HUMAN FACTORS ISSUES OF GLASS COCKPIT AUTOMATION

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submitted by ÇİĞDEM GÜNEŞ in partial fulfillment of the requirements for the degree of **Master of Science in Industrial Design Department, Middle East Technical University** by;

Prof. Dr. Canan ÖZGEN
Dean, Graduate School of **Natural and Applied Sciences** ___________________

Assoc. Prof. Dr. Gülay HASDOĞAN
Head of Department, **Industrial Design** ___________________

Assoc. Prof. Dr. Mehmet ASATEKİN
Supervisor**, Industrial Design Dept., Bahçeşehir University** ___________________

Examining Committee Members:

Assoc. Prof. Dr. Çiğdem ERBUĞ
Industrial Design Dept., METU ___________________

Assoc. Prof. Dr. Mehmet ASATEKİN
Industrial Product Design Dept., Bahçeşehir University ___________________

Assoc. Prof. Dr. Gülay HASDOĞAN
Industrial Design Dept., METU ___________________

Dr. Canan E. ÜNLÜ
Industrial Design Dept., METU ___________________

Ali BERKMAN
NANObiz Limited ___________________

Date: 30.04.2010

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: ÇİĞDEM GÜNEŞ

Signature:

ABSTRACT

HUMAN FACTORS ISSUES OF GLASS COCKPIT AUTOMATION

GÜNEŞ, Çiğdem

M.Sc., Department of Industrial Design

Supervisor: Assoc. Prof. Dr. Mehmet Asatekin

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With the advances in technology, clutter of mechanical indicators in the aircraft cockpit is replaced with digital displays. This revolution does not make only visual changes, but also changes the use of the cockpit design. Cockpit automation has changed cockpit design philosophy with many promised benefits such as improvements in the precision, improved system safety, efficiency of operations, less workload etc. However, to achieve perfect design has not been fulfilled yet. Despite providing innovation and easiness, cockpit automation brings about some “Human Factors” problems because of lack of support of human-machine interaction and cooperation.

In this study, advantages and disadvantages of the cockpit automation will be discussed according to a survey that is conducted to pilots who fly with automated cockpits in Turkey about how automation affects them.

The main purpose of this study is to contribute to the modifications of current cockpit systems and development of new design philosophy for advanced flight decks by gathering data from pilots' attitudes on cockpit automation philosophy.

Keywords: Human Factors Issues, Automation, Glass Cockpit, Aviation

ÖZ

SAYISAL KOKPİT OTOMASYONUNDA İNSAN FAKTÖRLERİ SORUNLARI

Güneş, Çiğdem

Yüksek Lisans, Endüstri Ürünleri Tasarımı Bölümü

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Teknolojinin gelişmesi ile birlikte, kokpitteki karmaşık mekanik göstergeler dijital olanlarla yer değiştirdi. Bu değişim, sadece görsel bir değişiklik yapmakla kalmamış aynı zamanda kokpitteki kullanım alışkanlıklarını da değiştirmiştir. Kokpit otomasyonu, kokpit tasarım felsefesini bilgi hassaslığı, artırılmış sistem güvenliği, operasyon verimliliği, daha az iş yükü gibi birçok vaatle değiştirmiştir. Ancak, henüz mükemmel tasarıma ulaşılamamıştır. Otomasyon, yenilikler ve kolaylıklar getirdiği gibi insan-makine iletişim ve koordinasyon eksikliği yüzünden, beraberinde bazı "İnsan Faktörleri" hataları da getirmiştir.

Bu çalışmada, kokpit otomasyonunun avantaj ve dezavantajları tartışılacak, ve Türkiye'de otomatik kokpitlerde uçan pilotlarla otomasyonun onları nasıl etkilediğine dair bir araştırma yapılacaktır.

Bu çalışmanın asıl amacı pilotların otomasyona karşı tutumlarını göz önünde bulundurarak, mevcut kokpit tasarımlarının modernizasyonlarına ve ileri düzey kokpitlerde yeni tasarım felsefelerinin tasarımına katkıda bulunmaktır.

Anahtar Kelimeler: İnsan Faktörleri, Otomasyon, Sayısal Kokpit, Havacılık

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LIST OF ABBREVIATIONS

ADI: Air Data Indicator

AP: Autopilot

ATC: Air Traffic Control

CARP: Calculated Air Release Point

CDU: Control and Display Unit

FCU: Flight Control Unit

FMA: Flight Mode Annunciators

FMS: Flight Management System

GPWS: Ground Proximity Warning System

HSI: Horizontal Situation Display

MFD: Multi Function Display

ND: Navigational Display

PFD: Primary Flight Display

TCAS: Traffic Collision Advisory System

V/S: Vertical Speed

WPT: Waypoint

CHAPTER 1

INTRODUCTION

Automation, as it is one of the most influential trends of twentieth century, is everywhere in our daily lives. One can see it in the alarm clock that plays the radio to wake up, the smell from the coffee machine which is timed to wake up time, automatic doors that are opened when you enter your office and certainly your computer which you work with during a work day.

The myths related to automation, attract with its promises and opportunities as well as causes fright from the automation. There are lots of science fiction movies, cartoons and books related to the opportunities or threats of automation. One of these cartoons is "*The Jetsons*" (Hanna-Barbera, 1962) that describes a world, in which there are homes and businesses raised high above the ground on adjustable columns, flying saucers that can go its route without human control, robots that make the household chores or machines that change the human's hair or clothes automatically. Although there are such machines which make all these jobs, somehow a human is still needed for specified jobs even for just "push the button". In the movie "Surrogates" (Mostow, 2009), human lives the life via a robot which is living with a desired life, body and even gender instead of human, so the human can stay at his/her safe home. But yet, automation brings the threat with it, eventually. These kinds of films mentioned the opportunities of automation, in the films like "*Cyborg*" (Pyun, 1989), "*Terminator*" (Cameron,

1984) it is mentioned that robots which are the result of automation would cause the end of the humanity. In the movie Terminator it is mentioned that a computer named "*Skynet*" which can develop itself, produce robots which are alternate to humans and try to replace them with human.

Despite people's fear and suspicion, automation has an active role in everyday life. Whereas people have just got used to some of automatic machines, they face with new stuffs every day. For instance, with the "smart home" concept, it is possible to control your whole home via a remote control from any room of your home or a computer from your office. "Smart home" concept allows the homeowner to set the temperature of each room, feed the dog or water the plants even if the owner is at vacation.

Some of automated systems are accepted by people easily, some of them are not. User's interaction with the automation will affect the user's attitudes on it; therefore affect the communication the designer tries to create. To avoid automation can be a solution in some cases; for instance instead of getting money from ATM machines, one can go to the bank, wait his/her turn and get the money. However, in a little while, due to transaction cost or risk management and etc. the automation technology will be inevitable anymore and -people have to use it whether they want it or not.

As the automation spreads over our everyday life, one of the domains which have to implement automation inevitably is the aviation industry. End of the 1960s, the great opportunity in the aerospace industry makes this sector interested much. It is supposed to carry passengers more people more safely, faster and more effectively. Therefore, the dream to carry more passengers with faster and more safely could be real only with automation.

The main goal for applying automation in aviation is focused to the flight decks where it helps the pilot in his formidable job. This is because high speed, long distance, carried passenger number and various factors made flying systems more and more complex. During an ordinary flight, pilot had to track many various displays simultaneously. And it is recognized that, pilot may not fly long distances without help, therefore automated systems were created to help pilot. In addition to that, the developed CRT (Cathode Ray Tube) displays allow combining all the gauges which are located in the cockpit into a few displays. Although there were hundreds of displays before the glass cockpit revolution, with the glass cockpit technology one or a few displays are enough to present all information. Also the system can be controlled from a control unit which is called CDU (Central Display Unit). This new advanced technology, named "glass cockpit" – as the electronic displays which are assembled to instrument panel simulate the glass –. Glass cockpit is a new design concept for pilots which they should communicate with.

Nevertheless, at the outset, as Amalberti (1998) stated, automation affects pilots, socially. Pilots reacted to the use of advanced glass cockpits because now they have a new partner and this new partner may get their job while the real ones are losing. During 1980s, pilot unions were annoyed to transfer to glass cockpits owing to the reduction of flight crew members and pilots refused transitions in their companies although it was applicable. As a result it is recorded that in those years with the first introduction of glass cockpit technology, in France where the most effective protests were done, there were more accidents from any other regions in the world (Amalberti, 1998). As it can be understood from this experience, the attitudes on a job or machine or something the human interacts with may affect using it effectively and correctly.

Despite these protests and displeasures, glass cockpit aircrafts created a new era and have been used in aviation industry intensely. With the introduction of glass cockpits, automation is applied by some promises such as; increased safety, situation awareness, accuracy, and decreased human workload, cost, and complexity. However, with this new technology, pilot has encountered with a new cockpit environment with its controls and displays and a new man-machine interaction. Although automation was applied with good intentions and high expectations, and being successful in terms of some aspects such as accuracy and economy of operations, unfortunately researches, accident reports, simulation studies and pilot experiences have shown that glass cockpits caused some interaction problems with the user as it changed the nature of the work, so the cognitive action of the human operator that cannot be foreseen by designer (Bainbridge, 1983). Therefore, this created complex work environments inevitably. One of major reasons of this situation is the belief of designers how much the human activity is decreased; system will be successful so much (Christoffersen and Woods, 2002). However, it should not be ignored that the system is still used by human as well as designed by human (Parasuraman and Wickens, 2008).

These problems have been pointed out by some Human Factors researchers such as Wiener, Curry, Woods, Wickens, Parasuraman and other scholars. Ninety four different human factors issues in the literature are reported by Jones, Lyall and Wilson with supporting reasons (FDAI, 2009). Some of the issues are selected and related issues are combined in terms of the aim of this study. Some of the issues are ignored such as software related problems because they are not the concern of this study. Eleven issues are emphasized in the field of this study; role of the pilot, cognitive conflicts in the mental model, excessive information, workload extremes (too much or too little), loss of situation awareness, insufficient feedback, loss of skills, design problems, human error, automation extremes and trust problems (too much or too little). These human factors issues and some literature evidences are listed in the table. These issues will be explained clearly in the study.

Table 1.1: Human Factors Issues in Literature

Human Factors Issues	**Literature**
New Roles for the Pilot	“Automation need human to monitor or setup and to operate when it fails.” (Wiener, 1993) “…the operator’s task has shifted from active control to supervisory control by the introduction of automated systems. Humans are no longer continuously controlling a process themselves (although they still sometimes need to revert to manual control) but instead they monitor the performance of highly autonomous machine agents.” (Sarter, Billings and Woods, 1997)
Cognitive Conflicts in the Mental Model	“The detection of the resulting discrepancy between expected and actual outcome of the pilot's input creates an 'automation surprise'.” (Sarter, 1994) “Appropriate trust and reliance depend on how well the capabilities of the automation are conveyed to the user. This can be done by making the algorithms of the automation simpler or by revealing their operation more clearly.” (Lee and See, 2004) “The introduction of advanced technology has created automation surprises: system operators are surprised by the behavior of their strong but silent machine partners; system designers/purchasers are surprised to find new problems that concern the coordination of people and automated systems.”(Sarter, Billings and Woods, 1997)
Information Overload	“One feature of automated systems is that they present more information than the pilot can process in the time available (information overload)” (Woods, Johannesen, Cook and Sarter, 1994)

Table 1.1 (Continued)

Human Factors Issues	**Literature**
Workload Dilemma	“While automated systems are often intended to reduce pilot workload, research indicates that the introduction of glass cockpit aircraft has had little effect on overall pilot workload. The introduction of automated systems tends to redistribute, rather than reduce, pilot workload.” (Wiener, 1989) “Certain forms of automation increase operator workload, or produce an unbalanced pattern of workload over time. These mostly involve automation that is difficult to initiate and engage, thus increasing both cognitive and physical workload.” (Kirlik, 1993)
Situation Awareness (SA)	“Pilots in the glass cockpits often ask these questions: What is it (the auto-flight system) doing? Why did it do that? What is it going to do next?” (Wiener, 1989)
Insufficient Feedback	“….the problem in highly automated devices is not automation per se, but the lack of feedback. A design principle is apparent here: simplify any system to the extent possible; then and only then turn to automation if it is still needed. When automation is compensating for some worsening condition, the crew must be informed.” (Wiener, 1993)
Pilot Skill Loss	“Unfortunately, physical skills deteriorate when they are not used, particularly the refinements of gain and timing. This means that a formerly experienced operator who has been monitoring an automated process may now be an inexperienced one.” (Bainbridge, 1983)
Glass Cockpit Design	“…data entry via keyboard into a digital system creates the possibility of latent errors which may lie dormant in the system for hours until they finally become active.” (Wiener, 1993)
Change in Human Error	“According to international civil aviation authorities, because of refinements over the years the number of accidents caused by the machine has declined, while the number caused by humans has risen proportionately.” (Sheridan, 1992).

Table 1.1 (Continued)

Human Factors Issues	Literature
Automation Use	"Humans tend to be less aware of changes in environmental or system states when those changes are under the control of another agent (whether that agent is automation or another human) than when they make the changes themselves (Endsley and Kiris, 1995; Sarter and Woods, 1995; Endsley 1996, 1999; Kaber et al.1999). If the human operator believes the automated system is untrustworthy, then he/she would not use it, on the other hand if the human operator trusts an automated system he will continue to rely on it for some time even when malfunctions." (Parasuraman and Riley, 1997)
Amount of Automation	"In response, many design engineers with human factors sophistication have recognized that simplification offers an alternative to automation. If the system can be simplified, there may be no need for complex automation, and the same goal can be achieved without placing the human into a potentially hazardous position." (Wiener, 1993) "The potential difficulty with over-automation of systems is that the crew simply cannot be aware of the state of the system at all times". (Wiener, 1993)

Surveys show that attitudes on a stuff or machine affect the user to use, misuse or even not use that stuff (Parasuraman and Riley, 1997). Therefore the organization of the study is applied over the pilot's attitudes on automation. The major question that the study will answer whether does automation change the human role in the system and which factors does created problems in this new system?

The major question that this study will answer is the pilot's attitudes on automation. How does automation change the human role in the system and which factors does created problems in this new system? In this study, the meaning of automation, the attitudes of pilots on automation, how the pilots use automation and the effects of automation will be discussed from human factors point of view.

