Text

/

0

-

ERJs'

ERJs' - Text

/

100

0

300

-

1.500

ATR 42-72

ATR 42-72 - Text

/

0

-

Dash 8

Dash 8 - Text

7000

/

2500

0

-

Other

Other - Text

2000

700

2000

1500

Fokker 70 - 3100

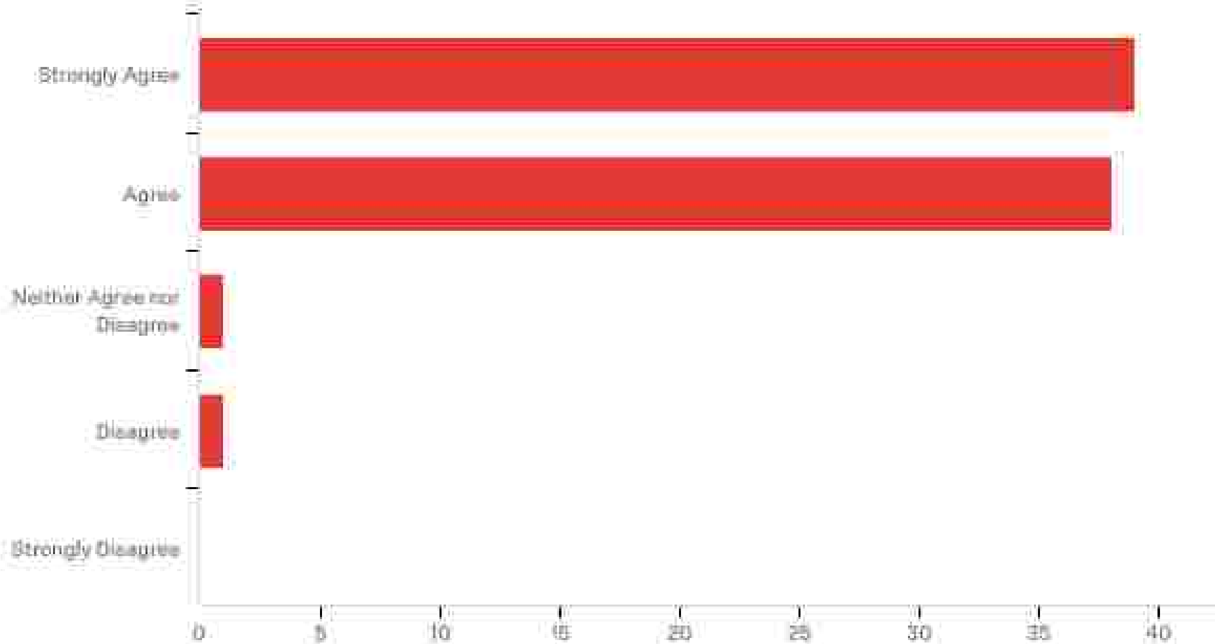
8 yrs

12000

2.400

500 hours
100
B767: 3600
0
12
2000
1290
B767 - 6 + years as Capt
2.500
1,500
8,700+
400 (B767)
3500
b757-200/300

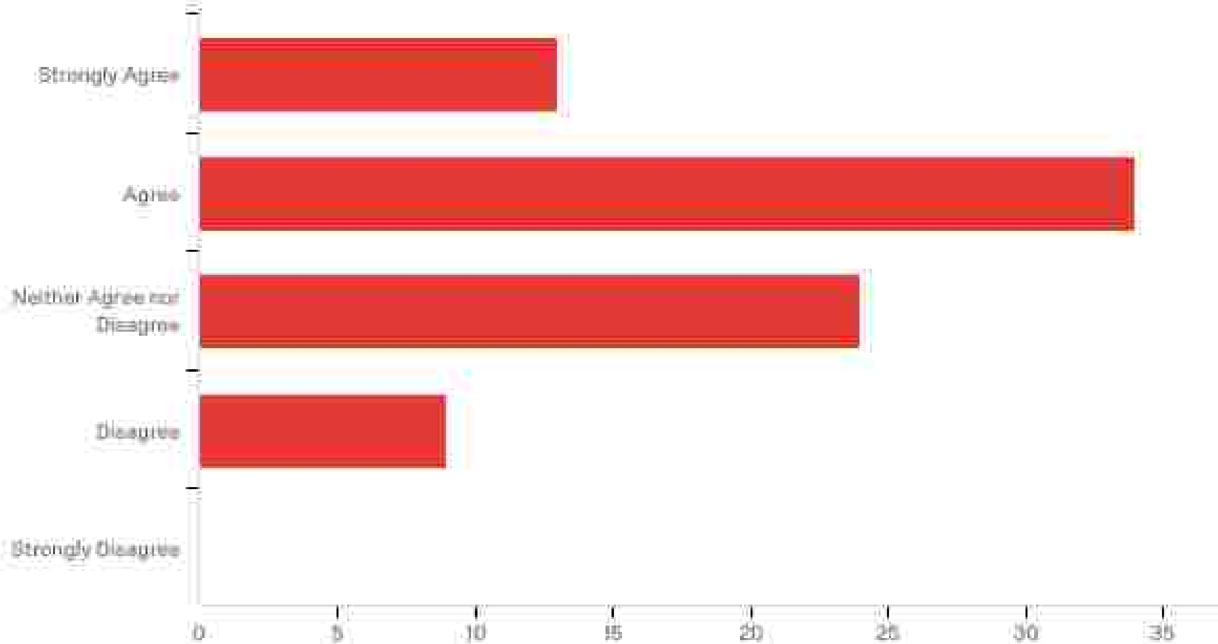
Q14 - Automation in the cockpit made my job easier



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Automation in the cockpit made my job easier	1.00	4.00	1.54	0.59	0.35	79

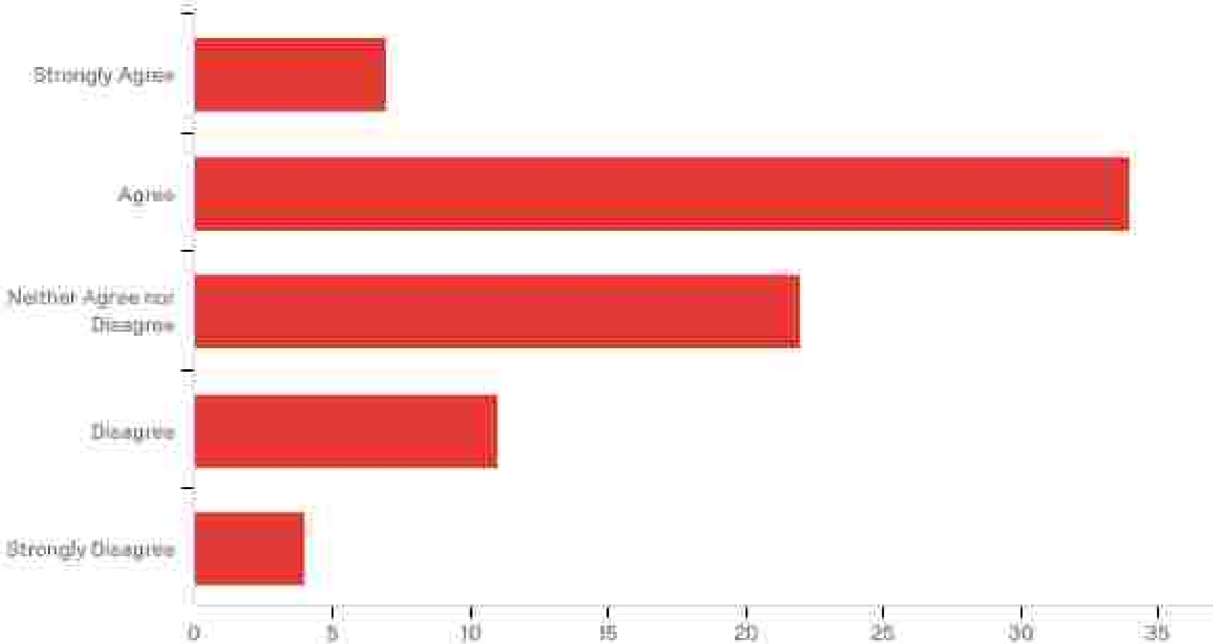
#	Answer	%	Count
1	Strongly Agree	49.37%	39
2	Agree	48.10%	38
3	Neither Agree nor Disagree	1.27%	1
4	Disagree	1.27%	1
5	Strongly Disagree	0.00%	0
	Total	100%	79

Q15 - Automation keeps me to engaged throughout the flight



#	Answer	%	Count
1	Strongly Agree	16.25%	13
2	Agree	42.50%	34
3	Neither Agree nor Disagree	30.00%	24
4	Disagree	11.25%	9
5	Strongly Disagree	0.00%	0
	Total	100%	80

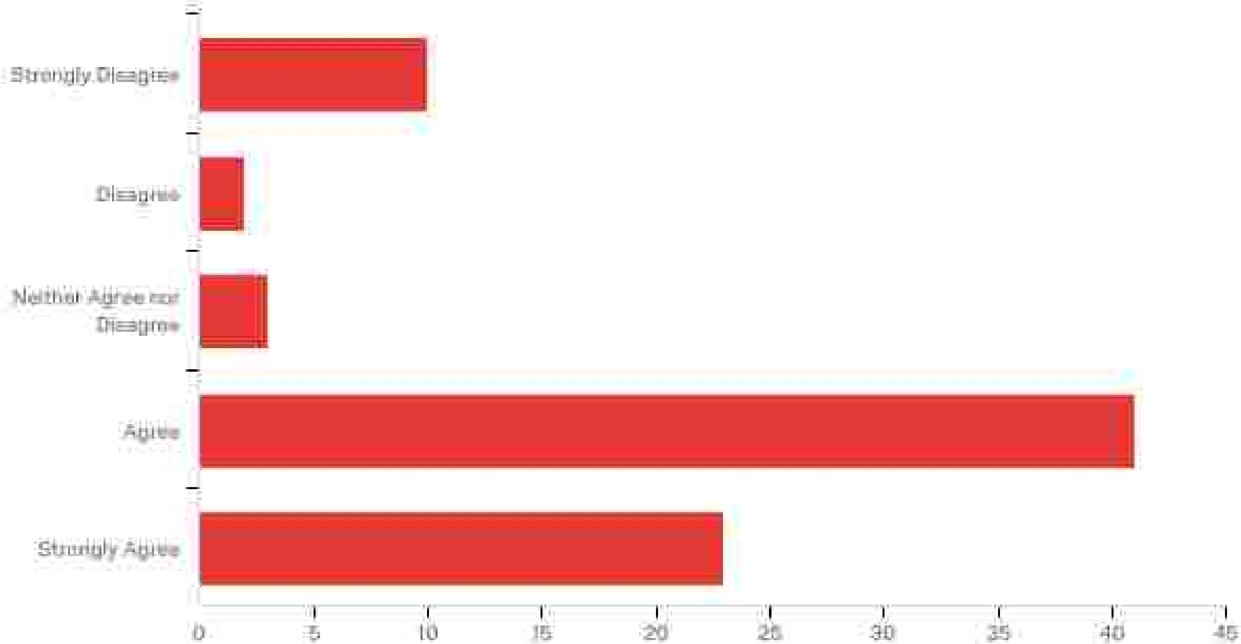
Q16 - I rely on automation to keep me safe



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I rely on automation to keep me safe	1.00	5.00	2.63	1.00	1.00	78

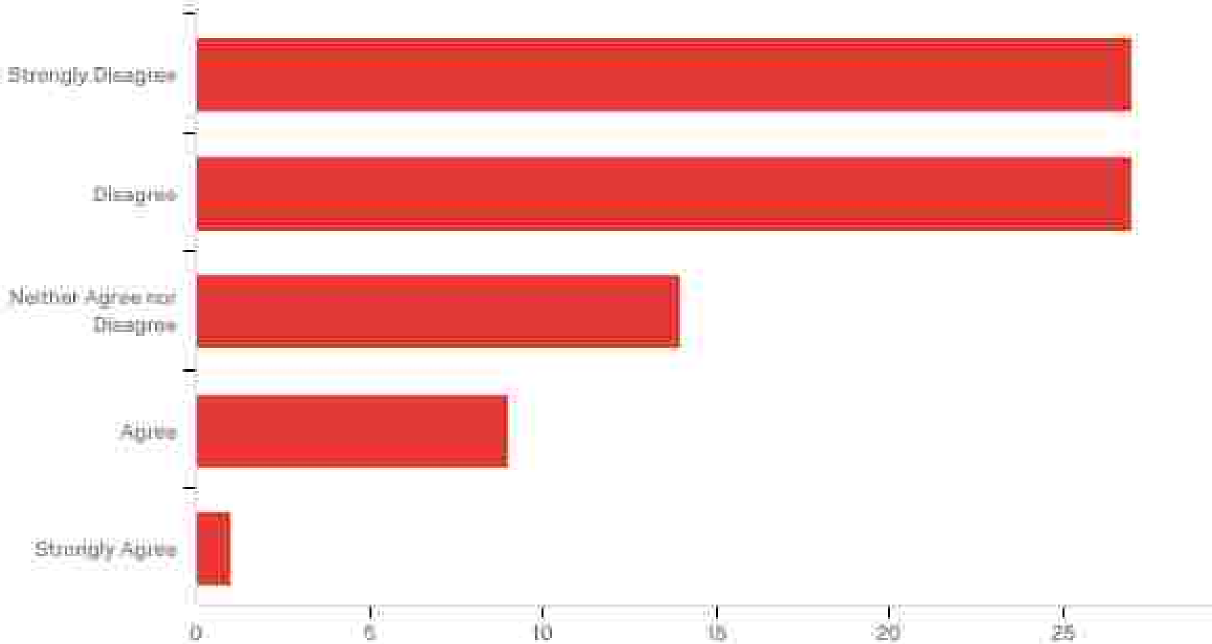
#	Answer	%	Count
1	Strongly Agree	8.97%	7
2	Agree	43.59%	34
3	Neither Agree nor Disagree	28.21%	22
4	Disagree	14.10%	11
5	Strongly Disagree	5.13%	4
	Total	100%	78

Q17 - Through use of the FMC (Flight Management Computer) for automated flight planning (e.g. planning of route, waypoints etc) my overall workload is lower.



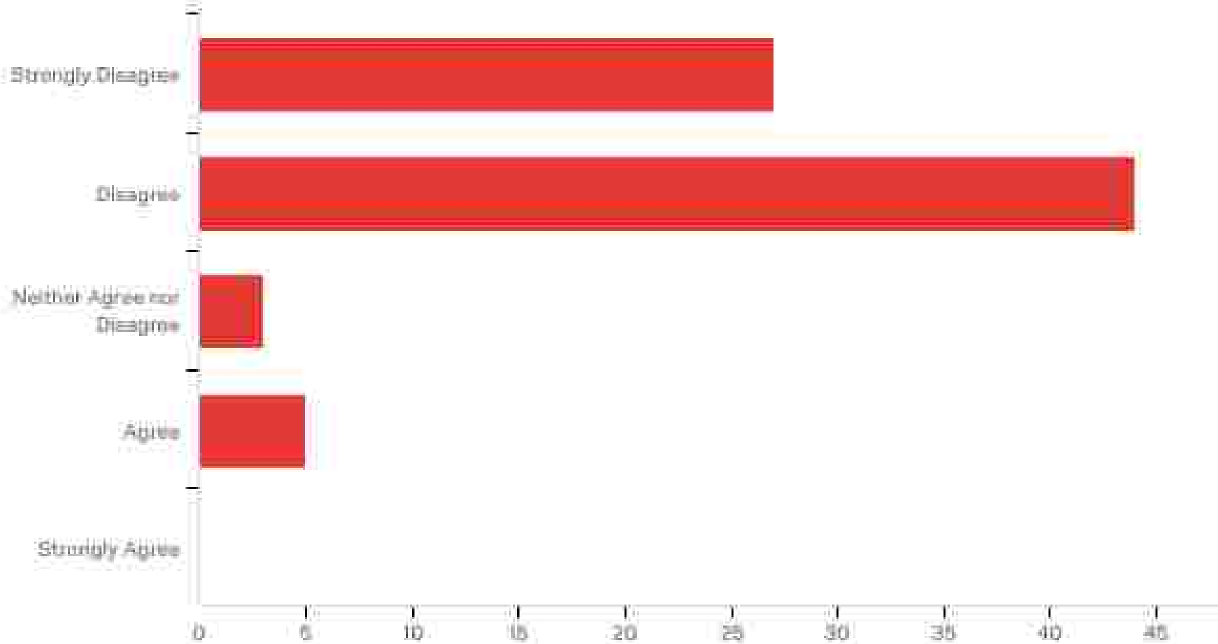
#	Answer	%	Count
1	Strongly Disagree	12.66%	10
2	Disagree	2.53%	2
3	Neither Agree nor Disagree	3.80%	3
4	Agree	51.90%	41
5	Strongly Agree	29.11%	23
	Total	100%	79

Q18 - I trust in automation more than I trust in myself



#	Answer	%	Count
1	Strongly Disagree	34.62%	27
2	Disagree	34.62%	27
3	Neither Agree nor Disagree	17.95%	14
4	Agree	11.54%	9
5	Strongly Agree	1.28%	1
	Total	100%	78

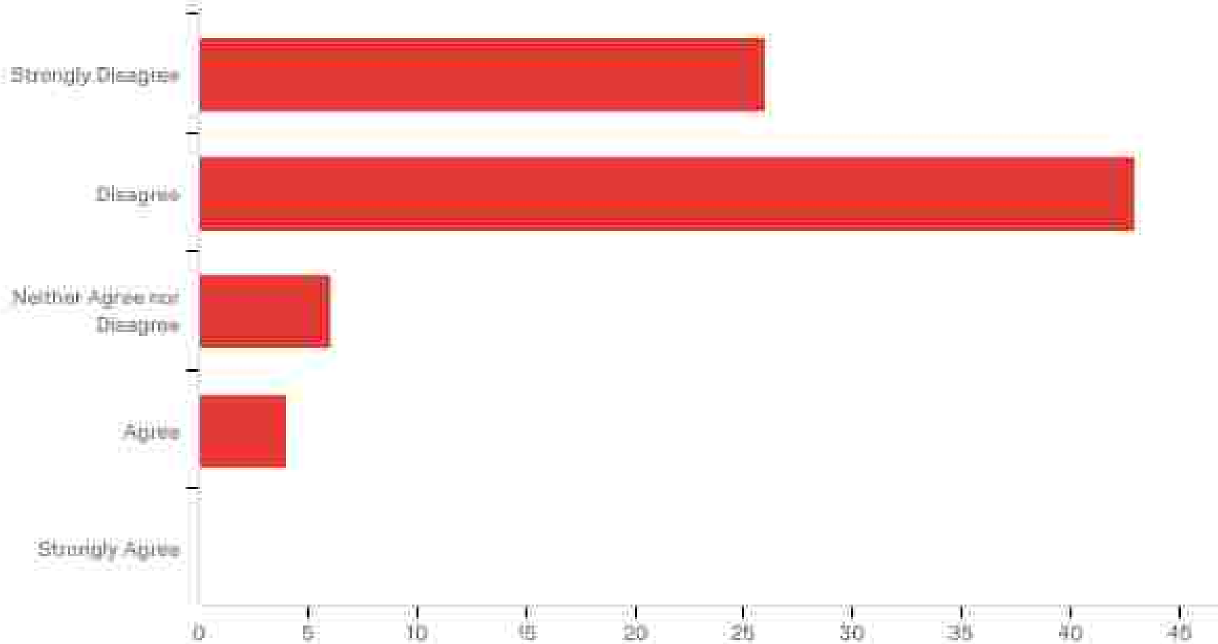
Q19 - Automation in the cockpit made my job harder



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Automation in the cockpit made my job harder	1.00	4.00	1.82	0.78	0.60	79

#	Answer	%	Count
1	Strongly Disagree	34.18%	27
2	Disagree	55.70%	44
3	Neither Agree nor Disagree	3.80%	3
4	Agree	6.33%	5
5	Strongly Agree	0.00%	0
	Total	100%	79

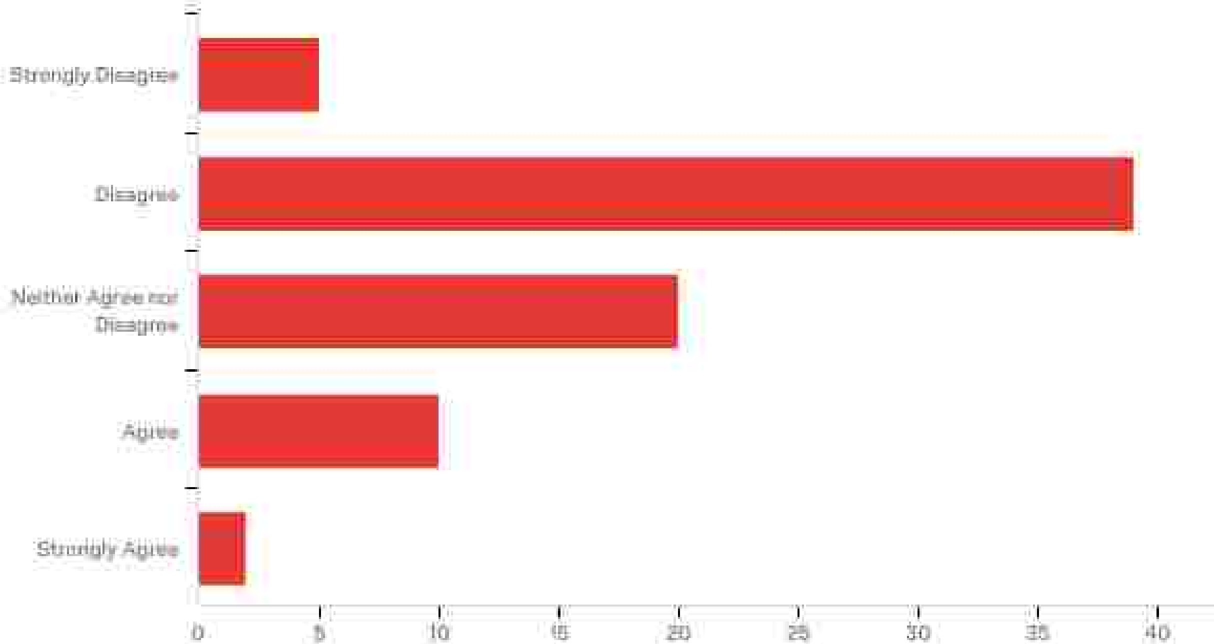
Q20 - I don't feel comfortable when autopilot controls vertical and horizontal flight paths (VNAVs and LNAVs)



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I don't feel comfortable when autopilot controls vertical and horizontal flight paths (VNAVs and LNAVs)	1.00	4.00	1.85	0.76	0.58	79

#	Answer	%	Count
1	Strongly Disagree	32.91%	26
2	Disagree	54.43%	43
3	Neither Agree nor Disagree	7.59%	6
4	Agree	5.06%	4
5	Strongly Agree	0.00%	0
	Total	100%	79

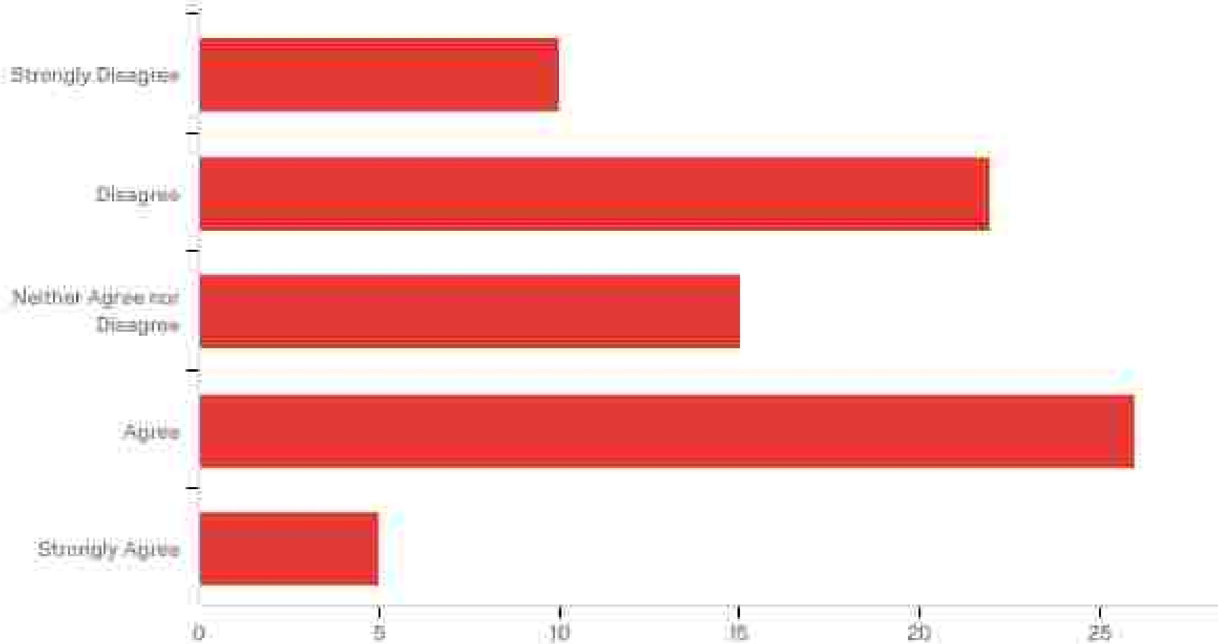
Q21 - The biggest obstacle to overall flight safety is ad-hoc and confusing communication from automated systems in the cockpit.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	The biggest obstacle to overall flight safety is ad-hoc and confusing communication from automated systems in the cockpit.	1.00	5.00	2.54	0.90	0.80	76

#	Answer	%	Count
1	Strongly Disagree	6.58%	5
2	Disagree	51.32%	39
3	Neither Agree nor Disagree	26.32%	20
4	Agree	13.16%	10
5	Strongly Agree	2.63%	2
	Total	100%	76

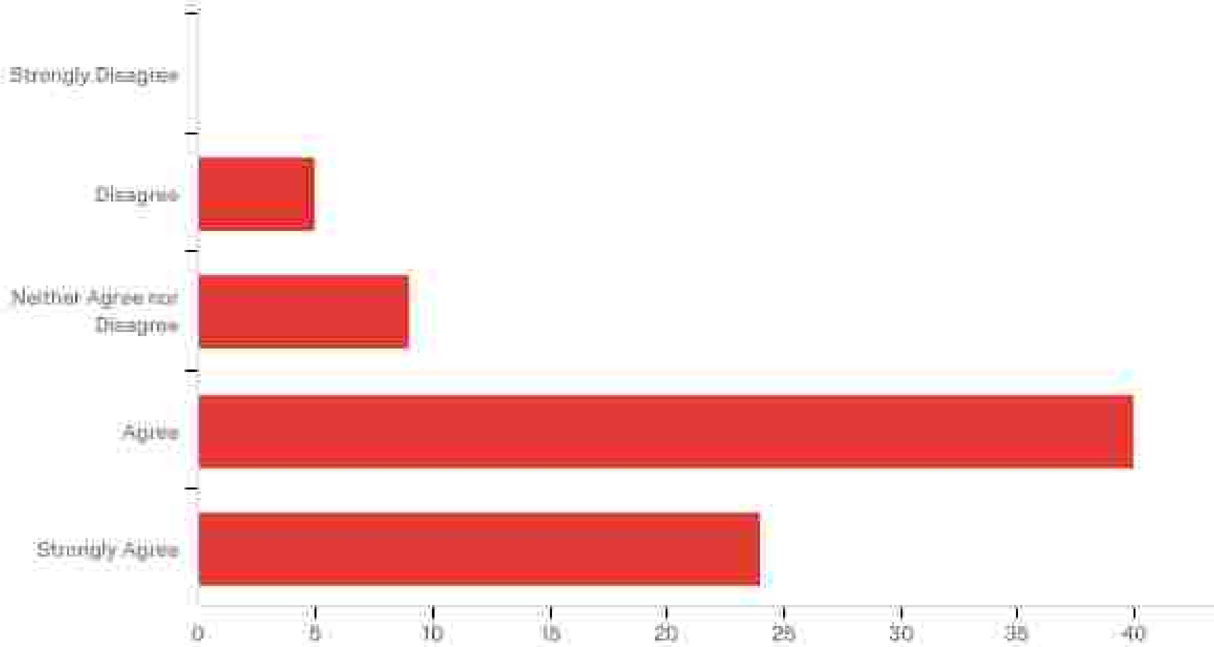
Q22 - When equipped, I rely on flight envelope protection to protect my aircraft and passengers in case I make any mistake



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	When equipped, I rely on flight envelope protection to protect my aircraft and passengers in case I make any mistake	1.00	5.00	2.92	1.17	1.38	78

#	Answer	%	Count
1	Strongly Disagree	12.82%	10
2	Disagree	28.21%	22
3	Neither Agree nor Disagree	19.23%	15
4	Agree	33.33%	26
5	Strongly Agree	6.41%	5
	Total	100%	78

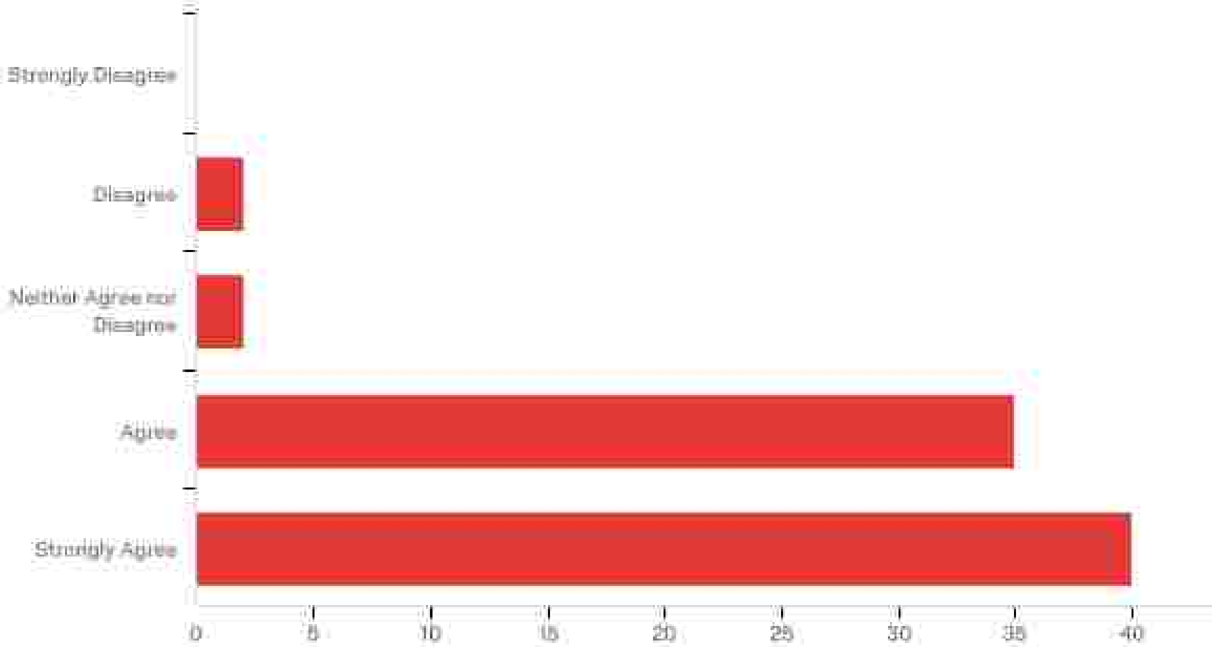
Q23 - I always check my next waypoint and I'm aware of pending heading changes



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I always check my next waypoint and I'm aware of pending heading changes	2.00	5.00	4.06	0.82	0.68	78

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	6.41%	5
3	Neither Agree nor Disagree	11.54%	9
4	Agree	51.28%	40
5	Strongly Agree	30.77%	24
	Total	100%	78

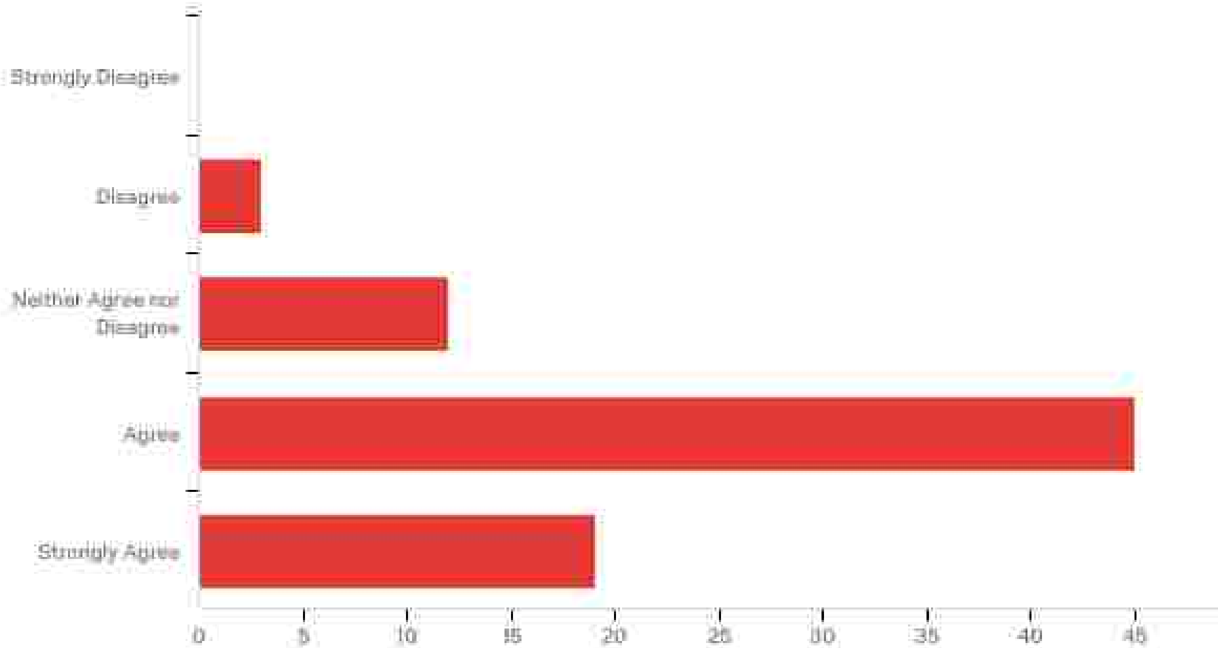
Q24 - I check my primary flight display very often throughout the flight



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I check my primary flight display very often throughout the flight	2.00	5.00	4.43	0.67	0.45	79

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	2.53%	2
3	Neither Agree nor Disagree	2.53%	2
4	Agree	44.30%	35
5	Strongly Agree	50.63%	40
	Total	100%	79