The main problem that will be examined throughout the study is;

1. How does the design of glass cockpit affect pilots in terms of Human Factors?

The study also concerns what are the attitudes of pilots to the following questions;

1. What are the new roles of pilots in glass cockpits?
2. Does glass cockpit automation decrease workload?
3. Does glass cockpit automation decrease human error?
4. Does glass cockpit automation increase Situation Awareness?
5. Does glass cockpit automation present sufficient feedback?
6. Does glass cockpit automation enhance safety?
7. Does glass cockpit automation design concept cause problems?
8. Does glass cockpit automation create cognitive conflicts between usage and operation?
9. Does glass cockpit automation cause information overload?
10. Does glass cockpit automation degrade skill?
11. Is amount of glass cockpit automation sufficient?

In this study, the rudiments and a general literature survey has done and related human factors issues are determined in the Table 1.1. A survey of pilots flying the advanced aircraft was carried out to gather information about the attitudes of pilots on automation. The analysis of these data revealed different categories of human factors problems. This survey is send to both military and civil pilots in Turkey via the internet survey “Questionpro”.

This study is presented in six chapters trying to argue the human factors issues of glass cockpits. In Chapter II, Glass cockpit design with cockpit instruments and controls will be introduced to readers. In Chapter III, a brief definition of automation and automation related terminologies will be described. And the reason why automation is needed will be explained. Chapter IV is the section where human information process and human role in an automated system will be described. Also, a brief definition of human factors will be given and human factors issues related to cockpit automation will be clarified with some accident examples and “Human-Centered Automation” approach that propose a model for a better communication between human and machine will be described. And Chapter V will determine the study methods and the results from the pilot survey. Finally, Chapter VI will conclude the total concept of this study.

Nevertheless, the main motivation for this study is the author’s experience in glass cockpit environment and system design. During the design process in professional practice, interviews were occasionally conducted with pilots who have not flied with glass cockpit yet, at regular intervals. In these interviews it is recognized that pilots have much expectation about the automation that it will solve all of the safety, workload and accuracy problems. However, as it is mentioned before from researches (Tenney, Rogers and Pew, 1995; Wiener 1989), pilots who are flying with glass cockpit have different attitudes on automation than these pilots. Therefore, one of the major aims of this study is to get the opinions of Turkish pilots on glass cockpit automation.

Aviation sector is being on the upgrade in Turkey. Designers modernize analog aircrafts into glass cockpits or design new automated glass cockpits with current projects. These designs are implemented according to design concepts by the reference of surveys done in abroad. There is not any reference formed according to Turkish pilots. However, as it will be mentioned in Chapter IV automation use can be affected by various factors such as motivational, social or cognitive processes. Designers should consider human factors regulations and surveys while designing. This is because, modernization of analog cockpits and designing new cockpits are continuing in current projects in Turkish aviation industry and the opinions of local user gradually becoming important. Thus, the study may contribute to the development of a design philosophy for new, advanced flight decks by gathering data on pilots' views on automation philosophy.

CHAPTER 2

GLASS COCKPIT AIRCRAFTS

A glass cockpit is an aircraft cockpit that contains electronic instrument displays with high-automated systems. "Glass Cockpit", the name comes from the Boeing's 757 and 767 displays which integrate the multiple independent mechanical flight instruments into one CRT or LCD display. This replacement allows simplifying instrument panel. Before that, a standard transport aircraft had reached more than one hundred cockpit instruments and controls which affect the pilots' attention cruelly.

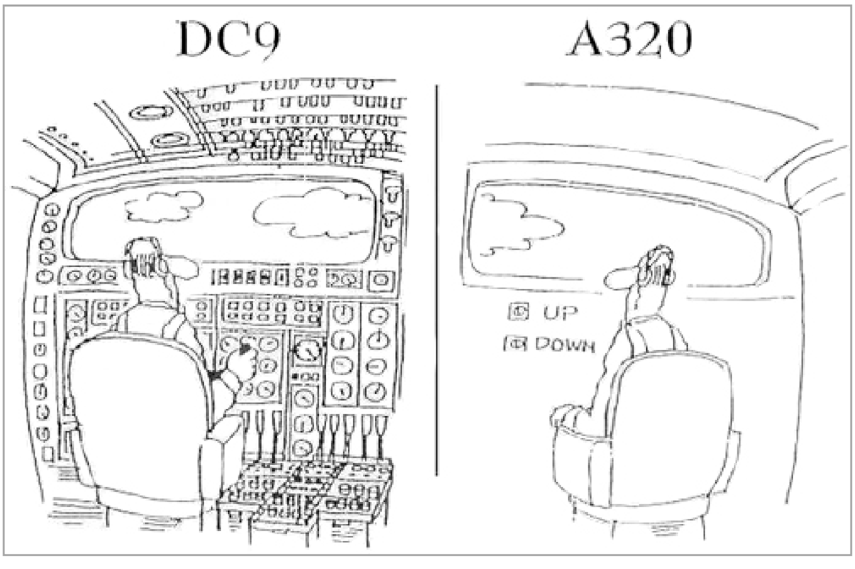

Figure 2.1: A cartoon which describes the revolution of cockpit technology from DC9-analog cockpit to A320-glass cockpit

Relative to the traditional aircrafts such as the B-727, DC-8 and DC-9, and older models of the B-737 and A-300, glass cockpit aircrafts (B-747-400, B-757/767, A-310/320, and A-300-600, F-100, MD-88, etc.) are equipped with an advance flight management computer/system (FMC/FMS) (Wiener, 1993).

Whereas a traditional cockpit utilizes numerous mechanical gauges to display information separately, a glass cockpit uses several displays driven by FMS (Flight Management System).

Figure 2.2: DC-9

Figure 2.3: Boeing_737

2.1 Glass Cockpit Layout

Basically, a glass cockpit consists of MFDs (Multi Function Display), CDUs (Control and Display Unit), EIDS (Engine Instrumentation Display System), Autopilot, and centralized warning and alerting systems. Although in general, cockpit layout is as described in this chapter; place, shape, name and logic may differ from one aircraft to another according to the aim of the design.

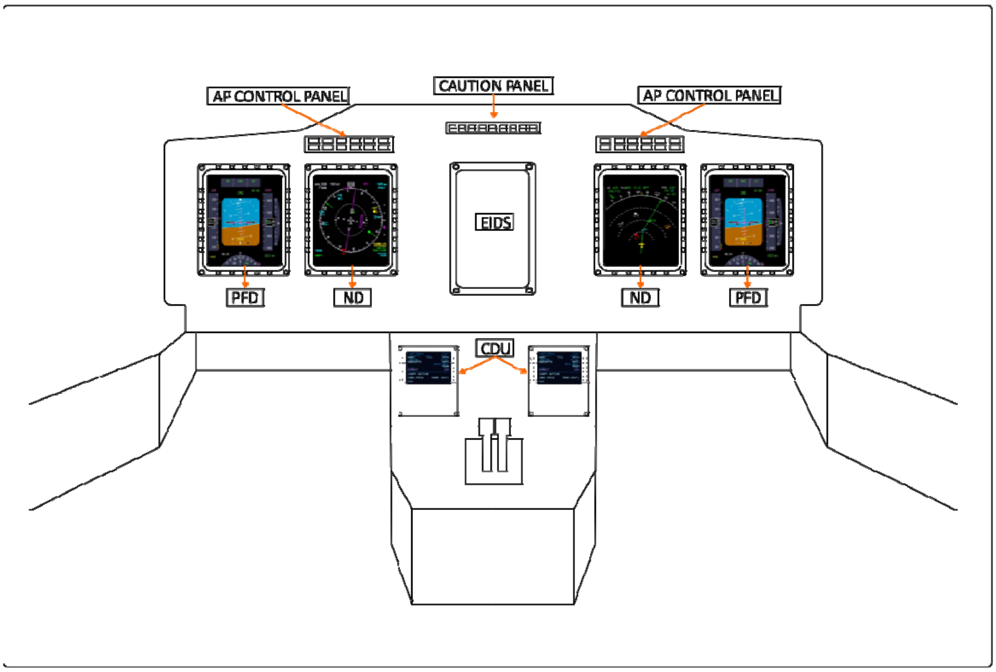

Figure 2.4: A typical glass cockpit

2.1.1 Multi Function Display (MFD)

A Multi-function display (MFD) is a screen in an aircraft that allows to display information to the pilot in one screen. A remarkable advantage of an MFD over analog display is that an MFD does not consume as much space as analog displays in the cockpit as they can combine various displays on a single display. There are four MFD screens in a cockpit; two of them for pilot and two of them are for copilot.

Formerly, displays used in the cockpits were Cathode Ray Tube displays (CRT) but by the end of the 1990s, Liquid crystal display (LCD) panels were increasingly used because of their ease of use, legibility, little space required in the cockpit and efficiency. Today, modern glass cockpits take advantage of LCD displays and most of the cockpit displays are upgraded to LCD displays such as C-130 aircrafts modernized by TAI (Turkish Aerospace Industry).

According to the design solution, MFD displays can have the control buttons that surround the display; or they can have an interdependent panel for controlling. Different display combinations can be created via these controls.

Generally, there are two multi- function display screens in a glass cockpit, which one of them displays the primary flight instruments; other one displays the navigational information that helps flying mission. These two displays are usually located in a prominent position, as they are needed much during flight.

2.1.1.1 Primary Flight Display (PFD)

In a PFD screen, various instruments are displayed that is a must during flight mission. These instruments should always be in the view of pilot that is imposed by FAR[1] (Federal Aviation Regulations) requirements.

Generally a PFD (Primary Flight Display) page consists of a Vertical Speed Indicator (VSI), Horizontal Situation Indicator (HSI), an Indicated Airspeed (IAS), an Attitude Deviation Indicator (ADI), an Altitude Indicator (AI)) and several other information which digitalizing the existing analog information. In analog cockpits, all these gauges were placed in the cockpit separately. A PFD page also displays the flight mode annunciators (FMA) and some indicators which leads flight.

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[1] The Federal Aviation Regulations are rules prescribed by the Federal Aviation Administration (FAA) governing all aviation activities in the United States. These regulations are also accepted by the other countries as well as Turkey to certificate aircrafts.

Figure 2.5: Multi Function Display Unit

2.1.1.2 Navigation Display (ND)

The Navigation Display (ND) which is adjacent to the PFD is a display system that provides the flight crew to display auxiliary information for navigation of the aircraft.

This display system can consist of a variety of pages or layers. ND display has a flexible design that allows pilot to modify the page. MFD control buttons allow transferring between these pages or open/close the layers. Generally, NDs allow the pilot to switch between screens of the navigation route, moving map[2], weather radar, GPWS[3] and TCAS[4] information on the same screen. Each flight crew would arrange his/her navigation page according to his/her needs.

2.1.2 Control and Display Unit (CDU)

The Control and Display Unit (CDU) is the pilot’s interface with automation that allows the pilot to plan aircraft’s route, navigate, and control the aircraft. There are two CDU in the cockpit; which one of them is for pilot and the other one is for co-pilot. CDU consists of a keyboard and a display. The keyboard (alphanumeric pad) is used to enter data by the pilots. The display includes lines which displays the data.

CDU has a number of lines which change according to the type of the CDU manufacturer. Each two line displays a set of data and a soft key[5] controls these two line set. At the bottom of the page there is a single line. This line is called “scratch pad” that is used to display the data entered via the keyboard of the CDU. The data entered to scratch pad can be transferred to the related line via the soft key belong to that line.

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[2] A moving-map system displays the real-time position of the aircraft on a map.

[3] GPWS – Ground Proximity Warning System – monitors the aircraft's height above ground and alerts pilots if their aircraft is in immediate danger of flying into the ground or an obstacle. GPWS also advises pilot what should be done to get away from collision.

[4] TCAS – Traffic Alert and Collision Avoidance System - allows pilot to display the traffic around the aircraft. System calculates possible collisions between the aircraft and intruders according to their speed, route and altitude. TCAS also advises pilot what should be done to get away from collision.

[5] A soft key is a key that’s function is changed according to the displayed page.

CDU consists of an architecture which is formed with various pages. Transferring between the pages is done via the hard keys[6]. Each hard key display the main pages and transferring to the subpages are done via the soft keys belongs to that main page. In CDU architecture, there are main pages as well as hard key quantity and there can be hundreds of subpages.

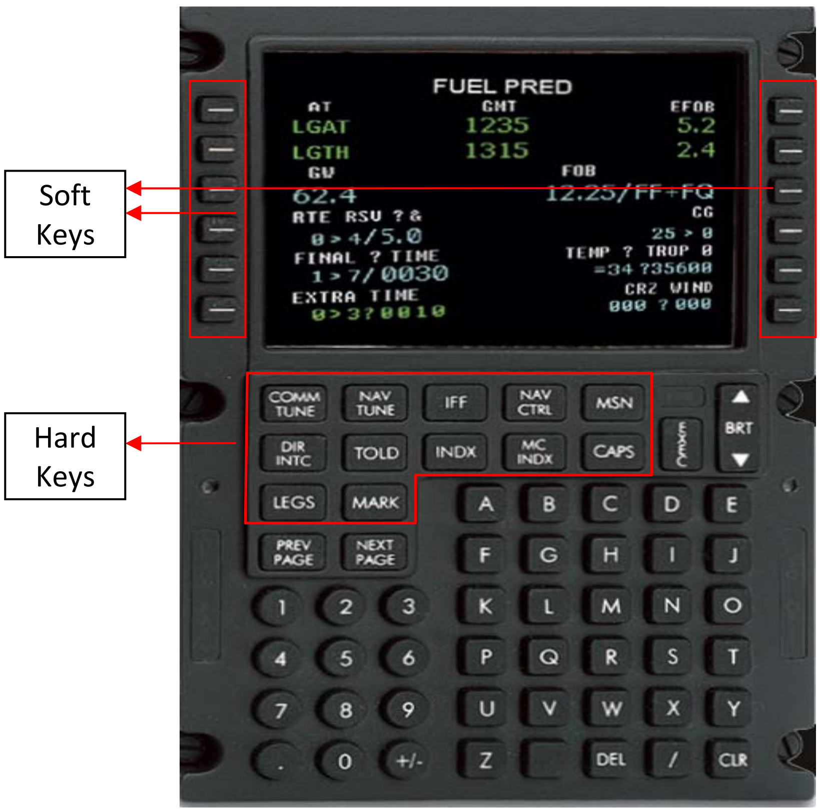

Figure 2.6: Control and Display Unit

[6] A hard key is a key that's function is always the same for each pages of the CDU.