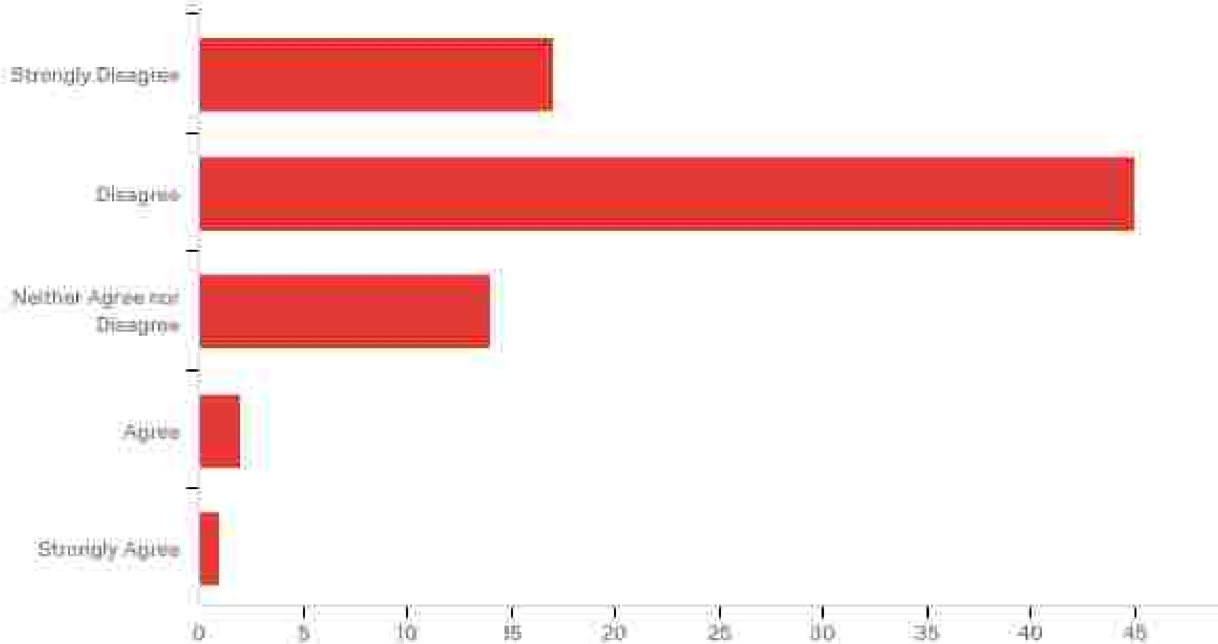
Q25 - Information represented on the Control Display Unit (CDU) is clear and easy to understand



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Information represented on the Control Display Unit (CDU) is clear and easy to understand	2.00	5.00	4.01	0.74	0.54	79

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	3.80%	3
3	Neither Agree nor Disagree	15.19%	12
4	Agree	56.96%	45
5	Strongly Agree	24.05%	19
	Total	100%	79

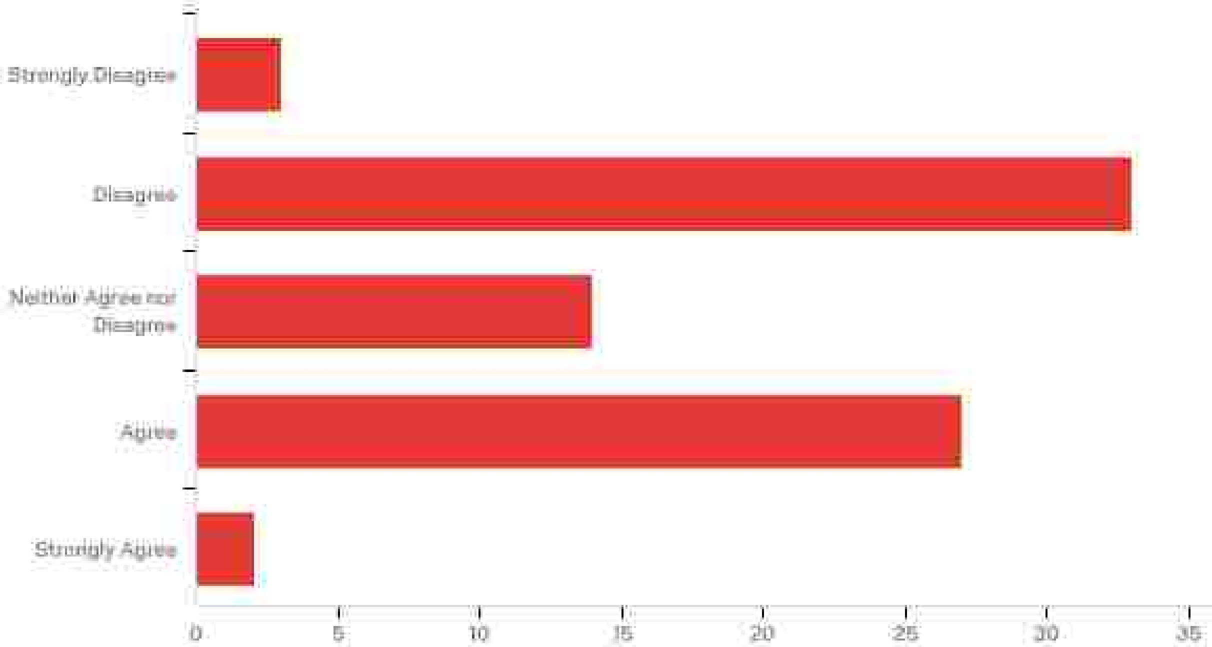
Q26 - Automation increased my workload, created more need to monitor



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Automation increased my workload, created more need to monitor	1.00	5.00	2.05	0.78	0.61	79

#	Answer	%	Count
1	Strongly Disagree	21.52%	17
2	Disagree	56.96%	45
3	Neither Agree nor Disagree	17.72%	14
4	Agree	2.53%	2
5	Strongly Agree	1.27%	1
	Total	100%	79

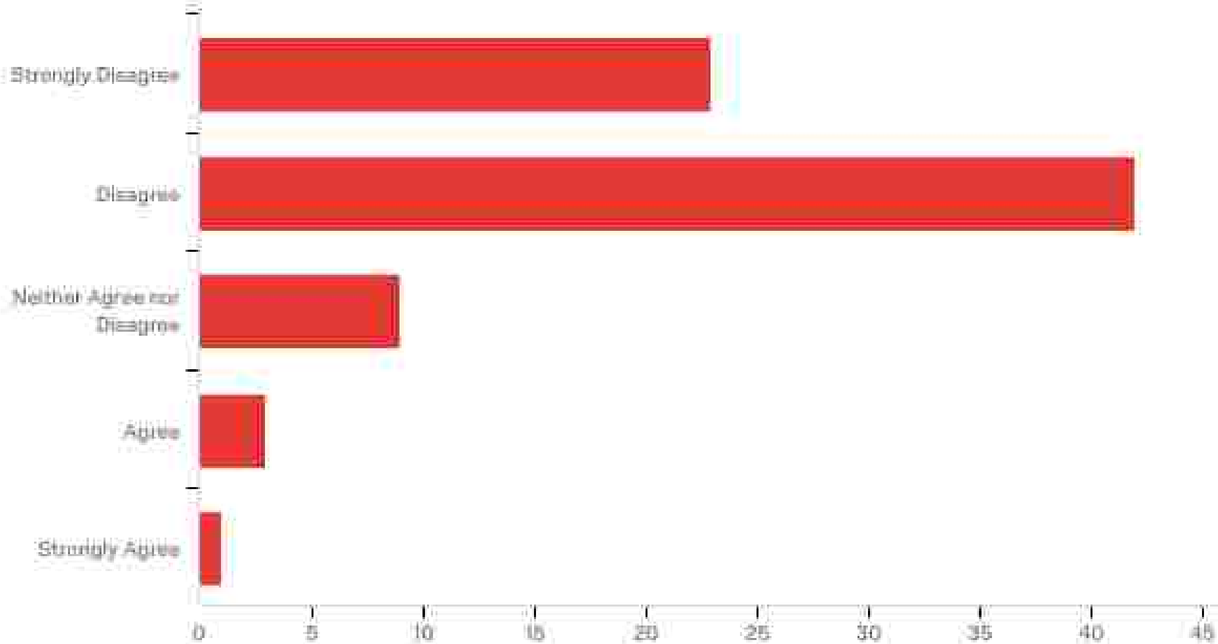
Q27 - During the automated flight phase, I am sometimes surprised by actions automation takes



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	During the automated flight phase, I am sometimes surprised by actions automation takes	1.00	5.00	2.90	1.00	1.00	79

#	Answer	%	Count
1	Strongly Disagree	3.80%	3
2	Disagree	41.77%	33
3	Neither Agree nor Disagree	17.72%	14
4	Agree	34.18%	27
5	Strongly Agree	2.53%	2
	Total	100%	79

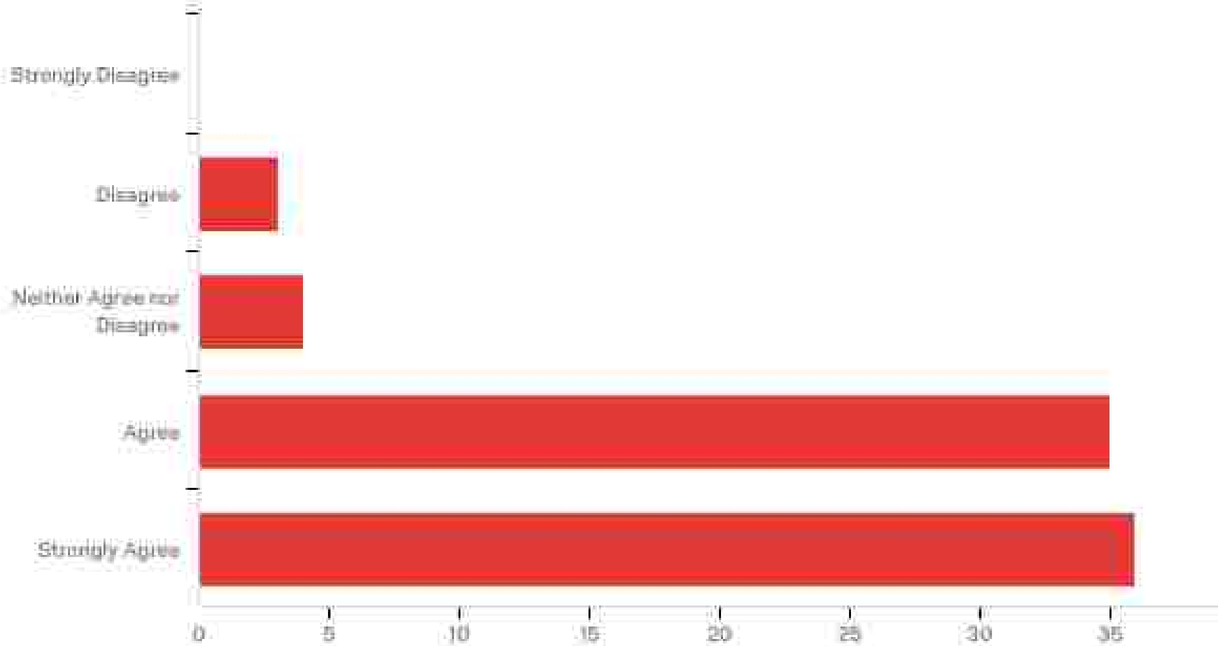
Q28 - When I use autopilot to control HDG, SPD or ALT I feel automation creates distraction.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	When I use autopilot to control HDG, SPD or ALT I feel automation creates distraction.	1.00	5.00	1.94	0.82	0.68	78

#	Answer	%	Count
1	Strongly Disagree	29.49%	23
2	Disagree	53.85%	42
3	Neither Agree nor Disagree	11.54%	9
4	Agree	3.85%	3
5	Strongly Agree	1.28%	1
	Total	100%	78

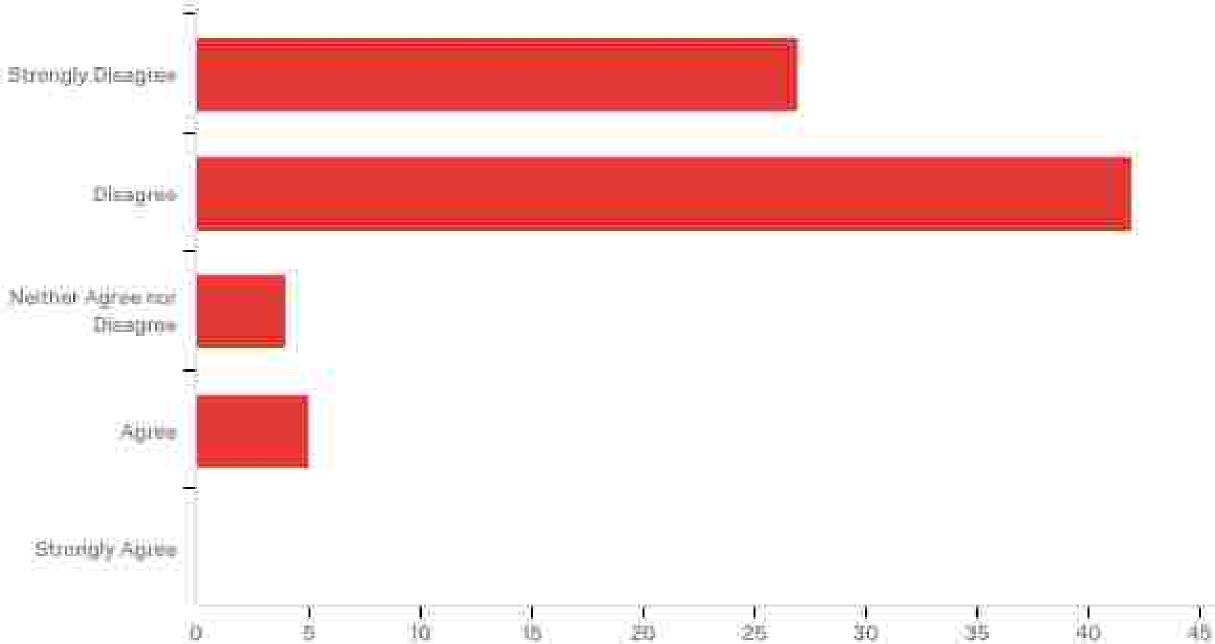
Q29 - I check the flight mode annunciator very often to understand which mode the autopilot flight director system is in (what autopilot is doing)



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I check the flight mode annunciator very often to understand which mode the autopilot flight director system is in (what autopilot is doing)	2.00	5.00	4.33	0.75	0.56	78

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	3.85%	3
3	Neither Agree nor Disagree	5.13%	4
4	Agree	44.87%	35
5	Strongly Agree	46.15%	36
	Total	100%	78

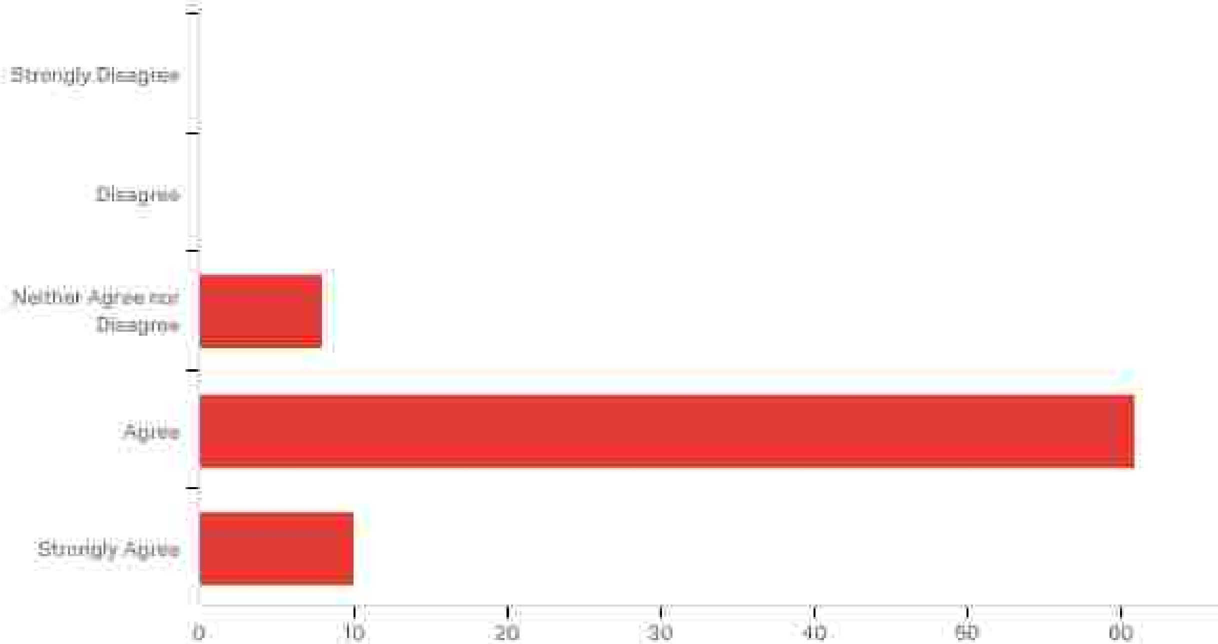
Q30 - When I use autopilot to control HDG, SPD or ALT my understanding of the big picture diminishes



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	When I use autopilot to control HDG, SPD or ALT my understanding of the big picture diminishes	1.00	4.00	1.83	0.79	0.63	78

#	Answer	%	Count
1	Strongly Disagree	34.62%	27
2	Disagree	53.85%	42
3	Neither Agree nor Disagree	5.13%	4
4	Agree	6.41%	5
5	Strongly Agree	0.00%	0
	Total	100%	78

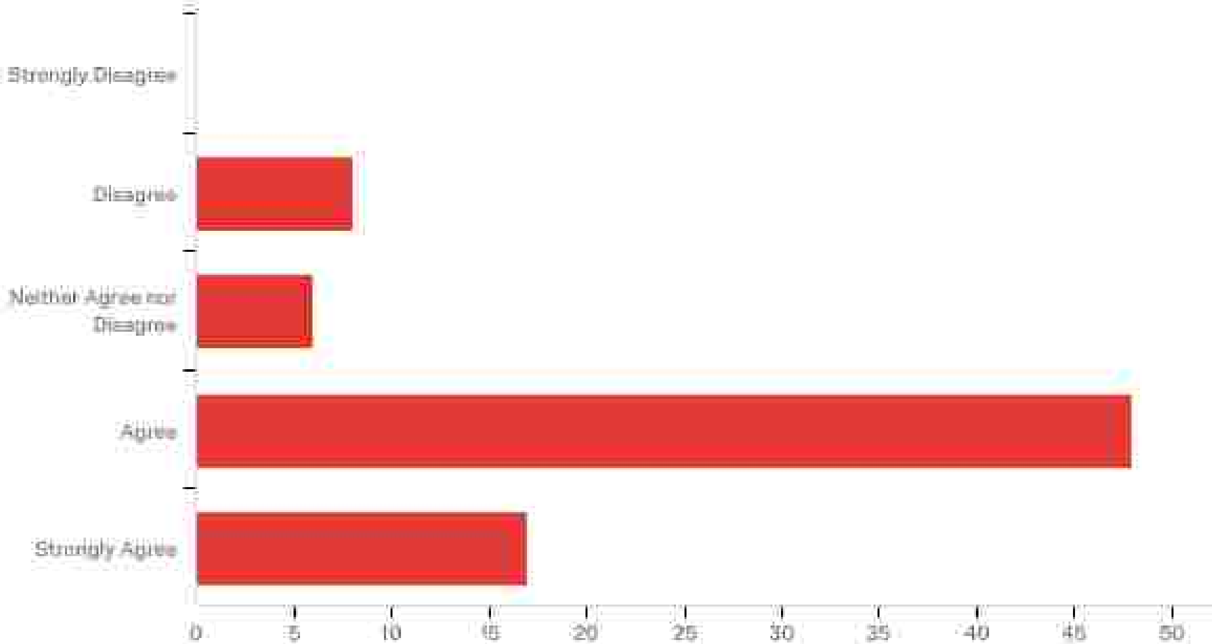
Q31 - I can predict the behavior of the automation with ease



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I can predict the behavior of the automation with ease	3.00	5.00	4.03	0.48	0.23	79

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	0.00%	0
3	Neither Agree nor Disagree	10.13%	8
4	Agree	77.22%	61
5	Strongly Agree	12.66%	10
	Total	100%	79

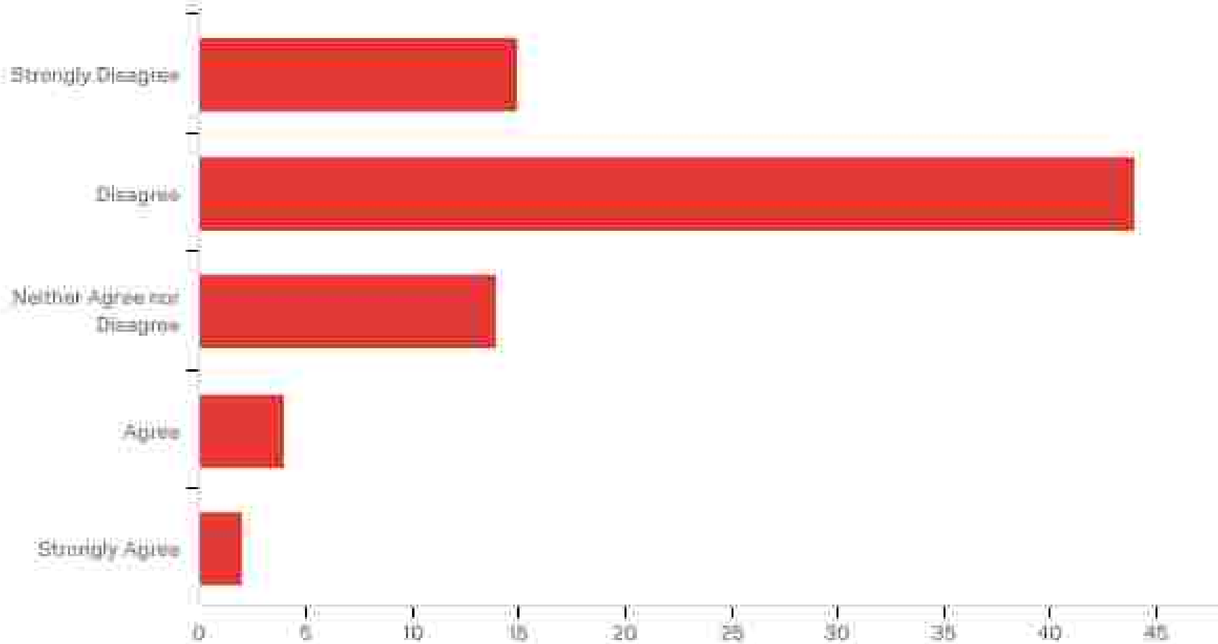
Q32 - When I use autopilot to control HDG, SPD or ALT my workload gets lower.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	When I use autopilot to control HDG, SPD or ALT my workload gets lower.	2.00	5.00	3.94	0.83	0.69	79

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	10.13%	8
3	Neither Agree nor Disagree	7.59%	6
4	Agree	60.76%	48
5	Strongly Agree	21.52%	17
	Total	100%	79

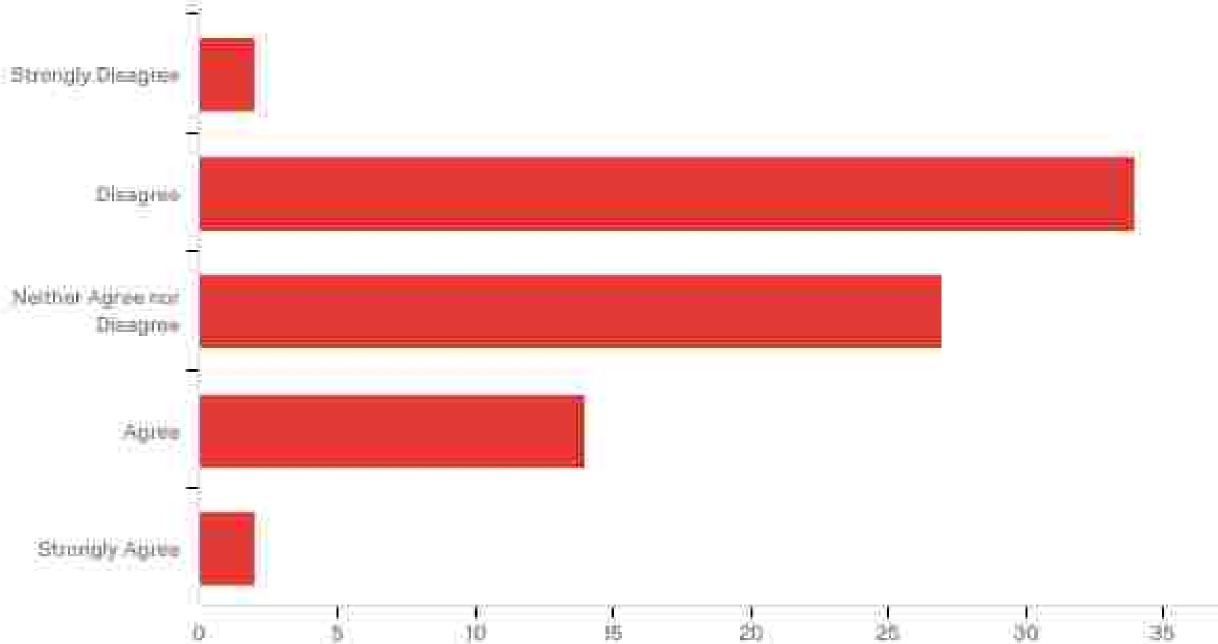
Q33 - I think the overall amount of information available on my aircraft is too much.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I think the overall amount of information available on my aircraft is too much.	1.00	5.00	2.16	0.88	0.77	79

#	Answer	%	Count
1	Strongly Disagree	18.99%	15
2	Disagree	55.70%	44
3	Neither Agree nor Disagree	17.72%	14
4	Agree	5.06%	4
5	Strongly Agree	2.53%	2
	Total	100%	79

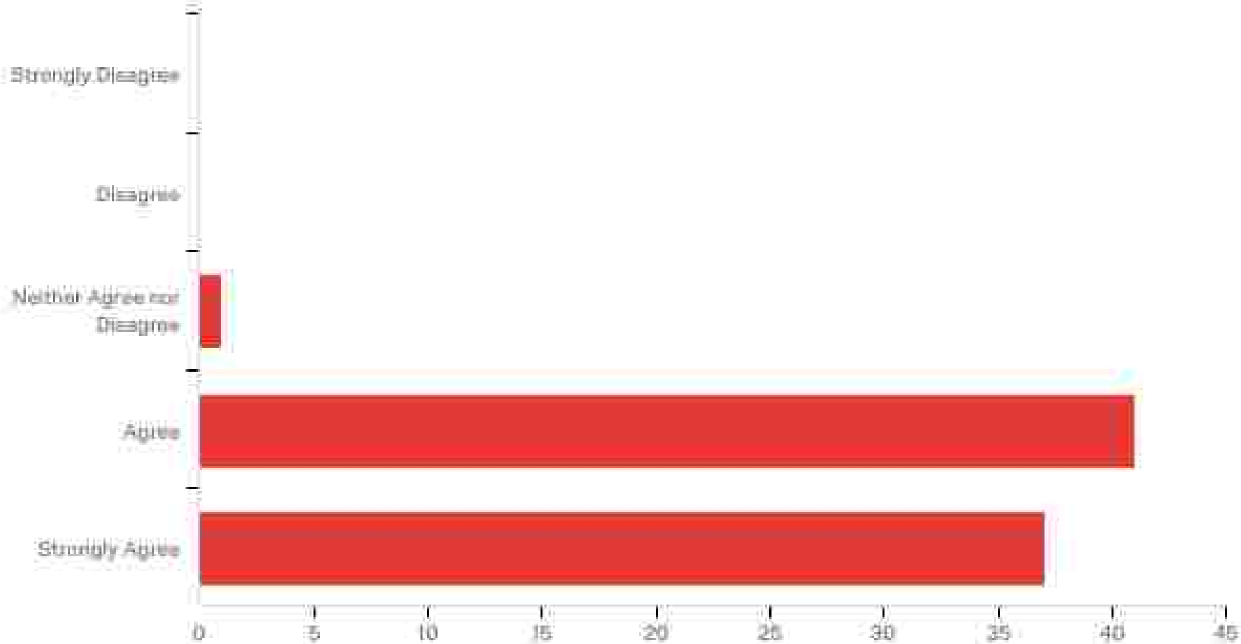
Q34 - My response to visual warnings is better than aural (sound) alerts



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	My response to visual warnings is better than aural (sound) alerts	1.00	5.00	2.75	0.86	0.75	79

#	Answer	%	Count
1	Strongly Disagree	2.53%	2
2	Disagree	43.04%	34
3	Neither Agree nor Disagree	34.18%	27
4	Agree	17.72%	14
5	Strongly Agree	2.53%	2
	Total	100%	79

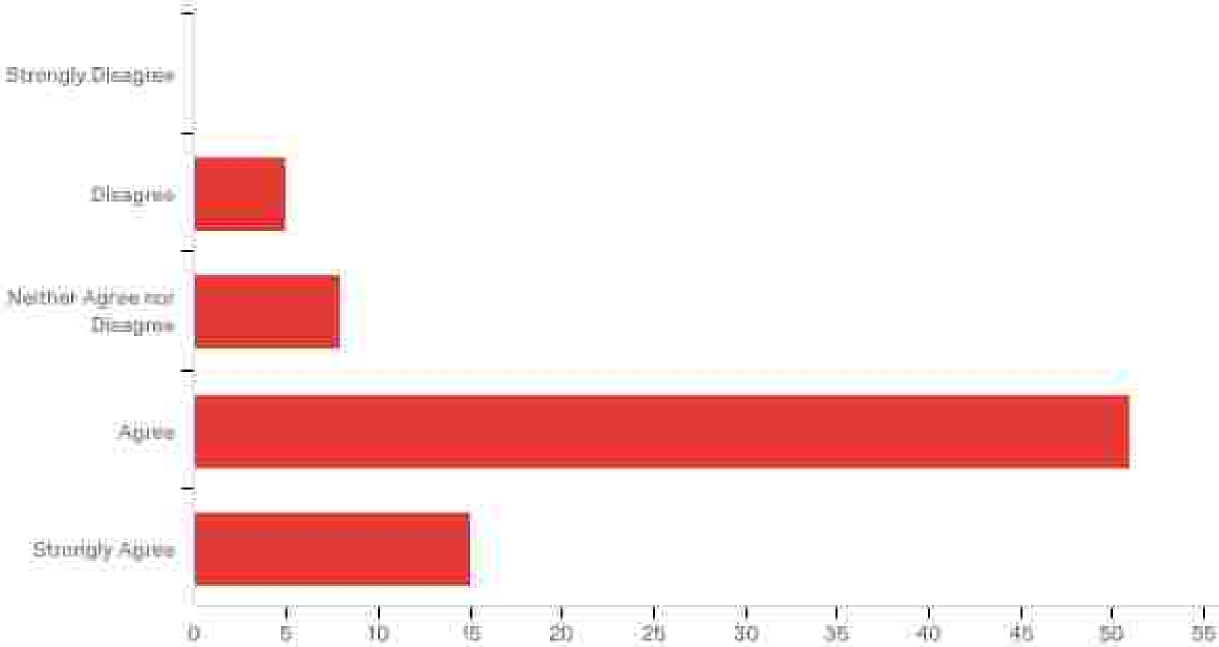
Q35 - When a master caution and warning alert occurs; it gets my attention immediately



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	When a master caution and warning alert occurs; it gets my attention immediately	3.00	5.00	4.46	0.52	0.27	79

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	0.00%	0
3	Neither Agree nor Disagree	1.27%	1
4	Agree	51.90%	41
5	Strongly Agree	46.84%	37
	Total	100%	79

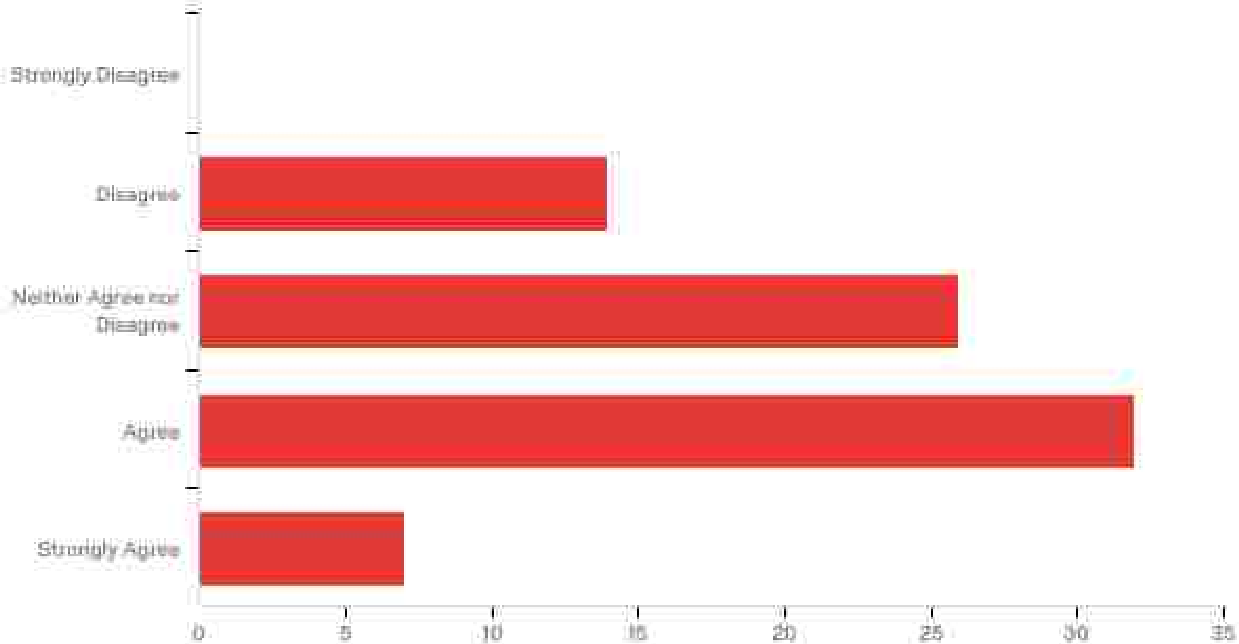
Q36 - When a master caution and warning alert occurs; I trust the alert signals are a real event



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	When a master caution and warning alert occurs; I trust the alert signals are a real event	2.00	5.00	3.96	0.74	0.54	79

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	6.33%	5
3	Neither Agree nor Disagree	10.13%	8
4	Agree	64.56%	51
5	Strongly Agree	18.99%	15
	Total	100%	79