2.1.3 Autopilot (AP)

With the advance in technology, aircrafts allow flight of many hours. It became more difficult for pilots to maintain their attention on the flight. Therefore, Autopilot system is designed to help the pilot in long distance flights.

Autopilot was first designed only a few years later the Wright Brothers had discovered the first aircraft. And it is used in aircrafts since late 1930s. At those years it only maintained the aircraft's current position without a pilot's attention.

Nowadays, Autopilot System ensures remaining aircraft position on the flight path that is set by the pilots and calculate the flight path parameters without assistance of human operator.

An Autopilot system divides the flight into several phases; taxi, takeoff, ascent, level, descent, approach and landing. And it could function during all these phases except taxi relative to its advance. An advanced Autopilot System could even make automatic landing (CAT III category Autopilot). Although autopilot is designed for maintain the flight route, they generally used for fuel-consumption in commercial airlines as it keeps the aircraft being unstable.

2.1.4 Warning and Alerting Systems

Warning and alerting systems are the main defense domains against the human error. Warning and alerting systems anticipate the impending errors or current conditions and warn the pilot about these situations. These warning systems are generally used as a backup to human vigilance[7]. In many cases they are used to warn the human operator about a coming condition such as warning pilot about out of balance fuel conditions before the system reaches the alarm condition. In other times, it is used as extensions of human sensory capability such as warning an opened door (Wiener, 1993). These alerts can be displayed on PFD (generally time critical warnings), on ND (generally situation of aircraft) or on an independent system such as caution panel.

2.1.5 Engine Instrumentation Display Systems (EIDS)

Engine Instrumentation Display System is an integrated system used in modern glass cockpits to provide flight crew with aircraft engines and other systems instrumentation and annunciations. The entitlement of engine system may differ from one manufacturer to other. (For example Airbus uses the acronym ECAM – Electronic Centralized Aircraft Monitor – and Boeing uses the acronym EICAS – Engine Indicating and Crew Alerting System –).

EIDS displays combine various engine parameters such as RPM (revolution per minute), temperature values, oil pressure, fuel flow and fuel used, etc. allows replacing all analog gauges related to engines with electronic displays.

2.1.6 FMS

Flight Management System (FMS) (or the Flight Management Computer – FMC) is the software that runs behind the displays and control units in the cockpit. FMS

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[7] The term human vigilance refers to the ability of human to maintain his/her focus of attention on a particular situation during a period of time.

provides the management of the systems via a control unit – CDU. Pilots can program and control the flight plan by the help of the FMS. Also when the FMS is coupled to the autopilot, FMS controls the flight rather than pilots. This coupling helps pilots during long flight legs and maintains a high degree of precision in flight.

CHAPTER 3

WHAT IS AUTOMATION

The term "automation" has been defined in a many ways in the literature as it is always faced with and it will take place more and more in daily lives. In technical approach it is defined by Rusinoff (1957, p.1) as "an industrial technique; in other words, that is involved in the processing of industrial materials and the production of consumer goods." His definition is about the computer technology used for mass production that has some autonomy.

However technological approach is not the focus of this thesis. Automation terminology will be analyzed by the means of human factors approach. Wickens and Hollands (2000, p.531) defined "automation should be used to perform functions that the human operator either cannot perform, performs poorly, or in which the human operator shows limitations."

Parasuraman and Riley (1997) defined automation as "the execution by a machine agent (usually a computer) of a function that was previously carried out by human." In addition to that, they point out that the *automation mentality* will change with time and "Today's automation could well be tomorrow's machine" (p.232). According to them, a function is allocated from human to machine and once the reallocation is complete and permanent, the function of machine will be perceived as the operation of machine instead of automation. They gave the example of starter motors for cars and automatic elevators and they think cruise controls[8] in cars and flight management systems (FMS) in aircrafts will be added to these examples in the future.

According to these definitions, it can be said that automation is not getting a higher technology such as increasing the engine power or replacing your washing machine with more automated programs, it is related to getting the job from human partially or fully by the help of the machines.

3.1 Forms and Levels of Automation

As automation is a complex term, lots of scientists tried to define and analyze the automation concepts with various models. Automation can be subdivided into two categories; open-loop automation and closed-loop automation which can then be subdivided into sub-categories.

In open-loop automation; once a command is given, automation starts the progress and gives the final response to the operator. The "Washing machine" can be given an example of this type of automation. First the operator puts in the dirty clothes and arranges the machine according to its limitations. Then the final product – cleaned clothes in this case – will be taken out. During the process, operator has the ability to terminate, to pause the operation, or to modify the program steps which have not been started, yet. For example, if the squeezing has not been started, yet, operator can change the drying rpm.

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[8] Cruise Control System ensures the automobile to maintain the speed. The advanced Cruise control Systems allow the vehicle keep pace with the car it is following, slow when closing in on the vehicle in front and accelerating again to the preset speed when traffic allows. Some systems also feature forward collision warning systems, which warns the driver if a vehicle in front - given the speed of both vehicles - gets too close (within the preset headway or braking distance). (Wikipedia, 2010)

In the closed-loop automation progress is open to get new responses from the operator or the operation being performed itself. In this case it is important for the operator to receive information from the automated system. According to this feedback, operator can give the instructions which are needed to complete the operation. This type of automation needs direct communication between human and machine (Science Encyclopedia, 2010).

It should also be concerned about the application of how much automation is applied to a machine process as well as type of the automation. Human machine interaction will be affected by the level of the automation. The levels of automation can be defined in several ways. The following table (Table 3.1) shows 10-level automation classification based on the concept of Sheridan (1992).

Table 3.1: Levels of Automation (Sheridan and Verplank, 1978)

Scale of Levels of Automation of Decision and Control Action		
HIGH	10.	The computer decides everything and acts autonomously, ignoring the human.
	9.	informs the human only if it, the computer, decides to
	8.	informs the human only if asked, or
	7.	executes automatically, then necessarily informs the human, and
	6.	allows the human a restricted time to veto before automatic execution, or
	5.	executes that suggestion if the human approves, or
	4.	suggests one alternative, and
	3.	narrows the selection down to a few, or
	2.	The computer offers a complete set of decision/action alternatives, or
LOW	1.	The computer offers no assistance: the human must take all decisions and actions.

According to this hierarchy, at the first level, there is no automation whereas at the tenth level full automation which does not give any information or needs any response from human.

Under full manual control, human control the all functions, with no machine involvement. In this level machine performs the job that the human operator wants it to do, machine has no effect on the job.

In the higher levels of automation, system allows less freedom for decision making to human operator. In these levels, human is less involved in the process and some human factors issues such as lack of feedback, job satisfaction, situation awareness, etc. that will be described later are encountered, constantly. Under full automation, human is not in the loop of any step of job, machine controls all the aspects of the function and not gives any clue to the human operator about its internal operations. There is not any communication between human and machine.

According to Wickens, Gordon and Liu (1998); automation can be applied to various categories. One of the categories is the *perception*. In this category, automation is used to replace human perceptual capabilities. TCAS systems which monitor aircraft position according to the other aircrafts and GPWS systems which scan the terrain are the examples of perception category. These systems replace the human's ability of process of pattern recognition. The other automation category is the *cognition* which replaces human thought and decision making. In this category, automation recommends action according to the determined situation. The TCAS and GPWS systems also recommend pilot what he/she should do to be freed from the existing circumstance. The final category of automation is the *control* which replaces the human's action and control functions. For cars autonomous cruise control which uses a radar or laser allowing the car to slow to maintain the tracking distance and accelerate again to the adjusted speed when traffic allows, and for aircrafts autopilot systems which control the aircraft's movement according to several parameters are the examples of control based automation.

Parasuraman, Sheridan and Wickens (2000) enlarge these categories and defined a framework for designers what types and levels of automation should be implemented in an automated system (Figure 3.1). The four functions of automation they described are different stages of human information processing; Sensory Processing, Perception/Working Memory, Decision Making and Response Selection which are replaced with the automated system processes in four stage model of Parasuraman et al. (2000).

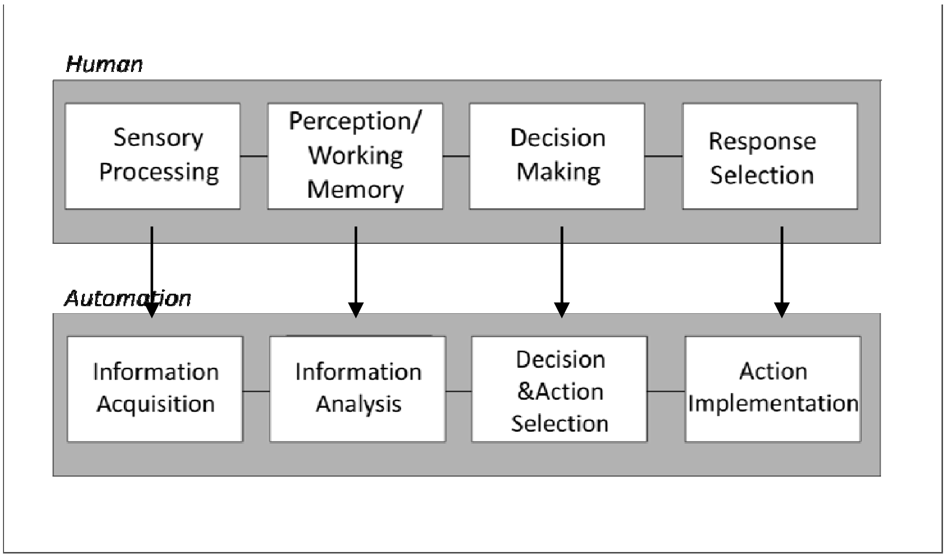

Figure 3.1: Designing Automation to Support Information Processing (Parasuraman, Sheridan and Wickens, 2000)

While 10-level Sheridan (1992) scale is principally applied to “output” of functions, according to this four-stage model, automation may also be applied to “input” of the functions. (Parasuraman, Sheridan and Wickens, 2000)

The first stage; Sensory Processing is related with the human sensory functions. In this stage human perceives the event that he focused on in a particular environment with his/her sensors; eyes, ears, skin, taste and nose. This cognitive process is called selective attention that means concentrating on one aspect of the environment while ignoring other things. In the automated systems, instead of human, automation senses and registers the input data with its digital sensors in the Information Acquisition Stage.

The second stage includes conscious perception. Conscious perception is the process of being aware of the situation or distinguishing of sensory information. That is to say human brain processes the selected data and transfers the data to the working memory. Automation of information analysis contains high cognitive functions that the automated system processes the information and makes predictions, generates alternatives and augmenting information displays, etc.

The third stage, decision and action selection is the stage where the decisions are selected. Human decides the next action against to the current situation through solution alternatives. In this stage automation replace the human selection of decision with machine decision-making.

The final stage of action implementation is the driving unit of information process that takes action the decisions. In this stage, action is implemented according to the decisions taken in the 3th stage and human control is replaced with machine action.

Automation can be applied across of all four dimensions at different levels in a particular system as displayed in Figure 3.2. “Thus, for example, a given system (A) could be designed to have moderate to high acquisition automation, low analysis automation, low decision automation, and low action automation. Another system (B), on the other hand, might have high levels of automation across all four dimensions.” (Parasuraman, Sheridan and Wickens, 2000, p.288)

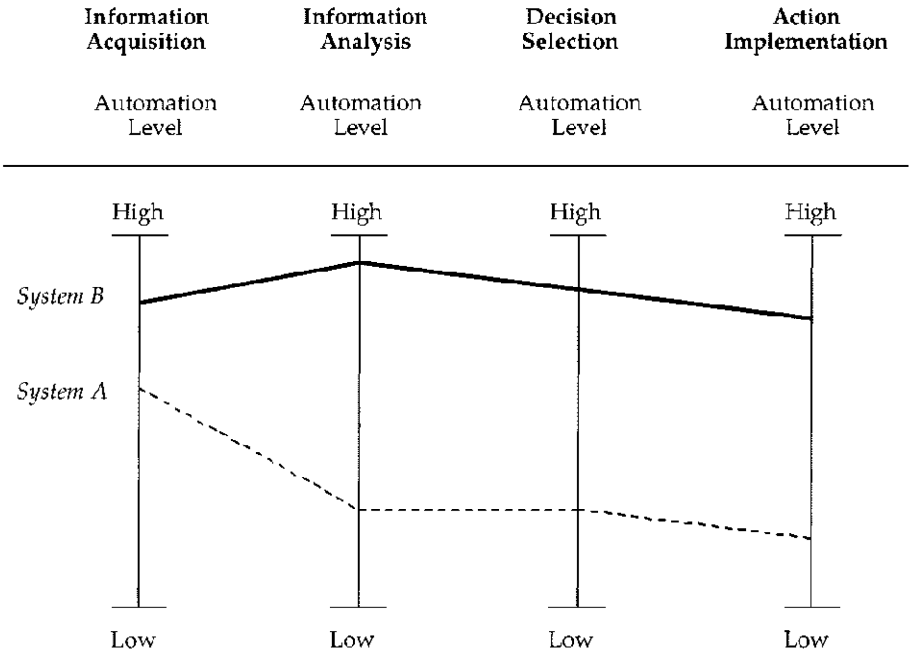

Figure 3.2: Levels of automation for independent functions of information acquisition, information analysis, decision selection, and action implementation. (Parasuraman, Sheridan and Wickens, 2000)

After decision of the stage of automation process, level can be determined. Figure 3.3 shows the application of the model of types and levels of automation. As seen in the figure, for each type of automation (acquisition, analysis, decision, and action) a desired level of automation from low (manual) to high (automatic) can be chosen.