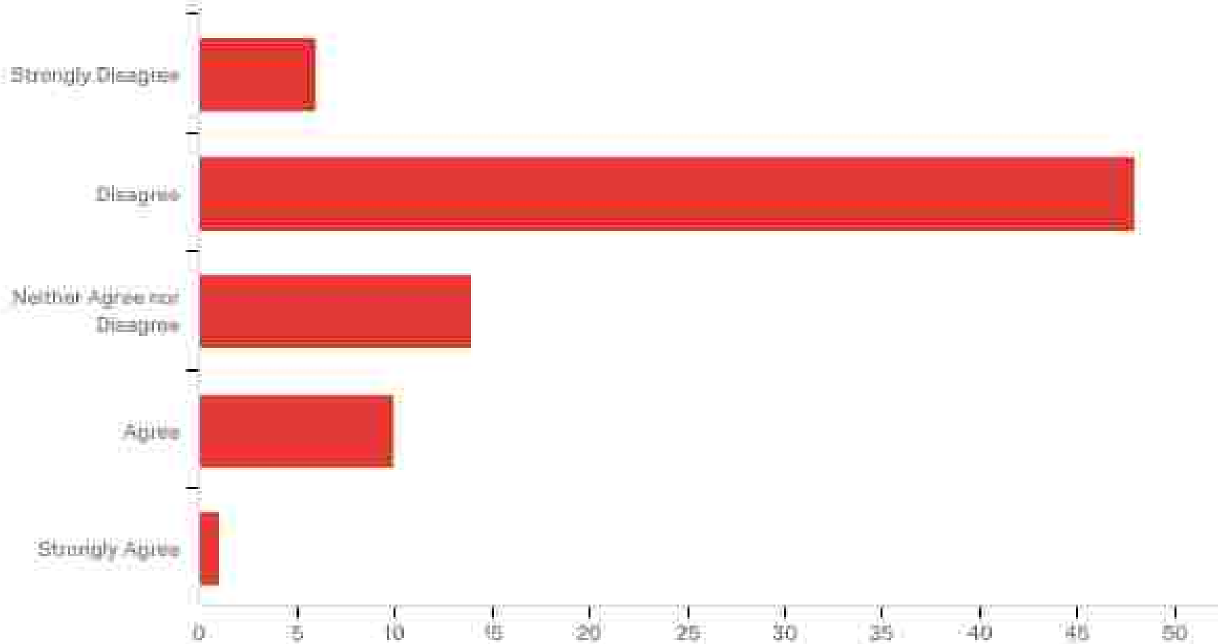
Q37 - My response to aural (sound) alerts is better than visual warnings



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	My response to aural (sound) alerts is better than visual warnings	2.00	5.00	3.41	0.88	0.77	79

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	17.72%	14
3	Neither Agree nor Disagree	32.91%	26
4	Agree	40.51%	32
5	Strongly Agree	8.86%	7
	Total	100%	79

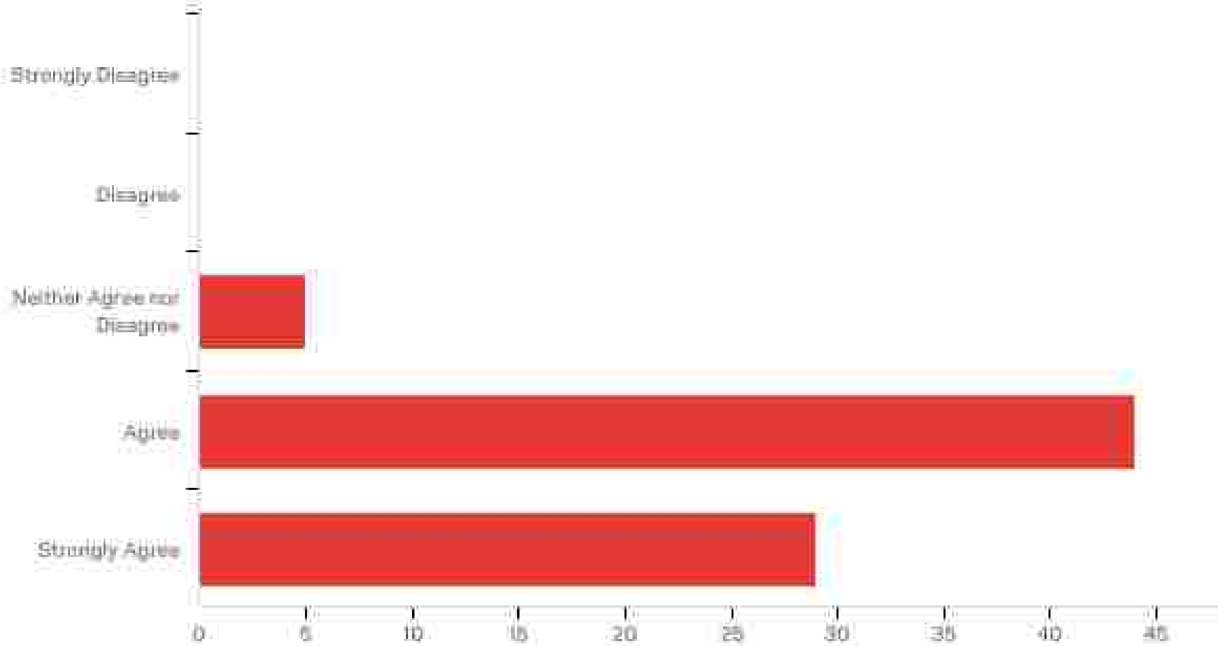
Q38 - I think the overall amount of information available on my aircraft is not enough



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I think the overall amount of information available on my aircraft is not enough	1.00	5.00	2.39	0.85	0.72	79

#	Answer	%	Count
1	Strongly Disagree	7.59%	6
2	Disagree	60.76%	48
3	Neither Agree nor Disagree	17.72%	14
4	Agree	12.66%	10
5	Strongly Agree	1.27%	1
	Total	100%	79

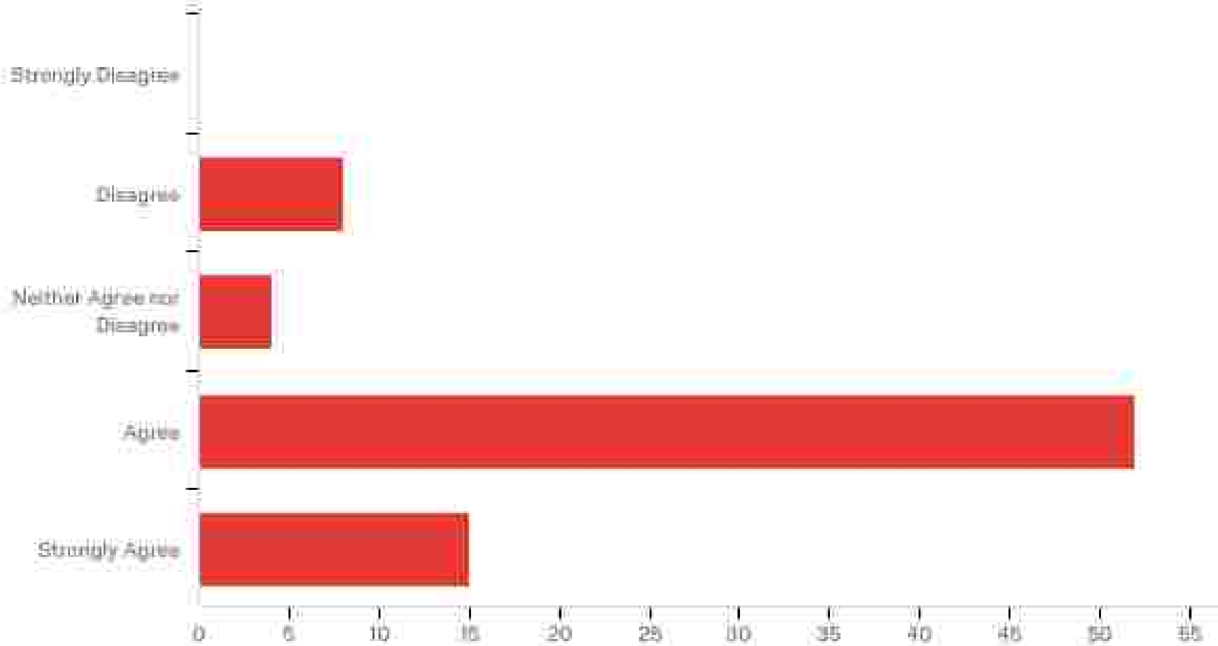
Q39 - When I face a problem in the cockpit I always follow the SOP's (Standard Operating Procedure) before trying another approach to solve the problem



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	When I face a problem in the cockpit I always follow the SOP's (Standard Operating Procedure) before trying another approach to solve the problem	3.00	5.00	4.31	0.58	0.34	78

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	0.00%	0
3	Neither Agree nor Disagree	6.41%	5
4	Agree	56.41%	44
5	Strongly Agree	37.18%	29
	Total	100%	78

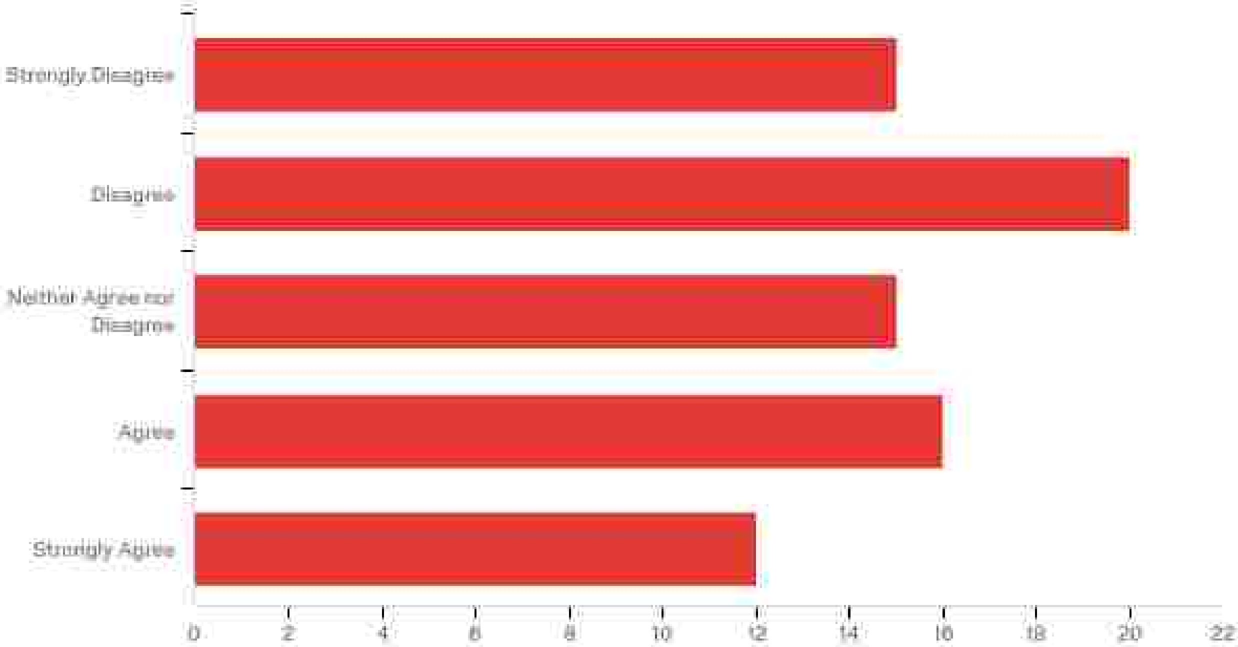
Q40 - In most cases an automatic system should prevent the aircraft from exceeding its performance envelope



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	In most cases an automatic system should prevent the aircraft from exceeding its performance envelope	2.00	5.00	3.94	0.80	0.64	79

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	10.13%	8
3	Neither Agree nor Disagree	5.06%	4
4	Agree	65.82%	52
5	Strongly Agree	18.99%	15
	Total	100%	79

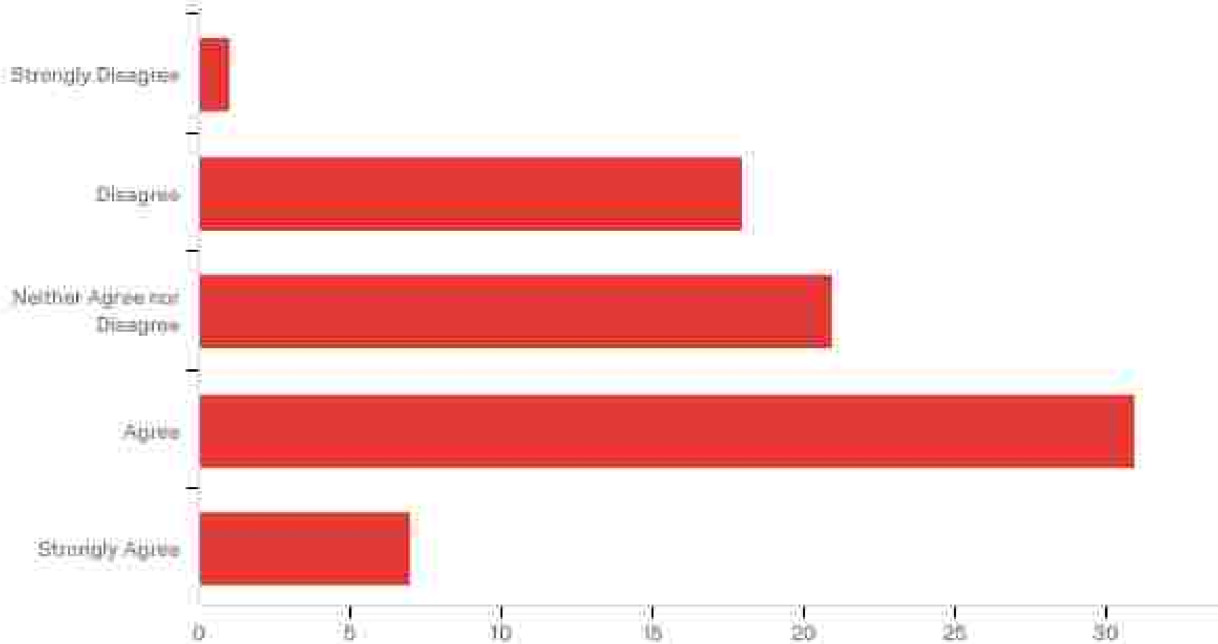
Q41 - My airline doesn't allow me to fly manually; they force me to fly automated most or all of the time.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	My airline doesn't allow me to fly manually; they force me to fly automated most or all of the time.	1.00	5.00	2.87	1.35	1.83	78

#	Answer	%	Count
1	Strongly Disagree	19.23%	15
2	Disagree	25.64%	20
3	Neither Agree nor Disagree	19.23%	15
4	Agree	20.51%	16
5	Strongly Agree	15.38%	12
	Total	100%	78

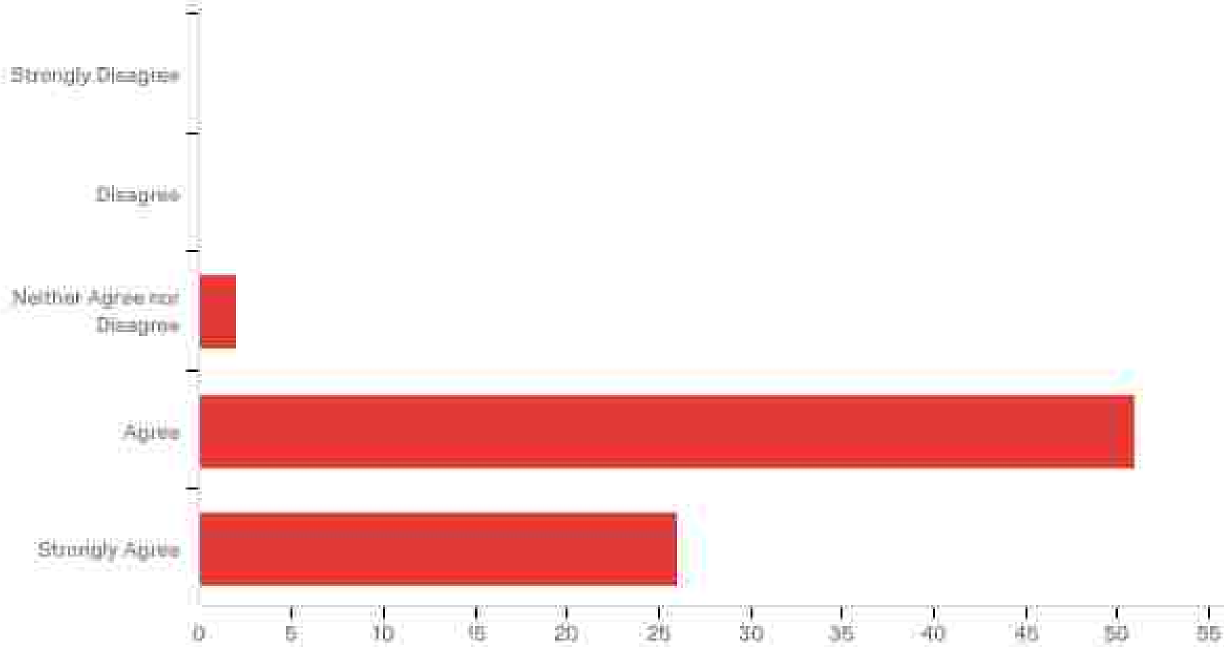
Q42 - When a problem develops in the cockpit, I always try to understand the broader picture before I follow the SOP's.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	When a problem develops in the cockpit, I always try to understand the broader picture before I follow the SOP's.	1.00	5.00	3.32	0.97	0.94	78

#	Answer	%	Count
1	Strongly Disagree	1.28%	1
2	Disagree	23.08%	18
3	Neither Agree nor Disagree	26.92%	21
4	Agree	39.74%	31
5	Strongly Agree	8.97%	7
	Total	100%	78

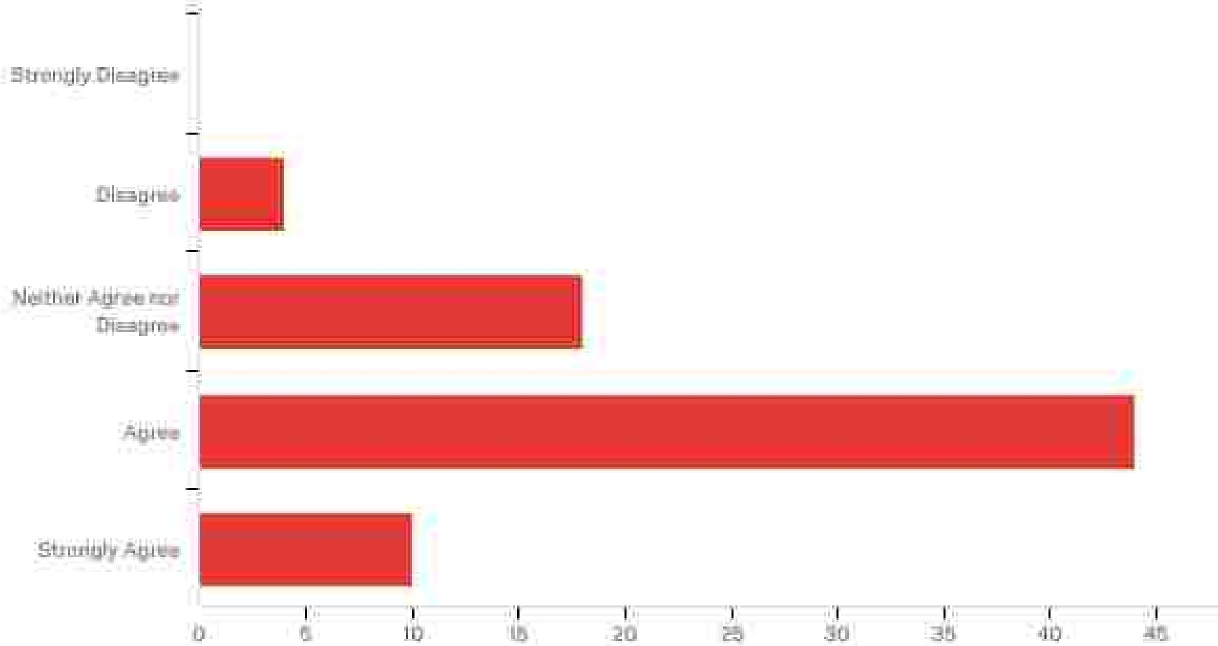
Q43 - I always adhere to the principles of Crew Resource Management (CRM)



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	I always adhere to the principles of Crew Resource Management (CRM)	3.00	5.00	4.30	0.51	0.26	79

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	0.00%	0
3	Neither Agree nor Disagree	2.53%	2
4	Agree	64.56%	51
5	Strongly Agree	32.91%	26
	Total	100%	79

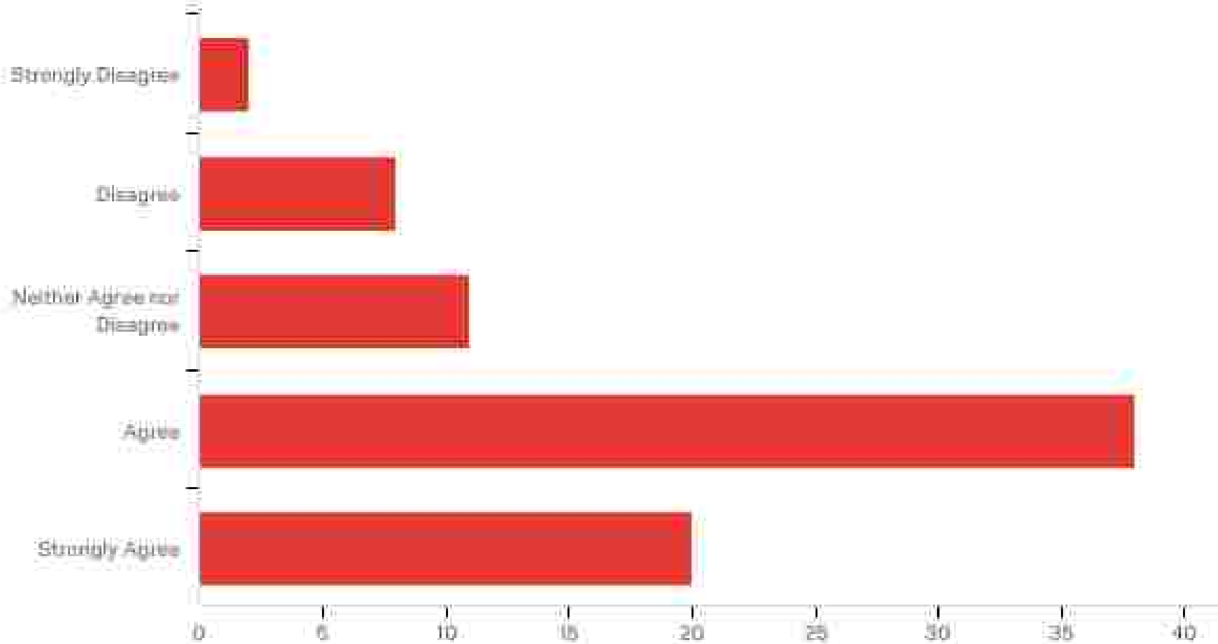
Q44 - Regulations should require cockpit automation to adhere to the principles of CRM when feasible.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Regulations should require cockpit automation to adhere to the principles of CRM when feasible.	2.00	5.00	3.79	0.73	0.53	76

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	5.26%	4
3	Neither Agree nor Disagree	23.68%	18
4	Agree	57.89%	44
5	Strongly Agree	13.16%	10
	Total	100%	76

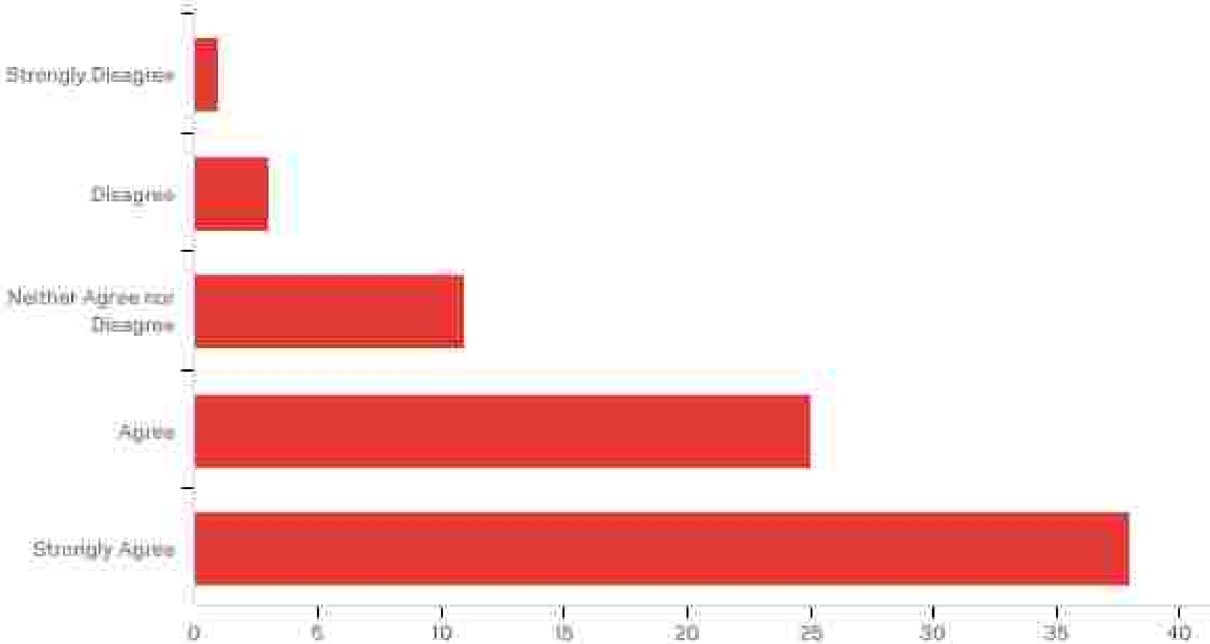
Q45 - In most cases an automatic system should warn the crew of flight envelope exceedance but not restrict pilots' control



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	In most cases an automatic system should warn the crew of flight envelope exceedance but not restrict pilots' control	1.00	5.00	3.84	1.00	1.00	79

#	Answer	%	Count
1	Strongly Disagree	2.53%	2
2	Disagree	10.13%	8
3	Neither Agree nor Disagree	13.92%	11
4	Agree	48.10%	38
5	Strongly Agree	25.32%	20
	Total	100%	79

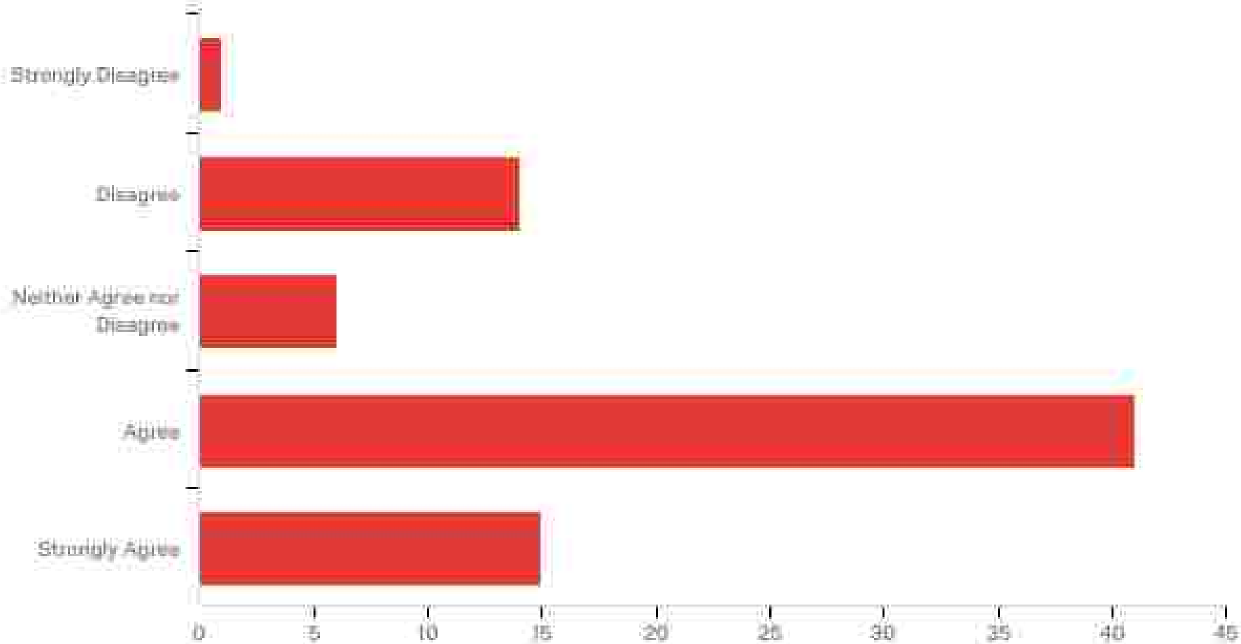
Q46 - A high level of competency in manual flying skills would benefit the industry



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	A high level of competency in manual flying skills would benefit the industry	1.00	5.00	4.23	0.92	0.84	78

#	Answer	%	Count
1	Strongly Disagree	1.28%	1
2	Disagree	3.85%	3
3	Neither Agree nor Disagree	14.10%	11
4	Agree	32.05%	25
5	Strongly Agree	48.72%	38
	Total	100%	78

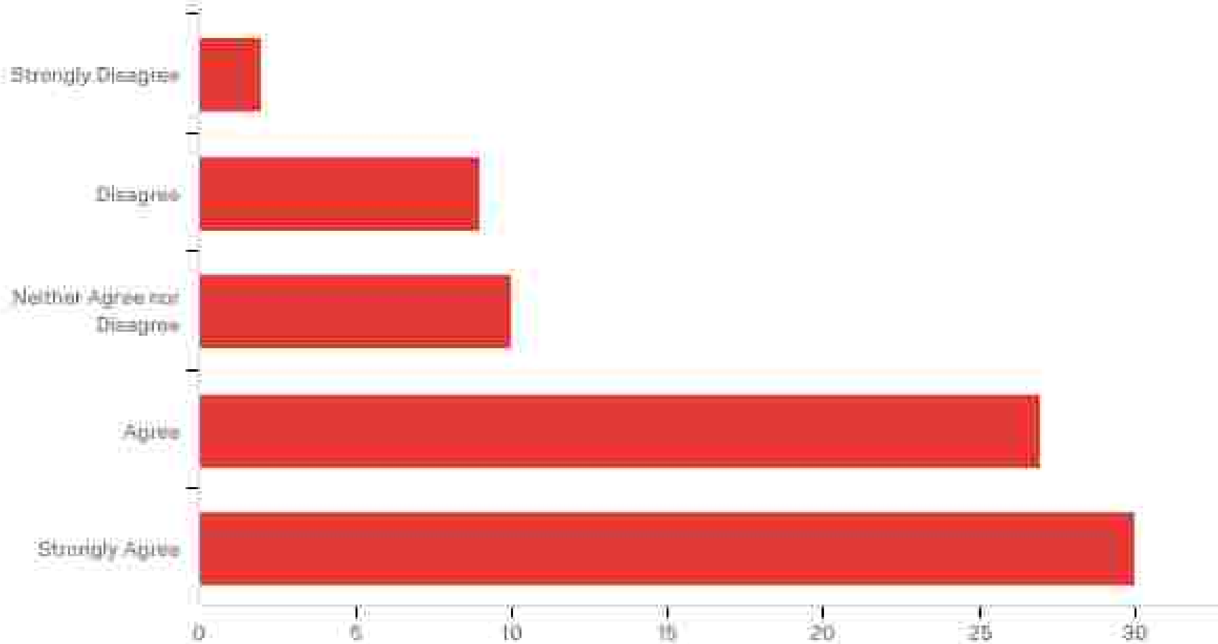
Q47 - Difficulties in understanding automation can be overcome solely by training



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Difficulties in understanding automation can be overcome solely by training	1.00	5.00	3.71	1.02	1.04	77

#	Answer	%	Count
1	Strongly Disagree	1.30%	1
2	Disagree	18.18%	14
3	Neither Agree nor Disagree	7.79%	6
4	Agree	53.25%	41
5	Strongly Agree	19.48%	15
	Total	100%	77

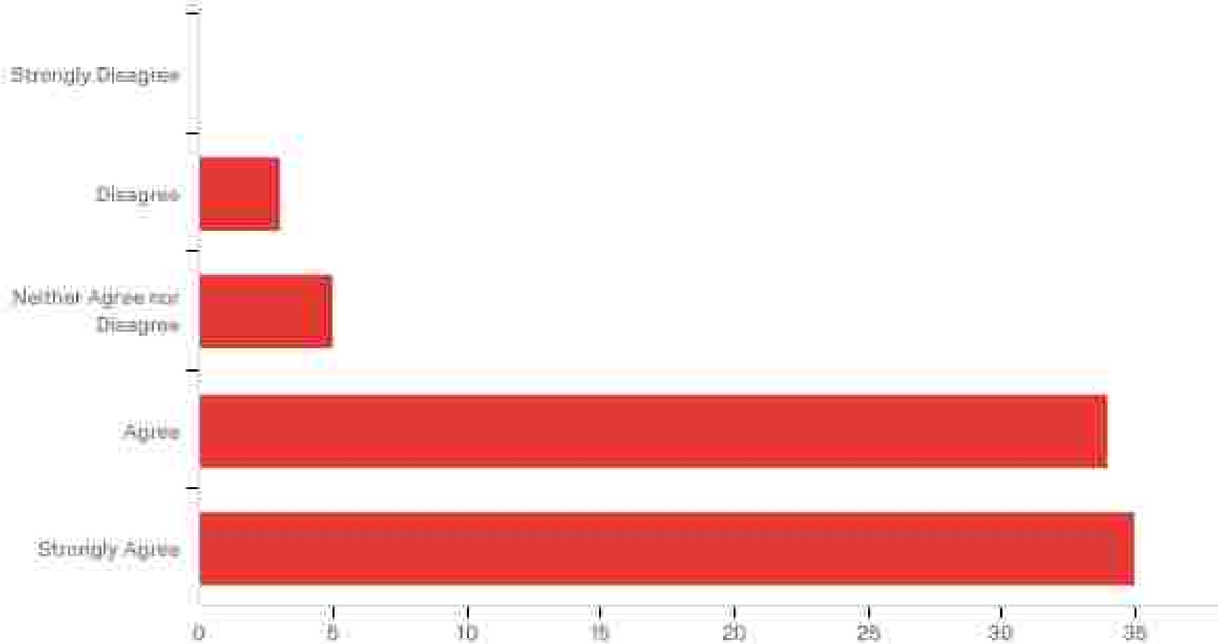
Q48 - A number of recent airline accidents/incidents could have been avoided if the pilots had been more proficient in manual flying skills.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	A number of recent airline accidents/incidents could have been avoided if the pilots had been more proficient in manual flying skills.	1.00	5.00	3.95	1.10	1.20	78

#	Answer	%	Count
1	Strongly Disagree	2.56%	2
2	Disagree	11.54%	9
3	Neither Agree nor Disagree	12.82%	10
4	Agree	34.62%	27
5	Strongly Agree	38.46%	30
	Total	100%	78