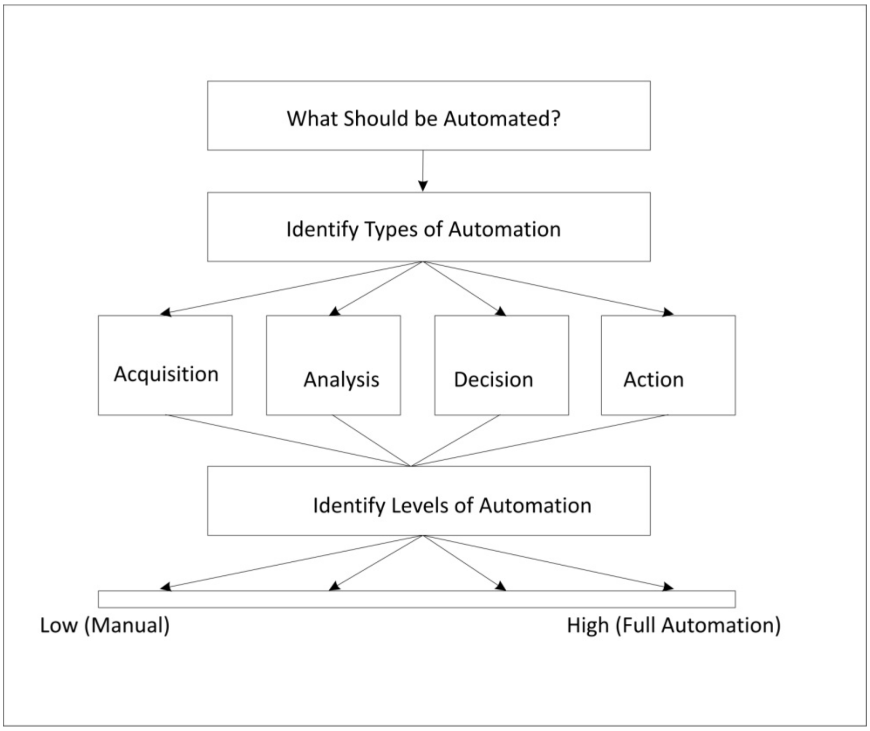

Figure 3.3: A Model of Types and Levels of Automation (Parasuraman, Sheridan & Wickens, 2000)

The main question in design is to decide at what level and at what stage of automation should be applied for a particular system. Ideal level of automation cannot be determined independently from the particular situation or context. (Tenney, Rogers and Pew, 1995)

There is no a moderate level of automation in a particular design. Level of automation should change according to the step of the work. The design decision will be given according to the need of the human and the job. For example in normal conditions there may be less need to automation but in abnormal conditions automation may be needed more than usual. There is not an exact design principle for defining automation degree. Too much or too little automation may cause different human factors issues which will be detailed in Chapter-IV.

3.2 Aircraft Automation

Aviation is the most affected domain of the industry from the evolution of automation technology (Sarter, 1994). With development of software and hardware technology, it has become possible to change analog instruments with digital ones. Therefore, this decreased the display quantity in the cockpit that pilot should track during flight.

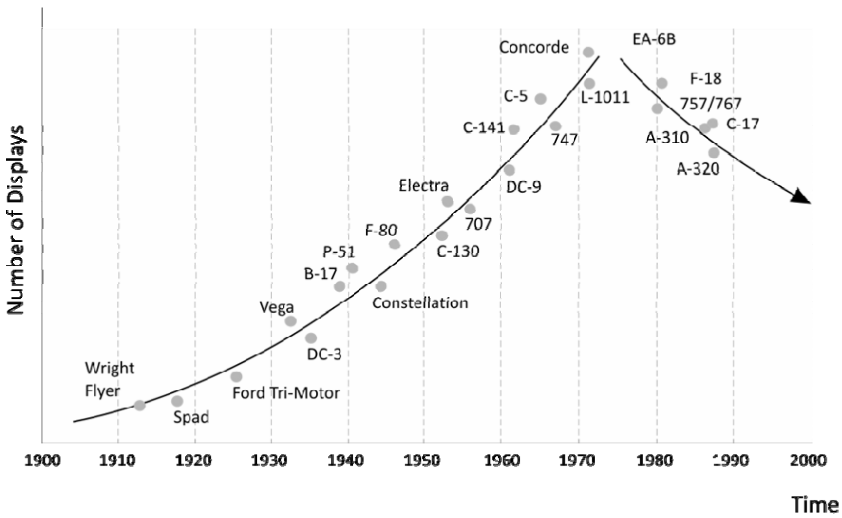

Figure 3.4: Evolution of Cockpit Displays (Sexton, 1998)

The evolution of aviation from the Wright brothers' time to the present day has made strides in the aircraft technology. Billings (1997) defined cockpit automation revolution as in the Figure 3.5.

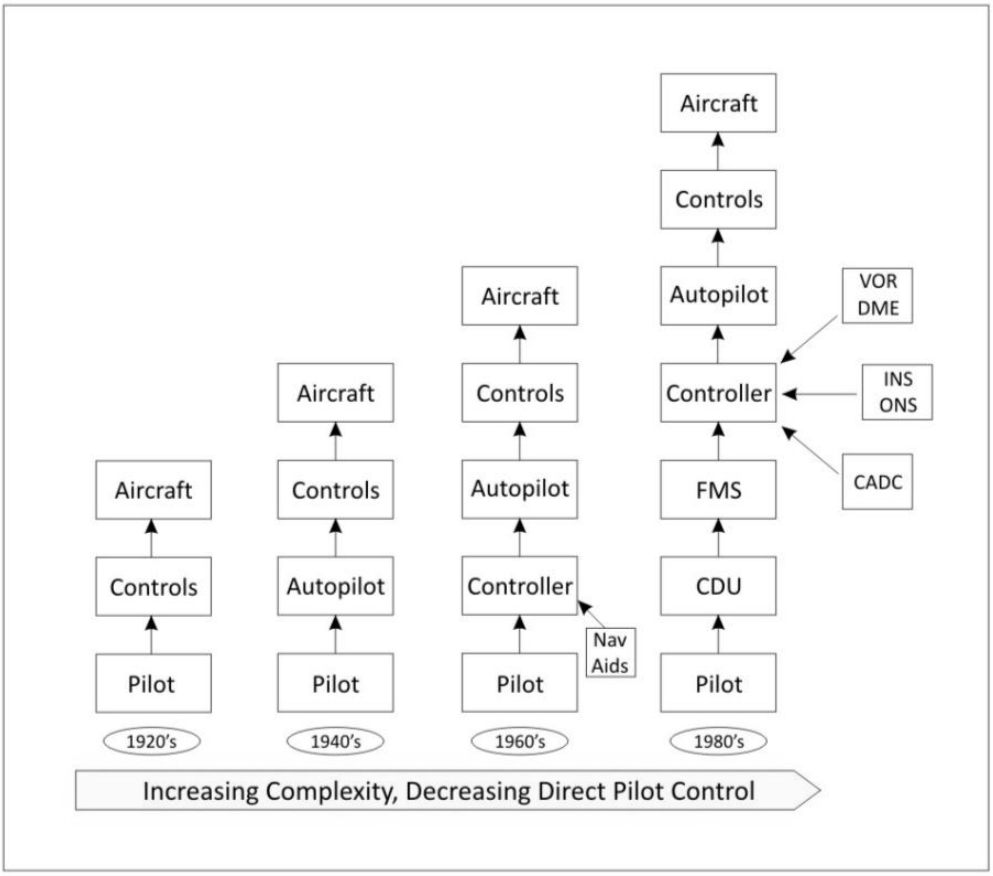

Figure 3.5 Trends in Aircraft Automation (Billings, 1997)

As displayed in the Figure 3.5, there were only the primitive controllers when the first introduced of the aircrafts. In 1940s, autopilots were the most remarkable change of primary flight control. The controls of the aircraft are controlled via the autopilot. In 1960s, an interface was designed to control the autopilot. Integrated navigation instruments were also introduced at these years that allow horizontal situation indicator and enhanced map displays. In 1980s, aircraft industry was introduced with FMS[9] that is the origin of today’s cockpit technology. The introduction of the FMS marked as an important turning point in aircraft automation as it changed the nature of the piloting activity by allowing commanding aircraft autonomously. Pilots controlled the FMS by the help of the CDU that was a new technology at those years. According to Billings, automation revolution will continue, because of the inevitable development of the technology.

Throughout 13 years when Billings created this revolution table, there have been great innovations in display technology. For instance, touch screens have been used in daily life even in cell phones. It is not a dream anymore to design a cockpit like “Crystal Cockpit” which is designed by James Cameron for Scorpion cockpits in the movie “Avatar” in near future.

Figure 3.6: Avatar the movie Scorpion Cockpit

[9] A Flight Management System (FMS) is the main part of a modern glass cockpit that controls the operation of the aircraft. The FMS is the avionics that holds the flight plan, and allows the pilot to modify if it is required in flight.

3.3 Why Aircrafts are Automated

The driving forces of the automation are; technology, safety and economics. Because of the advance of technology, change in cockpit is expected by the market. Improved performance, decrease in size, little power needed and affordable cost of new electronic devices make it inevitable to transfer from traditional cockpits to glass cockpits. However, as Wiener and Curry (1980) indicate that technology was not a goal of transition as safety and economics, but instead it is a facilitating factor.

The aim of eliminating the human is to make the operations safer. As air traffic congestion increases, Traffic Alert and Collision Systems (TCAS) prevent to crash with other aircrafts. Terrain Avoidance Warning Systems (TAWS) prevent to crash on land. With ILS (instrument-aided landing system) Advance Autopilot Systems allow to make an automatic landing if the airport has the supporting equipment. Wiener and Curry (1980) declared that since the introduction of GPWS there has been an appreciable reduction in terrain strike accidents.

Whilst motivation of automation in military is safety, commercial aviation's main concern is the cost of flight as the commercial aviation is a very competitive industry, it is important to reduce the flight cost. Automation advices on engine conditions, and make calculations how to save fuel and time. Therefore, according to these calculations mission will be completed in less time with less fuel. In addition to this, glass cockpits are also approved by airline companies as they allow to eliminate the flight engineers so the cost of flight crews. The missions of a flight engineer which are controlling the terrain, radar and weather and deciding the route according to these donates, warning pilots when to throw mine, or parachute, and performing the performance calculations of the aircraft, etc. are done by the FMS in glass cockpit aircrafts.

Furthermore, automation may reduce maintenance costs as it allows using equipments in the cockpit efficiently and surely it reduces the training time. As Amalberti (1998) declares that another benefit of automation is based on the "zero-flight" concept which allows pilots to be trained without any flight which is the most expensive part of the training by the help of the simulators.

CHAPTER 4

HUMAN FACTORS

The discipline "*Human Factors*" can be defined as *"the technology concerned to optimize the relationships between people and their activities by the systematic application of the human sciences, integrated within the framework of systems engineering"* (Edwards, 1988, p.9). Edwards (1988) remarked that human factors discipline is problem oriented based on the practical nature of human factors. It calls for solutions to the problems of human interaction with a system.

Human factors is an essential part of the design process as it may predict the possible interaction problems which may occur between human and system before late stages of design. Human Factors principles should be effectively considered during system design because if the system result is not appropriate for human-system interaction, then there is little that can be done at that stage of design. At this point it is essential to remind that Human Factors is not applying check lists and guidelines, or designing, or just a common sense. The objectives of Human Factors are increasing the efficiency of work, improve safety and increase comfort. Whilst doing this, the capabilities, limitations, characteristics, behavior and motivation of the human should be considered.

Wickens et al. (1998) assert that the goal of the human factors is reducing the error, increasing productivity, increasing safety and increasing efficiency of the interaction between human and the systems with which they work. Human factors discipline includes the study of factors and development of tools to achieve these goals.

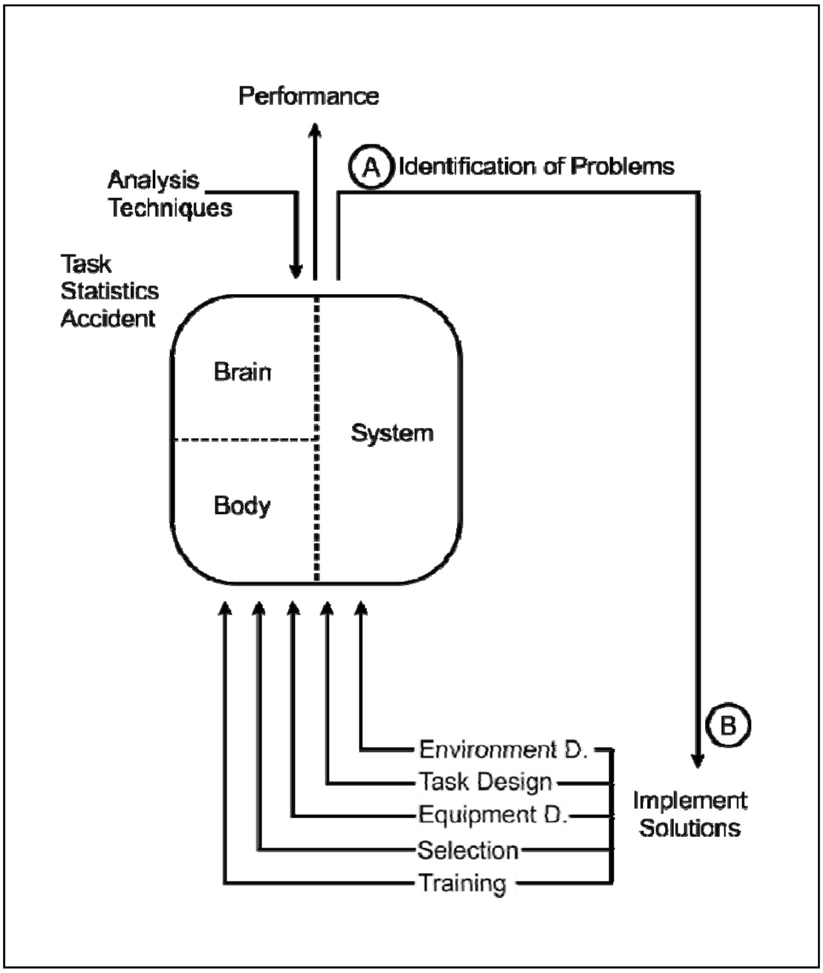

Figure 4.1: The Cycle of Human Factors (Wickens, Gordon, Liu, 1998)

Figure 4.1 illustrates the life cycle of the Human Factors. The human operator (brain and body) and the system which he/she interacts with are located at the center of the human factors life cycle. First step (A) is identifying the possible problems and deficiencies. To achieve this step, one should have the knowledge of physical body (its size, shape and strength) and the mind (human's information processing characteristics and limitation) and

After identifying the problems, at the second step (B), five different approaches may be applied to solve the problems; **Equipment Design** (design solutions for the physical equipments such as size, shape or labeling), **Task Design** (changes the operations of the human rather than the equipment he/she uses), **Environmental Design** (changes the physical environment such as lighting, temperature, or noise in which the human works), **Training** (focuses on giving necessary physical and mental skills that human may need in the job environment), **Selection** (intends to select suitable operator who has the necessary mental or physical skills for doing the job). Any or all of these approaches can be applied to design to solve the human factors problems (Wickens, Gordon, and Liu, 1998).