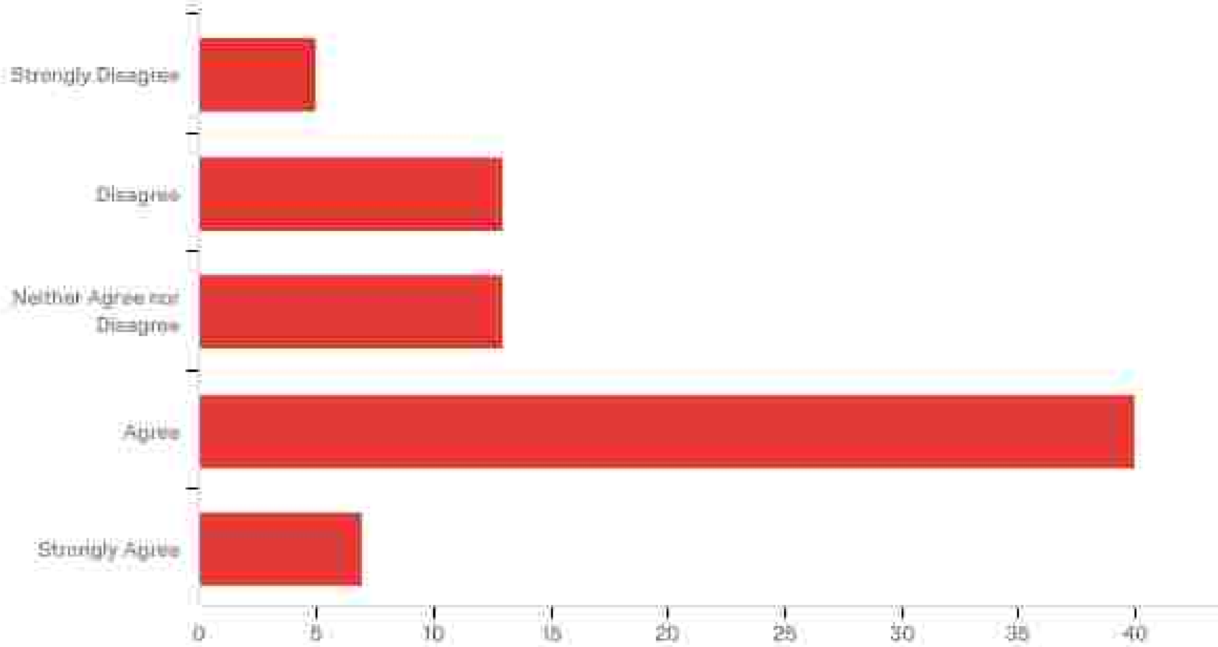
Q49 - Airline companies should facilitate more training to ensure that manual flying skills are kept current.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Airline companies should facilitate more training to ensure that manual flying skills are kept current.	2.00	5.00	4.31	0.76	0.58	77

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	3.90%	3
3	Neither Agree nor Disagree	6.49%	5
4	Agree	44.16%	34
5	Strongly Agree	45.45%	35
	Total	100%	77

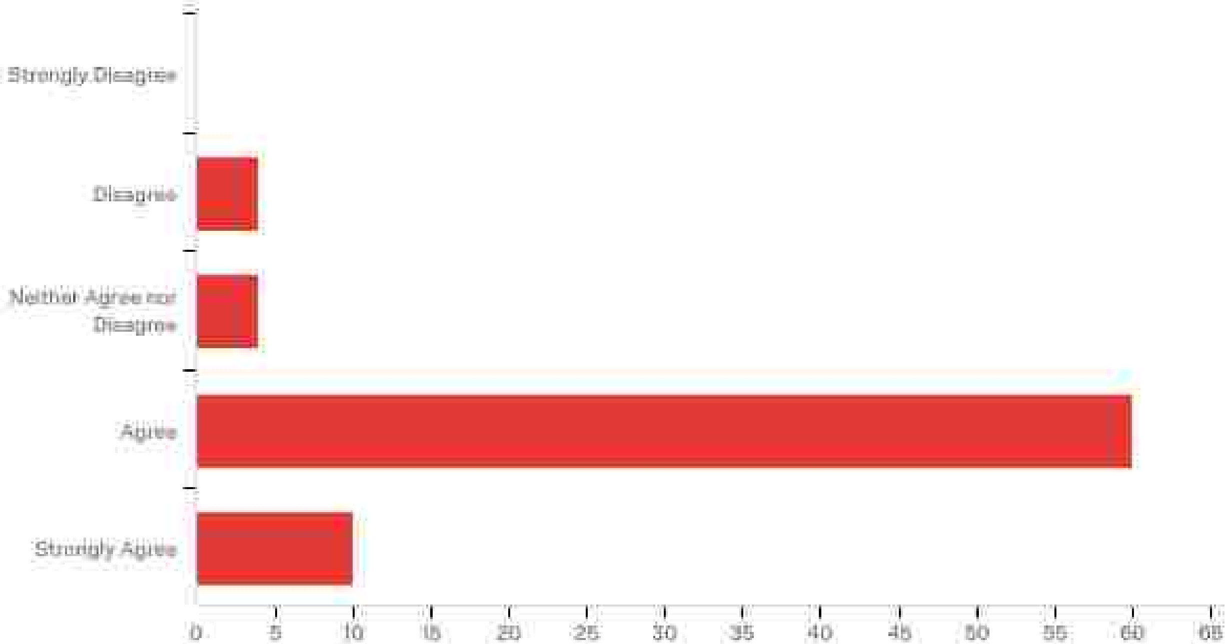
Q50 - Training is not the only answer for improving a pilot's ability to understand cockpit automation



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Training is not the only answer for improving a pilot's ability to understand cockpit automation	1.00	5.00	3.40	1.07	1.14	78

#	Answer	%	Count
1	Strongly Disagree	6.41%	5
2	Disagree	16.67%	13
3	Neither Agree nor Disagree	16.67%	13
4	Agree	51.28%	40
5	Strongly Agree	8.97%	7
	Total	100%	78

Q51 - Most pilots trained in the last 15 years learn the management of automation as in integral part of learning to fly an aircraft.



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Most pilots trained in the last 15 years learn the management of automation as in integral part of learning to fly an aircraft.	2.00	5.00	3.97	0.62	0.38	78

#	Answer	%	Count
1	Strongly Disagree	0.00%	0
2	Disagree	5.13%	4
3	Neither Agree nor Disagree	5.13%	4
4	Agree	76.92%	60
5	Strongly Agree	12.82%	10
	Total	100%	78

APPENDIX G. Raw Data Output from R on MJCA For Questions

Column	Name	mass	qlt	inr	k=1	cor	ctr	k=2	cor	ctr
1	Q14T:1	14	761	7	279	649	18	115	111	8
2	Q14T:2	14	692	6	-260	625	16	-85	67	5
3	Q14T:3	0	80	5	-177	16	0	351	64	2
4	Q14T:4	0	313	109	-275	12	0	-1397	302	32
5	Q15T:1	5	727	12	662	696	36	141	31	4
6	Q15T:2	12	479	6	-185	306	7	139	172	10
7	Q15T:3	9	170	6	-21	3	0	-150	167	9
8	Q15T:4	3	385	6	-264	181	4	-280	204	12
9	Q16T:1	3	593	8	578	579	19	89	14	1
10	Q16T:2	12	349	4	-15	3	0	153	346	13
11	Q16T:3	8	217	5	-125	128	2	-105	89	4
12	Q16T:4	4	195	6	-140	71	1	-186	125	6
13	Q16T:5	1	257	8	-212	19	1	-753	238	19
14	Q17T:1	9	357	5	188	274	5	104	83	4
15	Q17T:2	15	627	5	-219	622	12	21	6	0
16	Q17T:3	1	457	11	-445	85	4	-930	372	43
17	Q17T:4	1	148	7	481	113	3	-265	34	2
18	Q17T:5	3	488	9	534	487	16	13	0	0
19	Q18T:1	0	93	9	-252	12	0	-666	81	7
20	Q18T:2	3	100	7	131	42	1	154	58	4
21	Q18T:3	5	17	6	43	9	0	43	9	0
22	Q18T:4	10	387	4	-50	28	0	178	358	14
23	Q18T:5	10	433	5	-8	1	0	-220	433	22
24	Q20T:2	1	116	7	-5	0	0	-345	116	8
25	Q20T:3	2	374	7	-389	225	6	-317	149	10
26	Q20T:4	16	634	5	-207	612	11	38	21	1
27	Q20T:5	9	819	9	443	801	31	67	18	2
28	Q21T:1	1	325	10	1037	325	14	-33	0	0
29	Q21T:2	4	342	7	-323	257	7	-186	85	6
30	Q21T:3	8	392	5	-160	215	3	-144	176	7
31	Q21T:4	14	225	4	7	1	0	115	224	9
32	Q21T:5	2	501	11	844	495	22	93	6	1
33	Q22T:1	1	320	11	763	318	15	-53	2	0
34	Q22T:2	9	101	4	32	11	0	90	90	3
35	Q22T:3	6	253	6	-206	232	4	62	21	1
36	Q22T:4	8	290	6	-174	197	4	-119	93	56
37	Q22T:5	4	263	7	300	261	6	-28	2	0
38	Q23M:1	9	329	6	231	328	8	-13	1	0
39	Q23M:2	14	333	4	-103	211	3	78	122	4
40	Q23M:3	3	334	6	-214	124	2	-278	210	11
41	Q23M:4	2	14	6	77	10	0	-49	4	0
42	Q24M:1	15	340	5	157	332	6	24	8	0
43	Q24M:2	12	230	4	-131	228	4	12	2	0

44	Q24M:3	1	437	9	-382	53	2	-1026	384	35
45	Q24M:4	1	342	6	-586	257	4	337	85	4
46	Q25M:1	7	675	8	426	669	22	39	6	0
47	Q25M:2	16	393	3	-129	385	5	18	8	0
48	Q25M:3	4	145	6	-194	145	3	-6	0	0
49	Q25M:4	1	133	9	-70	3	0	-488	131	12
50	Q26M:1	0	194	7	702	143	3	-420	51	3
51	Q26M:2	1	480	12	-454	52	3	-1307	428	56
52	Q26M:3	5	293	7	-37	5	0	-286	288	19
53	Q26M:4	16	693	4	-155	382	7	140	311	14
54	Q26M:5	6	658	9	471	649	22	56	9	1
55	Q27M:1	1	97	5	-289	84	1	-112	13	0
56	Q27M:2	10	585	6	-45	16	0	-271	569	33
57	Q27M:3	5	276	5	-100	48	1	218	228	10
58	Q27M:4	12	320	4	17	5	0	146	316	11
59	Q27M:5	1	343	10	850	343	14	20	0	0
60	Q28M:1	0	52	7	414	47	1	-133	5	0
61	Q28M:2	1	307	9	-459	116	4	-587	190	17
62	Q28M:3	3	305	8	-225	103	3	-315	202	15
63	Q28M:4	16	562	4	-156	375	6	110	188	8
64	Q28M:5	8	731	9	433	731	26	4	0	0
65	Q29M:1	13	482	6	215	433	11	-72	49	3
66	Q29M:2	13	570	6	-230	484	11	97	87	5
67	Q29M:3	1	162	6	314	128	2	162	34	2
68	Q29M:4	1	262	8	-480	99	3	-614	163	12
69	Q29M:5	0	20	7	-244	16	0	-124	4	0
70	Q30M:2	2	437	8	-517	279	8	-390	159	13
71	Q30M:3	1	77	7	-127	17	0	-241	60	4
72	Q30M:4	15	552	4	-152	343	6	118	209	9
73	Q30M:5	10	662	8	345	634	20	-72	28	2
74	Q31M:1	4	682	11	688	682	30	-14	0	0
75	Q31M:2	22	661	3	-116	459	5	77	202	6
76	Q31M:3	3	466	9	-1	0	0	-552	466	40
77	Q32M:1	6	732	10	559	725	32	53	7	1
78	Q32M:2	17	529	4	-154	433	7	72	95	4
79	Q32M:3	2	396	8	-1	0	0	-572	396	32
80	Q32M:4	3	128	6	-211	104	2	-102	24	1
81	Q33I:1	1	295	9	873	294	10	41	1	0
82	Q33I:2	1	70	6	68	4	0	261	66	3
83	Q33I:3	5	156	6	-41	7	0	-182	149	7
84	Q33I:4	16	572	4	-158	475	7	71	97	4
85	Q33I:5	6	496	7	369	456	13	-109	40	3
86	Q35I:1	14	749	6	289	726	19	-52	23	2
87	Q35I:2	14	739	6	-268	697	18	66	43	3
88	Q35I:3	0	93	9	-252	12	0	-666	81	7
89	Q36I:1	6	665	9	496	654	23	-13	0	0
90	Q36I:2	18	518	3	-138	477	6	40	41	1
91	Q36I:3	3	101	8	24	1	0	-235	100	7
92	Q36I:4	2	68	5	-178	68	1	18	1	0

93	Q37I:1	3	522	10	697	520	21	-47	2	0
94	Q37I:2	11	522	6	-242	495	11	56	27	2
95	Q37I:3	10	77	6	98	76	2	-6	0	0
96	Q37I:4	5	44	5	-12	1	0	-85	43	2
97	Q38I:2	4	34	5	62	15	0	70	19	1
98	Q38I:3	5	52	5	-42	10	0	-85	42	2
99	Q38I:4	18	272	2	-74	218	2	37	53	1
100	Q38I:5	2	443	9	579	385	13	-225	58	5
101	Q39P:1	10	500	7	267	467	13	-71	33	2
102	Q39P:2	16	469	4	-140	346	5	84	123	5
103	Q39P:3	2	238	7	-258	86	2	-342	151	10
104	Q40P:1	5	743	12	652	743	37	0	0	0
105	Q40P:2	19	673	4	-152	481	7	96	191	8
106	Q40P:3	1	159	8	-144	19	1	-388	140	10
107	Q40P:4	3	386	7	-102	22	1	-416	364	23
108	Q41P:1	4	372	7	-93	25	1	-343	346	23
109	Q41P:2	6	25	5	15	1	0	59	24	1
110	Q41P:3	6	302	5	-184	180	3	152	122	6
111	Q41P:4	7	240	5	-52	22	0	166	218	9
112	Q41P:5	5	455	7	335	359	10	-173	95	7
113	Q42P:1	3	306	7	414	293	8	-88	13	1
114	Q42P:2	12	389	4	-172	380	6	-27	9	0
115	Q42P:3	8	44	5	49	22	0	-50	22	1
116	Q42P:4	6	137	5	17	2	0	140	135	6
117	Q42P:5	0	349	7	1086	344	7	121	4	0
118	Q43P:1	10	754	9	413	725	28	-82	29	3
119	Q43P:2	18	733	5	-216	681	14	59	51	3
120	Q43P:3	1	66	8	-81	3	0	-385	63	5
121	Q44P:1	4	154	7	167	75	2	-172	80	5
122	Q44P:2	16	147	3	-41	48	0	59	99	2
123	Q44P:3	7	128	5	90	64	1	-91	64	3
124	Q44P:4	1	397	5	-423	296	5	248	102	4
125	Q45P:1	7	387	7	117	67	2	-255	319	21
126	Q45P:2	13	692	5	-198	410	9	164	282	16
127	Q45P:3	4	235	5	232	225	4	-49	10	0
128	Q45P:4	3	10	6	30	2	0	-58	8	0
129	Q45P:5	1	332	10	1005	329	13	91	3	0
130	Q46R:1	14	351	5	9	1	0	-170	350	18
131	Q46R:2	9	572	5	-178	262	5	194	311	15
132	Q46R:3	4	49	6	3	0	0	120	49	3
133	Q46R:4	1	501	101	997	497	19	89	4	0
134	Q46R:5	0	174	9	912	165	5	215	9	1
135	Q48R:1	12	396	5	-25	6	0	-200	390	21
136	Q48R:2	9	252	5	-25	6	0	-200	390	21
137	Q48R:3	4	78	6	-112	37	1	118	41	2
138	Q48R:4	3	219	6	33	3	0	269	216	10
139	Q48R:5	1	524	13	1223	523	28	-64	1	0
140	Q49R:1	13	213	4	2	0	0	-120	213	9
141	Q49R:2	12	90	4	-34	19	0	66	71	2

142	Q49R:3	2	318	6	-224	89	2	360	230	11
143	Q49R:4	1	312	9	725	304	10	117	8	1
144	Q50R:1	3	158	6	259	141	3	-91	17	1
145	Q50R:2	15	73	3	-42	50	0	28	23	1
146	Q50R:3	5	273	7	-241	199	5	-147	74	5
147	Q50R:4	5	122	5	82	44	1	110	78	3
148	Q50R:5	1	234	7	484	234	6	-2	0	0
149	Q51R:1	4	683	10	657	678	27	56	5	1
150	Q51R:2	22	450	2	-90	444	3	10	6	0
151	Q51R:3	1	73	7	10	0	0	-262	73	5
152	Q51R:4	1	148	6	-397	146	3	-44	2	0