Human Factors science is a multidisciplinary field which interacts with various disciplines. The understanding of how people process information and make decisions is obtained from psychology, comprehension of sensory processes; detecting and transmitting information comes from psychology and physiology, the measures and movements of human body which is essential for appropriate design and layout of controls and physical characteristics of flight deck comes from anthropometry and biomechanics. In addition to these disciplines, also the biology is used to understand the nature of the body's rhythm and sleep, and their effects in night flying and time zone changes. Of course statistics is expressly needed to make proper analysis of data gathered from surveys or studies (CAP 719, 2002). Wickens et al. illustrate the relationship of the Human Factors with other domains of science and engineering.

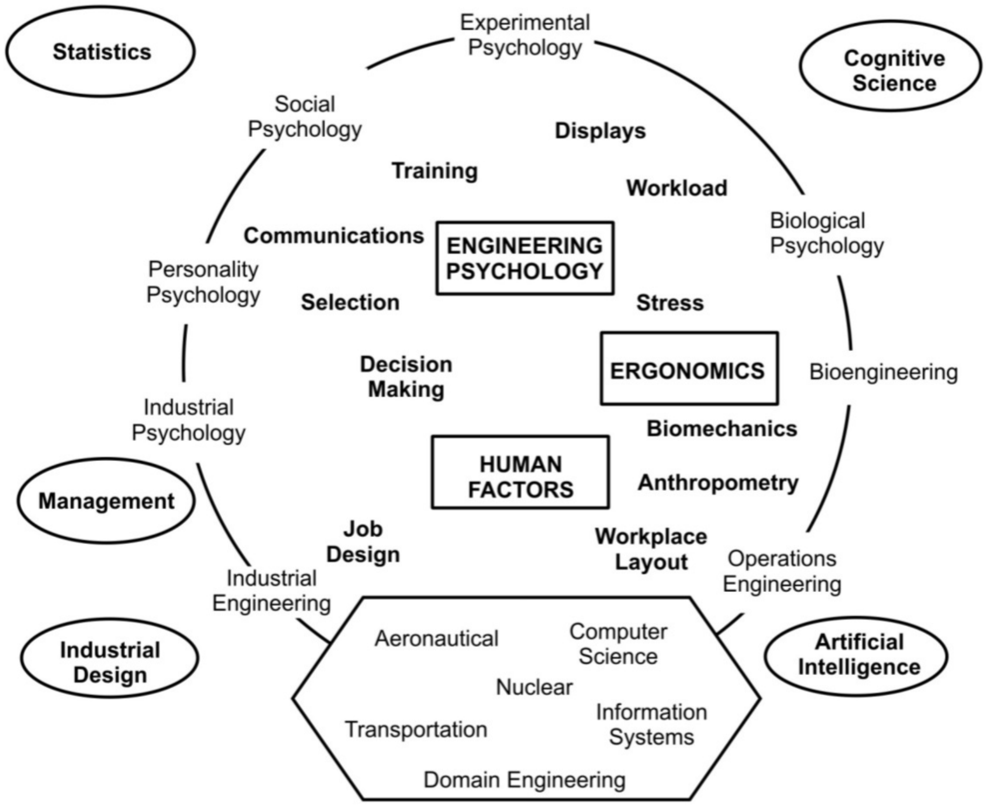

Figure 4.2: Human Factors and Related Disciplines (Wickens, Gordon, Liu, 1998)

Each item is related with a discipline near it. The Human Factors discipline is located at the center of the circle and surrounded with various sub-domains which are labeled in bold characters. Disciplines within the study of psychology and engineering are aligned on the circle. At the bottom of the illustration, domain engineering disciplines are located. And outside of the circle, some disciplines which have overlap with some aspects of human factors are identified.

There two other discipline “Engineering Psychology” and Ergonomics” which is closely related with the “Human Factors”. The term Ergonomics is described differently in Europe and United States. In United States it is accepted as the discipline that is related with the physiology of human. However in Europe, it describes the all aspects of Human Factors. Therefore, it is difficult to make a strict distinction between these two terms. Engineering Psychology on the other hand is interested in discovering the psychology of human as understanding the human mind is relevant to the design of systems as Wickens (1992) declared.

Within the literature research, some human factors problems related with cockpit automation are determined such as change in the pilot's role, cognitive conflicts between pilot and the automation behavior, information overload, lack of situation awareness, insufficient feedback, skill degradation, design based problems, change in human error, usage problems and over automation. These problems will be examined clearly in the following chapters.

Although in addition to these issues, some more issues may occur such as language problems and training, they are not discussed in this study. Language problems may appear because all the information presented to pilots is in English which is far from being the native language of most of the pilots all over the world (Amalberti, 1998). However, it is inevitable to use English in information language as it is accepted as lingua franca. The other issue training is generally out of the design process of automation, so it is discussed in this study.

4.1 Human Role in an Automated Cockpit – Human Automation Interaction

In order to understand the consequences of automation, first the human role in an automated system and the relation between human and automated system must be analyzed.

4.1.1 SHEL Model

As Edwards (1988) said, a designer must design according to the system resources which the human will interact during the mission. These resources are the software, human, environment and liveware whose initial characters gave the name to the model “SHEL”. SHEL model is a conceptual model that is designed to explain the interactions between human and all other domains. Model comprises four components; software, hardware, other people and environment in operational practice.

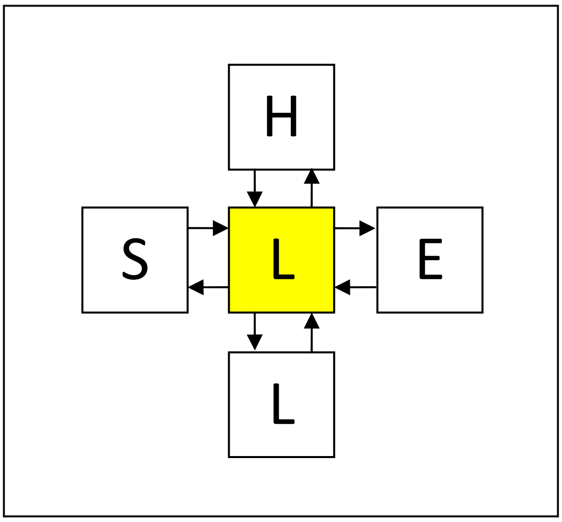

Figure 4.3: SHEL Model

The human operator, or the Liveware, is located in the center of the model which is represented by the yellow L. Human “the pilot” in this case, interacts with all these resources and gets feedback from each of the resources during flight. The dynamic structure of their interaction should be considered attentively.

The first resource is the hardware which is the physical property of the system such as vehicles, equipments, and buttons etc. covers the cockpit layout and controls. By a majority the Liveware-Hardware interaction is concerned with ergonomics which is a science concerned with the “fit” between people and work. For a healthy interaction, hardware should be designed by considering the human’s anthropometric (body dimensions), biomechanical (mobility of the limbs), and human performance (visibility, hearing, tactile, etc) limitations.

The second resource software is the intangible parts of the system such as the regulations, standard operating rules and practices which contains the information that operates the system. Of course the computer programs are one the most important element of this resource. Liveware-Software interactions include utilization of the computer software to gather information from the receiver which is the input of human operator.

Other resource is the liveware; humans who are in this system are the liveware elements of the SHEL model. Liveware – Liveware interface refers to the communication between the humans in a given environment. The Liveware – Liveware interaction is concerned with team coordination and cooperation in the cockpit.

Surely, the final resource is the environment of the system that includes physical, economic, political and social factors should be considered in which all the domains; software, hardware and liveware will interact. Liveware – Environment interaction includes the negative effects of environment on the liveware such as; too low or too high temperature, too much noise that obstruct hearing warnings or communication with ATC, or light glare that cause not to see the displays the pilot will get the information.

4.1.2 Information Processing

Information processing is an approach to understand human behavior and frame of his/her mind within the field of Cognitive Psychology. Wickens, Gordon and Liu (1998) generated a model that describes the concept of human information processing. This information processing approach assumes that “we receive the information from the environment, cognitively act on that information in various ways, and then emit some response back to the environment” (p.146).

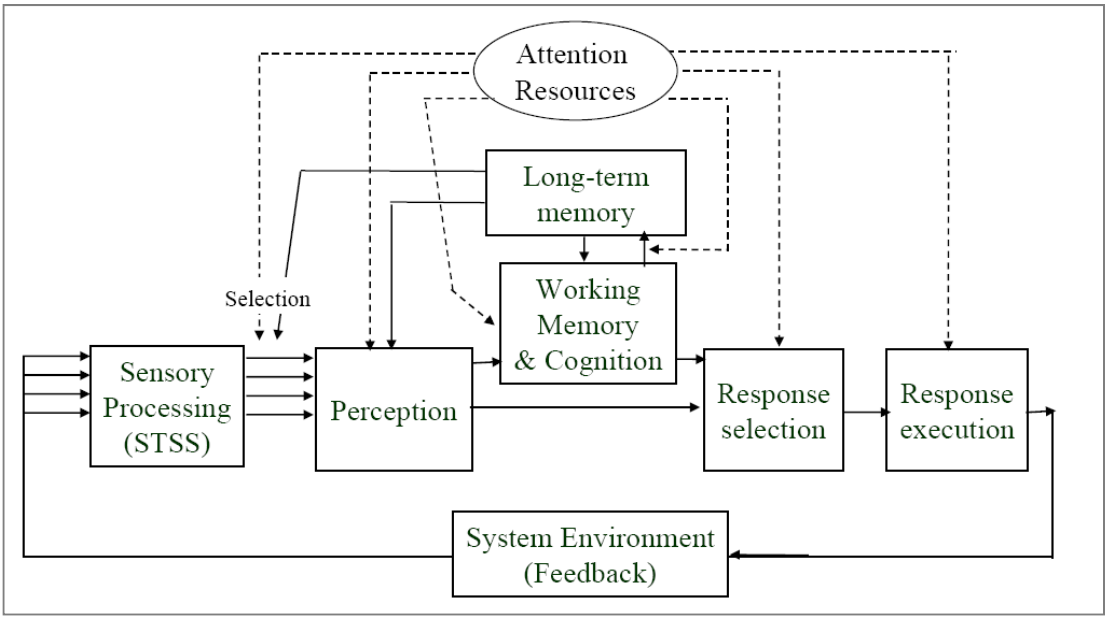

Figure 4.4: Generic Model of Human Information Processing with three memory systems.(Wickens and Hollands, 2000).

According to this model given in Figure 4.4; information is received by the sensations of human; hearing, vision, taste, olfaction and haptic in the sensory register stage and then these sensory information which receive attention is processed in depth in the perception stage. This stage also adds meaning to the incoming information by comparing it with the stored knowledge in the long-term memory. According to this processed information, human may react directly to the stimuli in some ways or the information may send to the working memory for further examination. "*Working Memory* is a term for both the short-term store of whatever information is currently active in control processing, and also for a kind of workbench of consciousness in which we compare, evaluate, and transform cognitive representation." (Wickens, Gordon and Liu, 1998, p.147) This stage is a cognitive stage where the human compare the information with current goals to solve the problems, consider the responses. In the response stage, first a response is selected and then execution processes occur. Under certain circumstances, information will be send to long-term memory for later use.

4.1.3 Fitts's List (Function Allocation)

The main aim of function allocation (a central component of systems engineering) is to determine which system-level functions should be in the responsibility of humans and which of machines. Functions of an operating system should be allocated early in the design life cycle. The principle is that some tasks which would be too boring, too hazardous, or too fatiguing should be assigned to automation and tasks which humans like doing them or that cannot be automated in technically should be assigned to humans. The most common approach of this decision is rely on the MABA-MABA (men are better at/machines are better at) list of Fitts (Hugo and Engela, 2005).

Fitts and his contributors (1951) determined the allocation of function between human and machines. They compare the capabilities of man and machine in terms of their abilities.

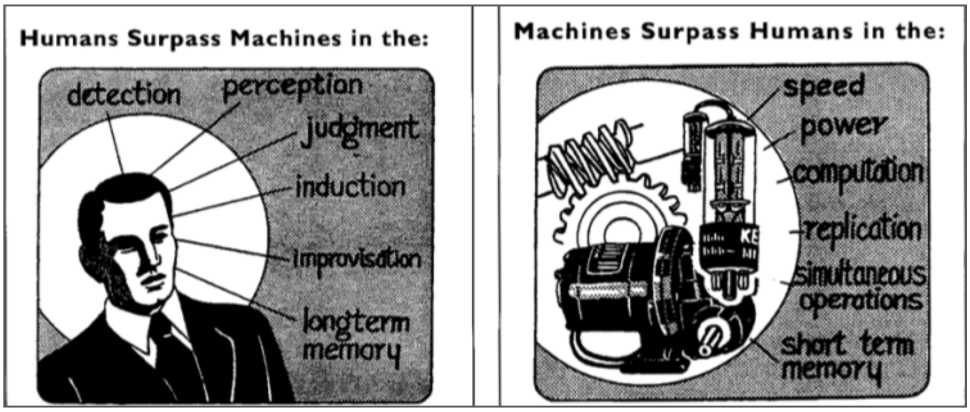

Figure 4.5: Fitts's Function Allocation List (Fitts et al., 1951)

According to the Fitts List;

Humans appear to surpass machines with respect to the following;

- Ability to detect small amounts of visual or acoustic energy
- Ability to perceive patterns of light or sound
- Ability to improvise and use flexible procedures
- Ability to store very large amounts of information for long periods and to recall relevant facts at the appropriate time
- Ability to reason inductively
- Ability to exercise judgment

Present day machines appear to surpass humans with respect to the following:

- Ability to respond quickly to control signals, and to apply great force smoothly and precisely
- Ability to perform repetitive, routine tasks
- Ability to store information briefly and then to erase it completely
- Ability to reason deductively, including computational ability
- Ability to handle complex operations, i.e. to do many different things at once

4.1.4 Human Supervisory Control (HSC)

Automation decreases the routine and time-consuming activities, however inherit human abilities such as cognitive flexibility, creative thinking and decision making activities cannot be supported by the automation. "*Automation of physical functions has freed humans from many time-consuming and labor-intensive activities; however, full automation of cognitive functions such as decision making, planning, and creative thinking remains rare*" (Parasuraman & Riley 1997, p.231).

As Sheridan (1987) said that, the development of the automated systems for the acquisition, storage and processing of information has shifted the role of the human operator from active controller to the supervisory control. Sheridan (1992, p.1) also described the supervisory control as; "In the strictest sense, supervisory control means that one or more human operators are intermittently programming and continually receiving information from a computer that itself closes an autonomous control loop through artificial effectors and sensors to the controlled process or task environment."

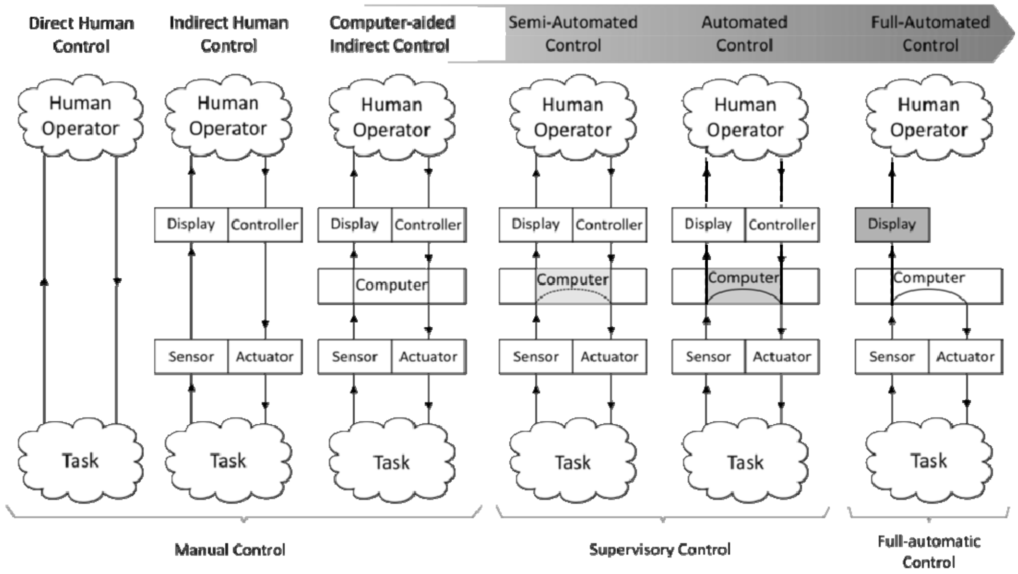

Figure 4.6: The spectrum of control modes (Adapted from Sheridan, 1992)

In supervisory control, a human operator follows operations of a system and executes some level of control on that process within the authorization given by the system. During this interaction with the controls and displays, human plans an activity and directs the automated systems with some commands to achieve that plan. Operator should oversee attentively the system to ensure that the action is performed correctly. If the automated system makes a mistake or requires assistance, human supervisor can interfere in the process. Therefore it is critical that the feedback mechanism should work effectively that allows the human operator to understand the process faults and treatments.

Supervisory control can be applied to any level of automation; from highly automated systems where the operator has slightly control on the system to minimal automated systems where the operator has the maximum control on the system.

In supervisory control, human's role is to oversee the automation process. Since most of the mission of the operator is just controlling, it is so monotone for operator to keep his/her attention on the displays. Rest of the job is compelling as it needs checking the all variables, making a decision according to the current situation, and taking all actions relevant to the decision in a very short time. Warm and Hancock (1996, p.1) says "Vigilance or sustained attention refers to the ability of observers to maintain their focus of attention and to remain alert to stimuli for prolonged periods of time."

As Parasuraman (1986) declared that although the most part of the responsibility for target detection in highly automated systems is allocated to the system, human operators are still needed to take over the control in case systems malfunctions.

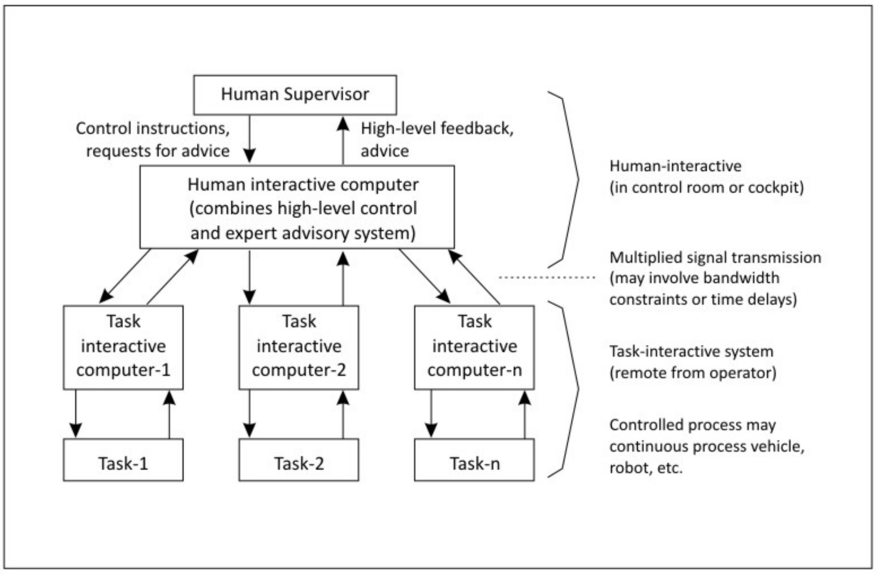

Figure 4.7: Hierarchical nature of Supervisory Control (Parasuraman, 1986)

The main purpose of designing advanced automated systems is to bypass the human operator who can make faults with a perfect and fast machine system. However, the consequences are not like that. The role of the human has changed in these new automated systems. Now, human is not the controller, but he/she is the supervisor and deliverer in emergency cases.

4.2 Human Related Accidents

With the introduction of the glass cockpits in the early 1980s, hundreds of accidents have occurred in which pilot-automated systems was the reason.

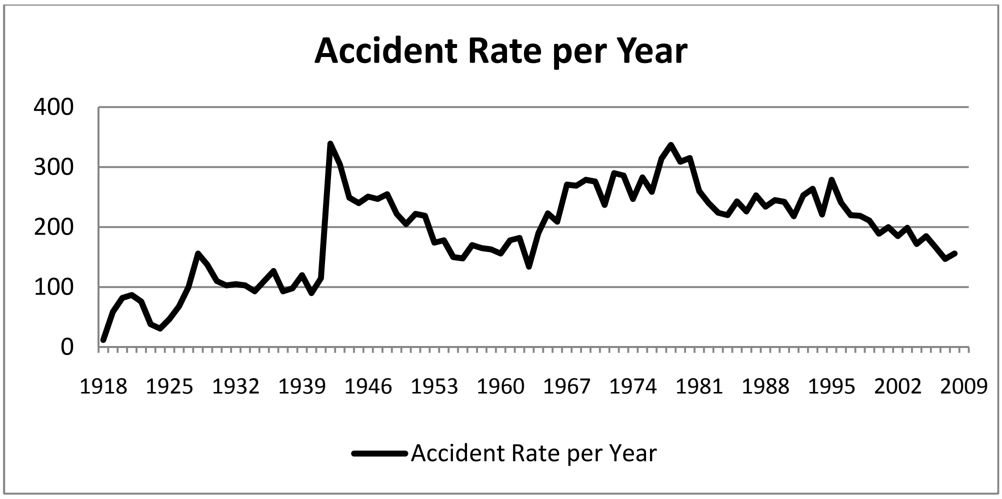

Figure 4.8: Accident Rate per Year (Aircraft Crashes Record Office, 2010)

Table 4.1: Causes of Fatal Accidents by Decade – percentage (Plane Crash Info Web Site, 2010)

CAUSE	1950s	1960s	1970s	1980s	1990s	2000s	All
Pilot Error	40	32	24	25	27	25	29
Pilot Error (weather related)	11	18	14	17	21	17	16
Pilot Error (mechanical related)	7	5	4	2	4	3	4
Total Pilot Error	**58**	**57**	**42**	**44**	**53**	**45**	**50**
Other Human Error	0	8	9	6	8	9	7
Weather	16	10	13	15	9	8	12
Mechanical Failure	21	20	23	21	21	28	22
Sabotage	5	5	11	13	10	9	9
Other Cause	0	2	2	1	0	1	1

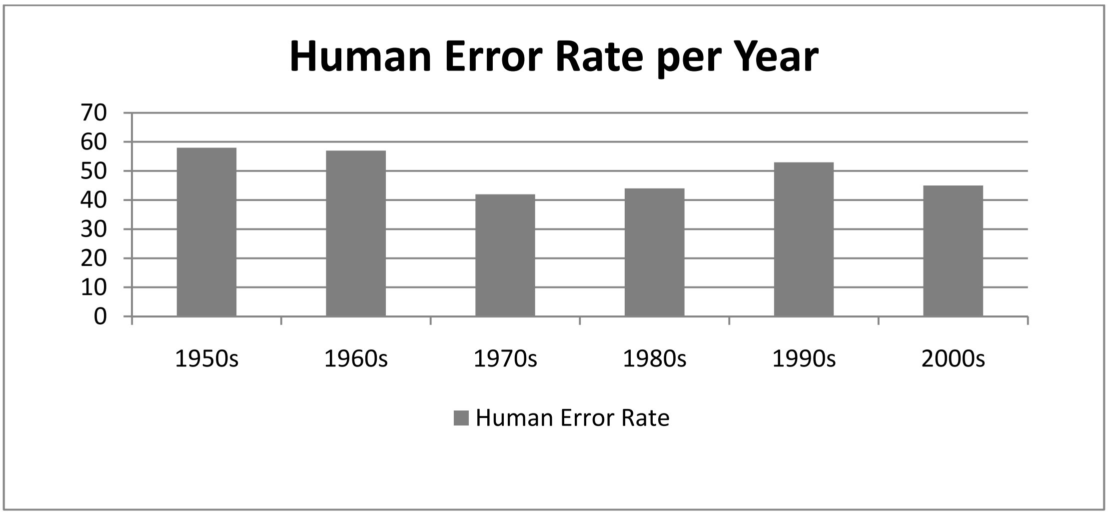

Figure 4.9: Human Error Rate per Year

It is thought that the major source of the accidents is the human operator. Therefore, to dissolve the human error is the fundamental issue which should be given point to.

When today’s air traffic is considered, it can be said that the percentage of air accidents has been decreased. However it is seen that there are still human errors that cannot be ignored. Being one of the main reasons of the application of glass cockpit automation, reducing the human error dream seems to be not real, yet. These statistics show that it is seen that human error is still the most important agent which cause accidents.

4.3 Human Factors Issues of Aircraft Automation

In this chapter automation related problems will be discussed that are gathered from the literature with some aircraft accident case studies. Some of the selected issues which are chosen according to the field of this thesis are described in this chapter. Issues related with the lack of automation capability are ignored. Also some of the issues are combined with similar issues and created new ones.

4.3.1 New Roles for the Pilot

As described in the Chapter III “Human Role in Automated Cockpit” the role of the human operator changed to active controller to passive monitor.

With rapid growth in microprocessor technology, designers have built very complex systems based on the rationale that the systems could operate automatically without human assistance. Wiener (1993) refutes this argument with two contrary aspects. First, there is almost no automated system operates fully automatically without human. All systems need a human to set up, feedback about what to do and monitoring. Secondly, they always need a human to operate the system when it falls to fail.

Human-computer monitoring, gives an example to attentional behavior of human. During World War II, improved radar systems are thought to be a great advantage towards the enemies by United States. However, radar misidentified Spaniel fish vessels and large whales as enemy submarines. Increased misidentification caused human operator’s vigilance decrement and to ignore critical signals (Parasuraman, 1987).

In the new highly automated systems signals are detected by the instruments, generally very precisely. The system can lead the human operator what to do or even it can operate by itself. Operators are no longer need to sense the critical signals; they only watch the ongoing processes. So what is the importance of the monitoring if the entire job is done by the automated system? Although the system can operate by itself, attentional factors still affect system performance. Because the human operator must watch the system in case a fault cannot be detected by the automated system or an emergency case is occurred. When needed human must always be in the loop (Parasuraman, 1987).

Just monitoring and giving feedback when required seems to be a very easy mission at first glance; however it is more complicated than estimated. As Wiener and Curry (1980) pointed out, while the human role is changed from active controller to passive monitor, vigilance problem still exists. Referring to Davies and Parasuraman (1982) and Warm (1984); Huey and Wickens (1993) defined the vigilance, or sustained attention, as “the ability of observers to maintain their focus of attention and to remain alert to stimuli for prolonged periods of time” (p.139). However human beings are not good at monitoring. Studies (Mackworth, 1950) have shown that human cannot maintain visual attention toward a source of information for more than about half an hour even if he/she is highly motivated (Bainbridge, 1983). Therefore Bainbridge claims that it is impossible for human to accomplish the function of the monitoring.

Eastern Flight 401 has given an example for vigilance problem by Wiener and Curry (1980). In this crash, autopilot descended the aircraft from 2000 feet by some reasons. The descent was not recognized by the crew members (despite the indicators and alarms), as they were absorbed in the disassembly of a warning light bulb. Soon, the aircraft crashed into Florida Everglades on the night of December 29, 1972, causing 103 lives lost. The crash was a result of the flight crew members' failure to monitor the flight instruments properly.

Actually, now with the highly automated cockpits, vigilance problem may increase because of various domains such as trust, boredom, complacency and stress. Wiener (1984) determined that the role of attention and vigilance is more complex and difficult than that is before the automation. These domains will be described in the title of Automation Use.

Parasuraman (2008) also claims that even operators behave equally in automated and manual systems when they are focused on a single-task, they are poor at monitoring in automated systems when they are engaged in other tasks compared with the manual systems.