APPENDIX H. Raw Data Output from R on MJCA For Demographics

Column	Name	mass	qlt	inr	k=1	cor	ctr	k=2	cor	ctr
1	Q2:1	NA	50	NA	-216	42	NA	-94	8	NA
2	Q2:2	NA	271	NA	-113	42	NA	-264	229	NA
3	Q2:3	NA	232	NA	93	144	NA	73	88	NA
4	Q2:4	NA	60	NA	-106	52	NA	42	8	NA
5	Q2:5	NA	55	NA	78	26	NA	81	28	NA
6	Q2:6	NA	59	NA	80	34	NA	70	25	NA
7	Q2:7	NA	62	NA	-173	62	NA	7	0	NA
8	Q2:8	NA	201	NA	-548	116	NA	-471	86	NA
9	Q2:9	NA	14	NA	123	7	NA	-123	7	NA
10	Q9:1	NA	131	NA	-94	100	NA	52	31	NA
11	Q9:2	NA	131	NA	43	100	NA	-24	31	NA
12	Q11T:1000	NA	90	NA	504	74	NA	238	16	NA
13	Q11T:10000	NA	148	NA	-538	141	NA	120	7	NA
14	Q11T:10200	NA	106	NA	-224	19	NA	486	88	NA
15	Q11T:10500	NA	70	NA	190	31	NA	-212	39	NA
16	Q11T:11000	NA	333	NA	-359	94	NA	574	239	NA
17	Q11T:12000	NA	26	NA	139	19	NA	-84	7	NA
18	Q11T:12500	NA	49	NA	298	48	NA	-54	2	NA
19	Q11T:12700	NA	234	NA	-233	44	NA	483	190	NA
20	Q11T:1300	NA	181	NA	-532	59	NA	-761	121	NA
21	Q11T:1400	NA	477	NA	-525	307	NA	391	170	NA
22	Q11T:14000	NA	168	NA	585	139	NA	-264	28	NA
23	Q11T:15000	NA	29	NA	-194	28	NA	-26	0	NA
24	Q11T:1500	NA	144	NA	637	144	NA	-24	0	NA
25	Q11T:15000	NA	100	NA	395	100	NA	-19	0	NA
26	Q11T:1700	NA	259	NA	1398	256	NA	-142	3	NA
27	Q11T:17583	NA	46	NA	-222	43	NA	56	3	NA
28	Q11T:1800	NA	90	NA	-274	10	NA	-774	80	NA
29	Q11T:18000	NA	164	NA	-573	112	NA	390	52	NA
30	Q11T:19700	NA	201	NA	-548	116	NA	-471	86	NA
31	Q11T:1900	NA	455	NA	-532	281	NA	418	174	NA
32	Q11T:2000	NA	110	NA	-514	105	NA	123	6	NA
33	Q11T:20000	NA	14	NA	123	7	NA	-123	7	NA
34	Q11T:2074	NA	207	NA	-703	158	NA	392	49	NA
35	Q11T:21400	NA	58	NA	-354	58	NA	-13	0	NA
36	Q11T:21000	NA	75	NA	149	8	NA	-424	67	NA
37	Q11T:2300	NA	290	NA	1332	290	NA	-25	0	NA
38	Q11T:2400	NA	3	NA	68	1	NA	2	2	NA
39	Q11T:250	NA	331	NA	-602	207	NA	467	124	NA
40	Q11T:2500	NA	112	NA	1	0	NA	360	112	NA
41	Q11T:2800	NA	161	NA	860	160	NA	64	1	NA
42	Q11T:2960	NA	55	NA	-193	10	NA	407	45	NA

43	Q11T:300	NA	325	NA	-300	11	NA	-1623	314	NA
44	Q11T:3000	NA	54	NA	120	17	NA	176	37	NA
45	Q11T:3350	NA	50	NA	-216	42	NA	-94	8	NA
46	Q11T:3500	NA	467	NA	-358	53	NA	-998	414	NA
47	Q11T:3700	NA	121	NA	-538	114	NA	-141	8	NA
48	Q11T:4000	NA	220	NA	-388	218	NA	32	1	NA
49	Q11T:4100	NA	196	NA	-506	113	NA	434	83	NA
50	Q11T:4200	NA	253	NA	-413	115	NA	453	138	NA
51	Q11T:4300	NA	171	NA	17	0	NA	508	171	NA
52	Q11T:4400	NA	90	NA	-349	78	NA	-133	11	NA
53	Q11T:4500	NA	55	NA	158	53	NA	26	2	NA
54	Q11T:4600	NA	18	NA	-5	0	NA	182	18	NA
55	Q11T:5000	NA	6	NA	25	0	NA	87	6	NA
56	Q11T:5600	NA	368	NA	1266	367	NA	-56	-56	NA
57	Q11T:5800	NA	18	NA	192	15	NA	94	3	NA
58	Q11T:600	NA	81	NA	-464	67	NA	-207	13	NA
59	Q11T:6000	NA	31	NA	-109	20	NA	-79	11	NA
60	Q11T:6200	NA	432	NA	-420	208	NA	435	224	NA
61	Q11T:670	NA	154	NA	659	114	NA	392	40	NA
62	Q11T:6700	NA	118	NA	-591	116	NA	61	1	NA
63	Q11T:7200	NA	18	NA	-163	11	NA	-126	7	NA
64	Q11T:7400	NA	270	NA	1183	267	NA	140	4	NA
65	Q11T:7900	NA	30	NA	158	15	NA	158	15	NA
66	Q11T:8000	NA	19	NA	143	14	NA	-87	5	NA
67	Q11T:8200	NA	23	NA	175	20	NA	-77	4	NA
68	Q11T:8500	NA	87	NA	267	76	NA	-102	11	NA
69	Q11T:9400	NA	118	NA	90	2	NA	-749	116	NA

APPENDIX I. Answers for Open Ended Questions (Q52-53)

Q52 - Please describe your overall experience with automated systems in the cockpit and how it affects your piloting skills.

1. Automation is inevitable and saves life, prevents human error.
2. Automation is good and means future for aviation
3. Normal, Following the SOPs
4. I am from the younger generation that 'grew up' with GPS and automation, so it's of great value to me and comes easily. I don't know any better than having these systems available. I think my workload would greatly increase having to work without them.
5. In my opinion A/P allows us to check all system. This provides us to notice the small deviations beyond limits; this improves our piloting skills.
6. Automation can be dangerous if you solely rely on it. Knowledge, situational awareness and manual flying skills are as important as knowing the FMC.
7. In general it decreases my manual flying skills. We don't fly manual often.
8. Good overall, can be a workload saver, but can also overcomplicate things as too many options can be available and it can take too long to make inputs.
9. Automated systems are good and assist the pilot, but they have to be monitored closely and corrected manually when needed.
10. Not enough exercise in manual flight during our daily business leads us to forget some basic flying skills
11. Very good

12. We should be allowed to fly more manually as automation decrease our flying skills
13. Reduces workload but increases complacency and erodes manually flying skills
14. Automation is a great tool if it works properly and is properly understood, if not, we as pilots should still have to recourses to fall back on our flying skills sadly especially on the long haul we do not get sufficient practice of manual flying skills, this problem should be addressed
15. Automation must be servant for a pilot but not a master. In many cases automation helps to reduce workload, helps you see big picture, helps improve SA but too much trust and to much usage of it get the things worsen sometimes you only need to fly your craft via the easiest way, with too much automation which you might be forgotten. (*forgeting manual flying skills)*
16. If you understand the automation, you can fly better, because you can plan better
17. Make it easier, less practice of the skills can be problematic
18. 6 years/4400 hours. Automation management should be considered part of piloting skills nowadays. Differentiating flying skills and piloting skills, if the question addresses manual flying skills, automation partially diminishes those skills. One advantage of automation is having much more observation time during normal operation, which is another type of important experience.
19. It makes you less tired by reducing the workload. But in some cases pilots use it too much so they lose their manual skills.
20. I started my career on full-automated aircraft (A320) and I've grown with the attitude to feel, understand and trust the automation. Even in rarely cases I had some

problem with it, I think it is the right way and the right device to improve air transport and safety

21. In my company there is a general aversion against flying with A/P off and especially F/D or A/T off. this diminishes my flying skills greatly. I feel many colleagues are already lacking in skill and situational awareness..
22. Automation has always been a big part of my aviation knowledge, since a have started flying b737-800 and then 777-300er, so I take automation as a big part of my automation, and I think general knowledge of automation is more important than the rest of skills.
23. My company doesn't want us to fly manual and therefore we're losing competency in manual handling creating dangerous situations when the automation fails or has to be switched off
24. Good experience, makes my life easier but I am getting worse in manual skills
25. Automation helps reduce workload but kills manual flying skills
26. Useful most of the time but needs to be monitored closely
27. Less effort on flying the aircraft, more time for flight management
28. It makes the job easier
29. Automation has complacency factor. All we know it. Pilots coming from manual aircraft, are better than the new adding pilots in term of understanding big picture and interaction with aircraft systems if something goes wrong.
30. Automation helps pilot to conduct the flight safely and prevents mishaps with applicable warning ,caution and envelope protection systems; on the other hand I realized that handling skills are getting weaker than before, and some young people

who are inappropriate for flying are joining fleets as cadets because of high level automation helps pilot to fly easily (i.e TAC helps pilot for engine failures)

31. They are good, but must be monitored
32. I've been using automation since I've started flying for airline. It has minor effect on my skills; you get less tired when you use automation.
33. I like automation but it can diminish my vigilance during flight
34. My last 5 year with autopilot. And it reduce my manual flight capability
35. Facilitate my life to reduce workload
36. Manuel flying also can be a appropriate level of automation. Guidance of automation can affects of my piloting skills in a positive way.
37. Automation is a high necessity in the Airline flying because the pilots are flying long flight hours for the one leg or also they are flying with the long crew duty times with the four legs in one day or night time... This can not be done without automation of the aircraft... That is why automation extends the flight times with the pilot monitoring... But, the automation of course is affecting the piloting skills in an adverse way which brings the need of training needs...
38. Ease my life
39. I have flown aircrafts that are both heavily automated and aircraft that generally lack automation. I've found I have better situational awareness when I hand fly. Additionally I have found automation presents the crew with a multitude of opportunities to make mistakes when inputting data into the FMS which will have a large impact on the flight and the safety of flight. It only takes one input error to potentially cause a serious safety of flight issue. I find I spend too much time

managing the system and it is often quicker and easier to just fly manually. My current aircraft has only basic automation and I much prefer it that way. I truly believe I am safer without it

40. After a fairly steep learning curve to understand proper use of automation, my workload is overall reduced. I must be sure to take time to manually fly the aircraft from time to time, in order to keep my flying skills recent. Almost all takeoffs and landings at this point are still flown manually.
41. Automation is a tool, not a crutch. It does not affect my skills, as I downgrade automation levels often to retain my skills.
42. I try and alternate between full auto, semi auto and manual
43. Automated systems compliment my flying skills
44. 25 years of experience. It enhances my piloting skills
45. Most of the time the automation helps us very much to decrease workload when attention is needed more in other fields than controlling the aircraft. however all automation has to be crosschecked and monitored constantly.
46. Automation has certainly made my manual flying skills degrade over the years
47. They're an added tool
48. I've large experience with automated systems (boeing + airbus), and I usually fly manually to keep my piloting skills up to date.
49. I use the automatics to complement my piloting skills and practice manual flying when appropriate.

Q53 - What design improvements would you recommend to enhance the communication between automation and the pilots to increase flight safety.

1. Software development and implementation of new safety features are very important.
2. Do it like IPad or IPhone as possible as much.
3. Nothing to Improve.
4. Some systems have not always got logical user interfaces. Current technologies allow for so much more options for input and data recovery (take the development of GPS systems and EFB for example) having to work with notepads to copy/paste information just seems "old-school".
5. No idea.
6. If it's important it needs a sound. Input needs to be made easier.
7. Some faults on the automated system (hold mode on B777) should be. improved. Generally its an issue of the SOP s of the companies which restricts the pilots.
8. Nothing.
9. Better interface, "plug & play concept", meaning natural understanding of the graphic interface and information from all.
10. Standardization of new interfaces such as head up displays for both crewmembers but only for the PF.
11. First of all I think training is an important part in better communication between automation and pilots, teaching to scan the FMA and call out changes, teaching that FMC needs correct inputs, which FMC page to have open in which phase of flight etc. I think Boeing's design of FMA and MCP etc. is very nice, but sometimes in

Boeing you notice that some crews don't realize what the airplane is doing in VNAV mode, because they don't realize what is in the FMC or what they put into the FMC, so I think Boeing could try to improve the awareness of crews in terms of what is in the VNAV climb cruise and descend pages.

12. Many combination of planning prompts and a better processor chip can be used.
13. Extra visual cues on FMA and instruments could be added. It is a long discussion for a short survey:)
14. Nothing.
15. The time is on our right ant the improvement in technology is getting better and better every day, so I think that an improvement in FMA messages in one of the right thing to do. Another think is an improvement in visual display like a HUD with higher levels of reliability for the flight path.
16. Simpler MCP design.
17. More visual.
18. NA.
19. Don’t know.
20. Continuous feedback would do so, not only visual but with aural.
21. Bigger screens, creative interfaces.
22. AoA indication on the flight deck.
23. Make less automation and program them easier not too complex.
24. Transponder codes maybe increased to communicate in comm. failure situation, for example; when in a comm. fail situation pilot sets 7600 and than we can use this feature for comm. by setting further codes like ;7601 "I'm following flight plan to

destination",7602 "I hear you but cannot xmit with you",7603 "I'm diverting to nearest airport" etc. In 777 FMS we cannot put alt and spd constraints together, also we cannot create Defined way points it is also another weakness of 777 FMS.

25. Better alerts for important things, and less alerts for trivial things. More pilot involvement in automation & software design.
26. I like Airbus family automation rather than others.
27. Confirmation in absurd situation.
28. The aural warnings can be higher with the visual references or warnings... Because, when you are busy with something (meal, a problem at the cabin, a failure management, comm. with the ATC, talking with the cabin crew chief or paperwork etc..) in the cockpit, it is often hard to see the warning light or caution coming with the visual references... In this case, most of the visual warnings or cautions must come with the aural warnings to focus on immediately ... On the other hand, they can aural confirmations to FCU and FMA system like for exp.; when we set the ALT to FL 360, FCU system aural sounds may come " FL 360" but of course, I am not sure about how much is true to make a this kind of warning... It can make the cockpit mass as well... That is why, cockpit stabilization and ergonomy is very important to think over it many times with the specialist and the experienced pilots or test pilots...
29. Automation should never have the ability to override pilot inputs. For instance, many new aircraft prevent any input that will stall the aircraft. However, the computer cannot make decisions like a person. The pilot should have the ability to exceed the parameters of safe flight for unimagined emergency situations.

Additionally, systems that have various tiers of automation need to have clear indication of what mode the system is currently in and notify the crew when transitioning modes. Further the crew needs extensive training on what each mode entails, how it affects control inputs, and ultimately whats happening to the aircraft in each mode.

30. No specific improvements.
31. None.
32. None.
33. More spoken audio for FMA changes.
34. I would like to have a HUD and more up to date NAVIGATION DISPLAYS (like in modern business jet aircrafts) ENHANCED VISION (TERRAIN) - more sophisticated weather radar (vertical display of cloud layers etc.).
35. Standard HUDs mandatory.
36. Manuals (airbus) and applications user's friendly, to improve pilot's learning/training.
37. Better integration of systems and improved displays

VITA

Aysen K. Taylor

EDUCATION

MEM from Old Dominion University Masters of Engineering Management and Systems Engineering 2011 –2013.

M.Sc. from Istanbul Technical University, Istanbul, Turkey. Master of Science in Industrial Engineering, 1990-1993 (Ranked first in the entrance examination of Masters program among more than 200 engineer graduates in 1990).

B.Sc. from Istanbul Technical University, Istanbul, Turkey, 1986-1990
Bachelor of Science of Textile Engineering in Mechanical Engineering Department.

Cum laude graduation honors.

1980-1986 Super College of Istanbul Halide Edip Adivar, Istanbul, Turkey, earned the honor roll distinction every year.

EXPERIENCE

Graduate Assistant at ODU in Engineering Management and Systems Engineering Department, 2013-Present

Professor/Teaching Instructor for Engineering Economics (ENMA302), 2016

Sales and Quality Control Manager & Principal Investigator for highly specialized production, Garanti Textile, Istanbul, Turkey 1999-2002

Project Leader, Koluk Yarn Company, Istanbul, Turkey 2000-2001

Production Development and Executive Sales-Export Manager/Engineer/Project Leader, Okan Holding, Istanbul, Turkey, 1997-1999

Sales/Export Manager/Engineer/New product development, Factories of Ceyteks Group, Istanbul, Turkey, 1995-1997

General Management Associate, Product Planning, and Marketing Group, Sanko Holding, Istanbul, Turkey, 1994-1995

Product Manager Assistant/ Production Planning Engineer, Edip Yarn factory, Istanbul, Turkey, 1993-1994

Quality Control Engineer/Production Planner, Quicksilver, Istanbul, Turkey, 1991-1992

RESEARCH EXPERIENCE

Edip Yarn Factory, Istanbul, Turkey, 1992-1993
Relation between Time-Motion Study and Productivity, an Application in the Textile Field (Master Thesis)

SPAWAR-MFOM, Systems Engineering Assessment and Evaluation. (July 21, 2014 – July 20, 2015) Aysen Taylor (Graduate Research Assistant), Charles Keating, Mamadou Seck , Andres Sousa-Poza, Steven Cotter, Investigators, Project worth: $328,083.80.

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President of American Society for Engineering Management, (ASEM) Student Chapter, 2015-2018

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RESEARCH INTERESTS

Human-Machine Systems and interactions of their soft and hard components, Cognitive Engineering, Systems Analysis, Decision Making in complex-dynamic environments

PUBLICATIONS

Taylor A.K., Bouazzaoui S. (2019) Moving Forward with Autonomous Systems: Ethical Dilemmas. In: Nunes I. (eds) Advances in Human Factors and Systems Interaction. AHFE 2018. Advances in Intelligent Systems and Computing, vol 781. Springer, Cham

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Taylor, A. K., & Cotter, T. S. (2014, October). Human Machine Intelligence Interaction. Paper presented at the *American Society for Engineering Management*, Virginia Beach,VA.