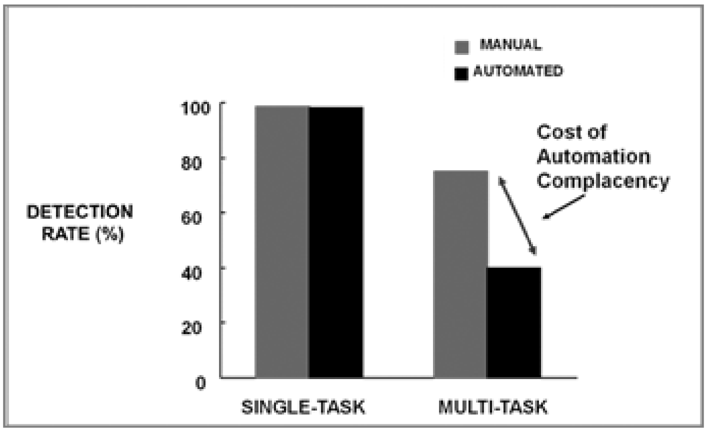

Figure 4.10: Monitoring Capability (Parasuraman, 2008)

Out-of-the-Loop Unfamiliarity (Wickens, 1994) is another problem of the change in human role as a consequence of automation. Out-of-the-Loop Unfamiliarity phenomenon may be encountered with highly automated systems. When the human operator is removed from the control loop due to function allocation the level of the interaction, therefore, the awareness of the operator may be reduced (Kaber & Endsley, 1997). Because of the highly automated systems over-reliance, complacency and skill degradation problems may occur (These problems will be explained in the following chapters). Wickens (1994) claimed that these costs of high-level automation – reduced situation awareness, complacency, and skill degradation – may collectively cause the “out-of-the-loop” unfamiliarity.

Although highly automated systems work precisely and generally very well, there will always be possibility of the automation to make an undesired action or fail. In case such conditions, the human operator is needed to take over the manual function and cope with the situation. However the “Out-of-the-Loop Unfamiliarity” may prevent the operator from settling the current situation of the aircraft successfully in time (Parasuraman et al., 2000).

4.3.1 Automation Use / Disuse/ Misuse

The use of the automation is relative to the positive or negative attitudes on automation. Generally these attitudes are affected by the reliability or accuracy of the automation. For instance, whereas automatic breaking systems have been welcomed and used efficiently, however smoke detectors are disliked by many people because of the false alarms and sometimes disabled (Parasuraman and Riley, 1997).

During interaction continuum with the cockpit automation, pilot develops a strategy about using it because of some various reasons. Although an appropriate usage is desired by designers, this strategy sometimes appears as disusing or sometimes misusing the automation.

According to Parasuraman and Riley (1997), disuse is “underutilization of automation (e.g. ignoring or turning off automated alarms or safety systems)” and misuse is “overreliance on automation (e.g., using it when it should not be used, failing to monitor it effectively)” (p.233).

Although Parasuraman and Riley (1997) based on the automation usage to reliability or accuracy Dzindolet, et al. (2001) claimed that it is not such simple. They created a framework of automation use. According to this model, automation usage depends on some processes that are originated from the causes of productivity loss in groups model of Mullen et al. (1991). They believe that this model can be applied to human-computer teams, as well. Several researchers also support this thought that the human-computer system can be accepted as a team in which one member is not human (Bowers et al., 1996; Woods, 1996). This model includes the cognitive processes, social processes and motivational processes of the human operator.

4.3.1.1 Cognitive Processes

Automation bias is one of the factors that influence the automation usage of the human operator. Mosier and Skitka (1996) defined automation bias as "the tendency to use automated cues as a heuristic replacement for vigilant information seeking and processing" (p.205). The decision reached by the automated aid before decision making may lead the operator to rely on the automation in a heuristic manner. Even though, this strategy is generally appropriate, sometimes this reliance may be inappropriate and causes misuse.

Dzindolet et al. (1999) conducted a study with students about the reliability of the aid was manipulated in a Visual Detection Task. Students are asked to mark the slides that a soldier is camouflaged in a terrain over two hundred slides. A group of subjects were informed that a computer program would help them in detecting targets and computer gave its result before the decision making of the participants. For the other groups of participants, automation bias is eliminated and computer gave the results only after the participant chose her/his own decision. In conclusion, it is emerged from the survey that when the automated aid's decisions is given first, that make automation bias to occur, participants tended to misuse rather than disuse their automated aids, however when automation bias is eliminated participants accept their own decisions, and they tended to disuse rather than misuse. In this survey Dzindolet et al. found that, automation reliability did not affect the automation bias.

4.3.1.2 Social Processes – Trust is Automation

Most of the researchers propose that trust is the one of the major variables that affects the automation use (Parasuraman & Riley, 1997; Lee & Moray, 1992; Lee & See, 2004). “Trust can be defined as the attitude that an agent will help achieve an individual's goal in a situation characterized by uncertainty and vulnerability" (Lee & See, 2004, p.51).

Pilot may show different reaction across the automation. The role of trust is mediating between human and automated systems. Pilots need to trust automation in some degree in order to use the automation. However, for a healthy interaction between automation and pilot, it should be neither too much nor too less.

If over-reliance on automation is occurred then the pilot gives up the tracking the automation that prevent the recognition of system malfunctions (Parasuraman and Riley, 1997). "When it works well, it usually works very well indeed – so well in fact that we sometimes that it more than we should. Yet on the rare occasions when it does fail, those failures may often be more catastrophic, less forgiving, or at least more frustrating than would have been the corresponding failures of a human in the same circumstance" (Wickens, Gordon, Liu. 1998, p.493). Pilots tend not to use cues available from the displays or controls when they trusted the automated system too much as Eastern Flight 401 case which was mentioned before.

If the human operator does not trust the automation, he/she will not use it. As mentioned before, during World War II, improved radar systems are thought to be a great advantage towards the enemies by United States. However, radar misidentified Spaniel fish vessels and large whales as enemy submarines. Increased misidentification caused human operator's trust to automated system's alerts and to ignore critical signals (Parasuraman, 1987).

As Lee and Moray (1994) said that the main goal is to achieve calibrated trust that means ensuring correspondence between human operators' trust to the automation and the automation capability. Good calibration of the automation relative to the trust is represented by the diagonal line in the Figure 4.11 that means above this line is overtrust and below is distrust (Lee and See, 2004).

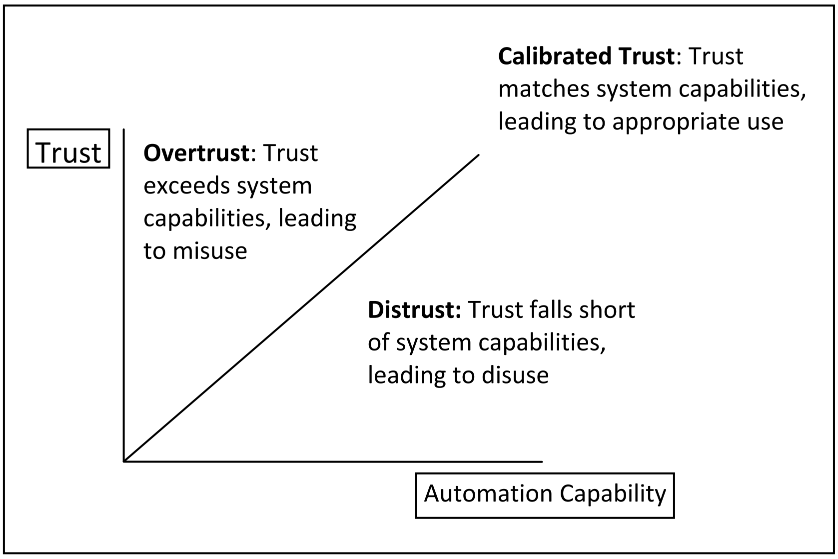

Figure 4.11: Automation Capability (trustworthiness) (Source: Lee and See, 2004)

Dzindolet et al. (2001, p.8) claim that trust is “outcome of a comparison process between the perceived reliability of the automated aid (trust in aid) and the perceived reliability of manual control (trust in self)”. However, some errors may be occurred in comparison which causes misuse or disuse problems. One of these errors is that humans tend to over-estimate their own performance, and the other is if information is given to the human operators about the reliability of the automated aids then the automation bias gets high.

4.3.1.3 Motivational Processes

Referring to Moiser and Skitka (1996), Dzindolet et al. (2004) determined the third variable of the automation use as the motivational processes of the human operator. Humans tend to feel less responsible when working with automated systems so they may not be motivated to effort much as regards when working alone. This phenomenon is called in social psychology by Latane et al (1979) “social loafing” or “free riding”. According to the Shepperd’s Expectancy Value Theory (1993, 1998) there are three factors that trigger the motivation; expectancy, instrumentality and outcome value (Kerr & Bruun, 1983).

Expectancy is the feeling of the human being necessary for the group in this case the human-computer team. If the human operator feels he/she is dispensable for the system, then the bias onto the automated aid will be high. However, in some instances this tendency may cause automation misuses.

Instrumentality is another factor of motivational process. If the human operator believes that the overall outcome contributes positive values to the job, then he/she will be willing to being in cooperation with the automated system.

The value of the outcome may also affect the motivation of the human. “Outcome value is the difference between the importance of the outcome and the costs associated with working hard” (Dzindolet et al., 2004, p.14). Number of tasks, interest in task, fatigue and cognitive overhead are the four contributor of cost. If the number of the tasks so the workload is increased, then the cost of performing that task increases. Boring tasks’ cost is higher than the interesting tasks’, so the boring the task is higher the cost. Fatigue is another cost of the outcome, if the operator feels fatigue then misuse may increase. Finally, if the cost of transferring from manual operation to automation or vice versa is high then the operator maintains the condition. This may cause complacency or misuses.

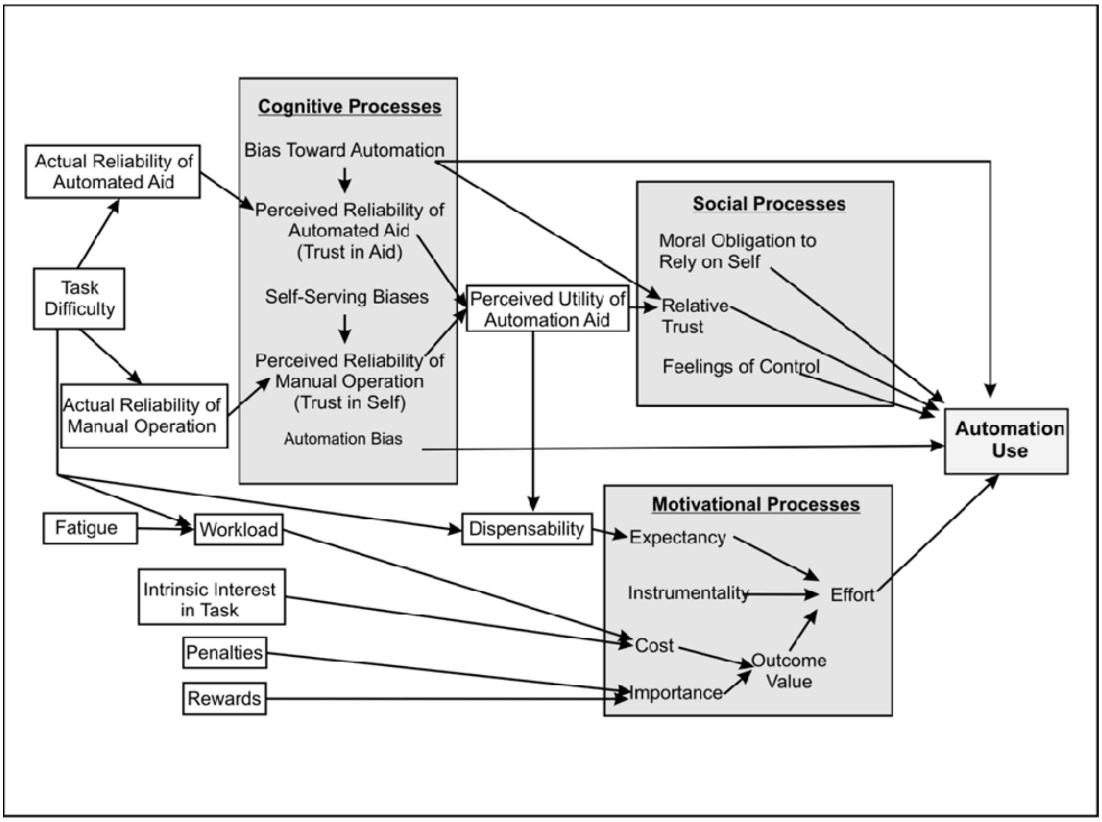

Figure 4.12: Framework of Automation Use (Dzindolet et al, 2001)

In conclusion, Dzindolet et al.'s (2001) framework of automation use indicates that the cognitive, motivational and social process of the human cause misuse, disuse and appropriate automation use which is illustrated in Figure 4.12. Designers should consider the interaction of these domains attentively to ensure the appropriate usage of automation.

4.3.2 Cognitive Conflicts in the Mental Model of Human and the Operation of Automation

Cognitive conflict between human mental model and the operation of automation are one of the consequences of the goal of removing human from the loop. Besnard and Baxter (2005, p.119) define the cognitive conflict as "an incompatibility between an operator’s mental model and the behavior of the process under control”. Therefore, in order to understand the mental conflict first how the human does understand the world / situations should be detected.

People produce schemas about the usage of a system with which they interact. Norman (1986) called these schemas “the system image”. Human perceives the real action of the automation as how it is coded in his/her system image and uses this image is processed and reaction is given according to this mental process outcome. The success of the human-computer interaction is provided by calibrating the mental model of the pilot with the working model of the glass cockpit. And this interaction gap often shows itself as a surprise on the operator (Besnard and Baxter, 2005). If this interaction cannot be performed properly, it is inevitable to face with accidents related with automation.

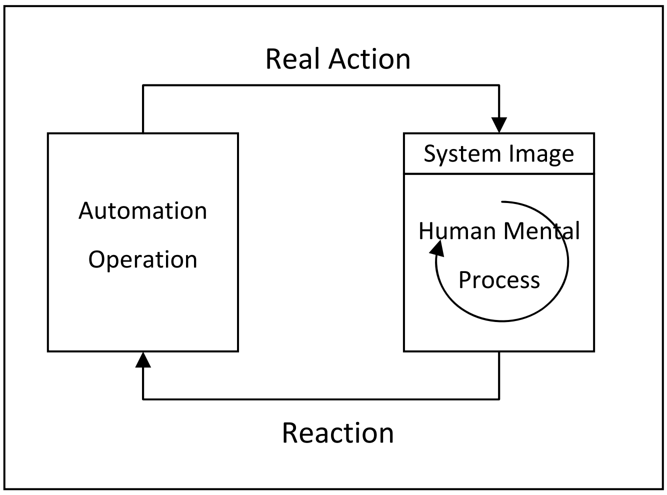

Figure 4.13: Human Mentality of Automation

Sarter and Woods (1997) declared that this mental model discrepancy can only be solved by better design, better displays and better training.

Besnard and Baxter (2005) claims that the conflicts between human mental model and the system's operation are because of some factors or a combination of them such as high-tempo-dynamic system, low predictability of machine's behavior, occurrence of an undetected error and erroneous continuation of an initial plan. The Cali accident which is accepted as a milestone in glass cockpit automation and examined by most of the human factors researchers (Endsley, 2001; Besnard & Baxter, 2005; Funk et al., 1999; Parasuraman et al., 1996; Phillips, 1999; Dzindolet et al., 2001; Wiener et al., 1999) illustrate the results of combination of all these factors. This accident shows that what a flight crew without a clear picture of the situation of the aircraft can cause.

> "In December 1995, a Boeing B757 flying at night from Miami (Florida) crashed into a 12,000ft mountain near Cali, Colombia, killing nearly all of the 163 people on board (Aeronautica Civil of the Republic of Colombia, 1996). This Controlled Flight into Terrain (CFIT) accident was attributed to the crew losing position awareness after they had decided to reprogram the flight management computer (FMC) to implement the direct approach suggested by air traffic control (ATC). ATC suggested that the aircraft could land directly on the southbound runway instead of flying around the airport. The approach for this landing starts 63 nautical miles from Cali and proceeds through a number of beacons. Because the crew knew they had missed the first one (TULUA), they reprogrammed the FMC and intended to enter another beacon (ROZO4) as the next waypoint to capture the extended runway centreline. However, when the crew entered the first two letters of the beacon name ("RO") in the FMC, ROMEO came first in the list and the crew erroneously accepted it. Unfortunately, ROMEO is located 132 miles east-northeast of Cali. It took the crew over a minute to notice that the aircraft was veering off to a wrong heading. Turning back to ROZO put the aircraft on a fatal course, and it crashed

into a mountain near Buga, 10 miles east of the descent track." (Besnard and Baxter, 2005)

Cali example shows how the pilots' expectations from the glass cockpit mismatch with the design of the interface.

4.3.3 Information Overload

Modern automated glass cockpits are capable of presenting vast amounts of data to the pilots. This information is presented to the pilots in text, numeric or graphic form via both MFDs and CDUs. Some of the information is displayed automatically when needed (e.g. CARP- Calculated Air Release Point or a message belong to a WPT-waypoint) or in an emergency situation (e.g. warnings), some of the information is needed pilot to access (information in the CDU pages). Glass cockpit technology is feasible to implement more and more information. Increasing of information load causes the system become more complex and sophisticated. As Woods et al. (1994, 2002) stressed that this situation is paradoxical although more and more data is available in principle; the ability of human operator to process this information has not been improved. Therefore information overload may create errors in the system that may cause human error.

Wiener (1993) concerns that if the complexity of the systems cannot be restrained, then the flight crews cannot perform their duties effectively and in an occurrence of failure they cannot take over the function. Because information overload may cause obscuring needed information among that too much information presented in the cockpit (Billings, 1991).

Woods et al. (2002) determined three characterization of information overload; (1) clutter problem, (2) workload bottleneck, (3) significance of data. The first way of characterizing data overload is that too much information is displayed to the human operators. Designers tend to present all the information available technically to the operators. This bog downs human as he/she has to know where to look or what to look for over all these information. If the cockpit environment is considered, there may be more than two hundred pages full of information. Ironically, although automation allows accessing any data, designers have to make a choice and eliminate some of the data in order to cope with the complexity. Secondly, workload bottleneck occurs in settings where access to the data has increased quickly. Human operator has to do too much work with time constraints. Finally, large amounts of data create obscurity in significance of information and may stress the operator's cognitive activity of focusing on the relevant data for a particular situation. Woods et al. (2002) indicate that when human face with explosion in available data, he/she feels like a baby seeing the world as a "great blooming".

4.3.4 Workload Dilemma

The word "workload" generally refers to the mental processes (cognitive and affective) of the human operator rather than the physical workload in aviation. Workload is defined by Hart and Staveland (1988) as "the perceived relationship between the amount of mental processing capability or resources and the amount required by the task". Huey and Wickens (1993) determined 4 factors that influence the workload; (1) Imposed task demands – if the task's difficulty, number, rate or complexity required from the human operator increases then the workload is expected to increase –, (2) The level of operator's ability – if the errors of the human operator increases then the workload is assumed to increase –, (3) The mental and physical effort the operator exerts – workload reflects the operator's response to a task rather than task demand directly –, (4) Operator's perceptions – operator's workload can also be affected by the feeling of being effortful and over-loaded even though his/her performance has not changed –. In addition to these factors; fatigue, stress, training, knowledge, crew coordination, environmental factors should also be considered while mentioning about the workload.

One of the promises of the cockpit automation is to reduce workload, by helping the pilot in his intractable missions. However, this expectation has not been achieved completely as some researches show that workload has not been decreased in practice, instead it affect pilot workload adversely. Wiener (1989) pointed that although automated systems support pilots in routine flight phases which require low workload, they increase the workload in time-critical phases when help is needed most. This phenomenon is coined by Wiener as "clumsy automation." According to his researches, introduction of glass cockpit has a little effect on overall pilot workload and he believes that automation tends to redistribute instead of reducing pilot workload. The major source of this increment in workload is because of the requirement to reprogram FMS when the conditions changed (e.g., changing the route, changing the mission, etc.). Therefore pilots feel that the overall workload has not been decreased.

In addition to Wiener, Kirlik (1993) also claims that automation which has difficulties in initiating and engaging, increases the operator workload, or produce an unbalanced pattern of workload. In this point, it should be underlined that excessive workload (too much or too little) levels may cause faults in the interaction. Pilots need a proper workload to maintain their attention on a particular task. If the workload is too little then the pilot may get bored and lose vigilance, and if the workload is too much then pilot may lose his/her motivation. Therefore, system design should have some challenge. Some human factors researchers believe that workload and performance have a complex relationship that means human performance is coherent under moderate workload that does not change suddenly or unpredictably (Kantowitz and Casper, 1988). According to the Yerkes-Dodson law, some arousal helps the increment in the performance up to a point, but when the optimal point is exceeded then the performance decreases (Figure 4.14).

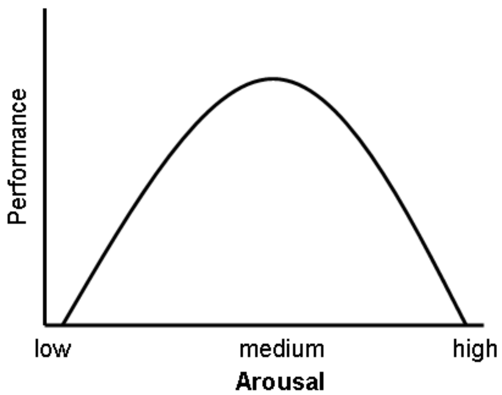

Figure 4.14: Yerkes-Dodson Law

The majority of the workload is imposed on the pilot who interacts with automation. Pilot-non-flying has to do more work in comparison with the pilot-flying, as he/she has to set up the automation. The feedback that the automated systems need is provided by this pilot such as changing the route or selecting an approach type. Therefore this may cause a “programming nightmare” on the pilot-non-flying (Sarter, Woods and Billings 1997).

According to a phenomenon called “cognitive tunneling” (Wickens, 1992) if the workload is very high, then the pilot tends to focus on only some particular cues and ignore the other information sources. Thus, pilots may fail to recognize other errors of automated systems and so may be late to take over the control. Billings (1997) gave as an example of this phenomenon the Eastern Flight 401 –this accident is given in this study in the title “New Roles of Pilot”– accident that the pilots cannot recognize the decent into the terrain while focused on a “burned lamp”.

4.3.5 Situation Awareness (SA)

One primary concern for the interaction of human and automated system is situation awareness. Situation Awareness concept was first born with the military ergonomics studies and air accident investigation in the mid-1970s, in order to clarify the variables that affect the cognitive performance of human. The concept is first generated in military surveys and barely a decade later concept is searched by the civil literature (Derek J. Smith Website, 2010).

Situation Awareness is described by Endsley (1988) “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (pp.36). It can be defined as knowing what is going on in an existing environment intuitively.

Situation awareness consists of three levels; Level-1: Perception, Level-2: Comprehension and Level-3: Projection (Wickens, 2008). The first level *Perception* refers to perceiving critical factors in the environment (Level 1 SA), second level *Comprehension* refers to analyze those factors in accordance to the operator’s goals (Level 2 SA) and finally the third level means understanding what will happen in near future (Level 3 SA). These levels of situation awareness allow the human operator to take action in a timely and effective manner even in very complicated and challenging tasks (Endsley, 2001). Wickens (2008) indicates that each of these levels point to different perceptual/cognitive operations and have different consequences in design. “For example whereas Level-1 SA lead to design better alerts, Level-3 SA may lead to incorporation of predictive displays.”(Wickens, 2008)

Pilot needs to have good situation awareness about the aircrafts state, potential threats, what automation is doing and what it is going to do to direct a flight mission well. However, sometimes they may not create a good mental model about what the automation is doing, as he/she delivered the control to the automation. Wiener (1989) says pilots in the glass cockpits often ask these questions: What is it (the auto-flight system) doing? Why did it do that? What is it going to do next?

When human has to make critical decisions in the operation of complex systems like aviation – generally in time constraints – most of the errors are occurred because of the lack of situation awareness (Endsley, 2001). As the aviation is fragile, sometimes results may be very catastrophic with many lives lost.

Furthermore, Woods and Sarter pointed to the “mode confusion” of autopilot which means that pilots cannot understand how the modes functioning and changing. Pilot may an insufficient awareness of how the selected autopilot mode functioning. Mode confusion problem may also occur when autopilot changes its mode from one to another. Pilots may not understand which mode the auto-flight system performing in some cases. Aircraft will behave different in each of the modes and if the pilot needs to get the authority, there is not much clue which mode the autopilot is.

> “In 1985, a China Airlines 747 suffered a slow loss of power from its outer right engine. This would have caused the plane to yaw to the right, but the autopilot compensated, until it finally reached the limit of its compensatory abilities and could no longer keep the plane stable. At that point, the crew did not have enough time to determine the cause of the problem and to take action: the plane rolled and went into a vertical dive of 31500 feet before it could be recovered. The aircraft was severely damaged and recovery was much in doubt.” (NTSB 1986; Norman, 1990)

In advanced glass cockpits, as pilot's monitoring ability the automation is via his/her expectations from the automated system, this may cause the pilot to canalize his/her attention on a particular situation. And there is a potential risk that he/she may miss an indication from the automation (Sarter and Woods, 1997). This may create "Automation Surprise" when he/she finally detects the result of this discrepancy between expected and actual (Sarter, 1994).

> "On 24 April 1994 an Airbus 300-600 crashed while on approach to Nagoya, Japan. During the approach, the copilot inadvertently engaged the aircraft's "Go around mode" which caused the automated systems to attempt to fly away from the ground using the aircraft pitch trim system, while the pilots attempted to continue the landing approach via input to the elevator. The pilots were unable to determine that the pitch trim input of the autopilot system was causing difficulties controlling the aircraft. Additionally, the design of the A300 autopilot (at that time) did not allow the pilots to override the autopilot by use of opposing control stick pressure. Thus, the pilots and automated systems continued to struggle for control, with the aircraft eventually pitching up to near vertical, stalling and crashing on the approach end of the runway killing 264 passengers and crew." (Sekigawa and Mecham, 1996, p.36)

This accident is an example of the phenomena that is called "Automation Surprise"; human is surprised by an unanticipated system behavior.

The "Out of loop syndrome" phenomenon is mentioned before has also effects on the situation awareness. Endsley (1999) urges that since automation takes the human "out of the loop", it is a potential risk for situation awareness to be decreased by function allocation. He also says that humans tend to be less aware when the control is under another agent.

On the other hand some researchers propose that the automation increases the situation awareness by providing assistance to the pilot. Curry and Ephrath (1977) stated that pilots who work with an automated system are better on monitoring than the pilots working with manual systems. They attributed this improvement to the monitors that helps the pilots in detecting system failures. Pilots were able to allocate their attention in automated system whereas; they needed to devote their attention on the manual systems that has a narrower range of cues (Endsley & Kiris, 1995).

Of course a proper design should increase the situation awareness with its highly safe systems. For example some designs display to pilot the route of the aircraft, current position, previous and next waypoints of the aircraft, by the help of the GPWS, radar, TAWS and TCAS systems displays and warns the pilot against the weather threats, terrain threats or intruders around the aircraft.

To sum up, an appropriate design is required to increase the situation awareness. Referring to Wiener (1992), Endsley and Kiris (1995) declared that situation awareness of the pilot may be increased with automated systems by providing superior, integrated information to the pilots.

4.3.6 Insufficient Feedback

Designers tend to automate everything that is feasible and remove the human operator out of the loop. Most of the human factors issues are emerged from this design approach that cause inadequate feedback of automation's actions and intentions (Norman, 1990).

As Norman (1990) says, automation isolates the pilot mentally from the operations of the aircraft with inadequate feedback of the moment-to-moment activities of the aircraft. Appropriate feedback prevents the cognitive conflicts between the human operator and the automated system, and many situation awareness problems so the human errors.

If the automatic pilot had informed the crew in the China Airlines 747 accident (which is mentioned in the title Situation Awareness) that it was recovering the balance because of a problem, so this would make pilots warned. When people work with automated systems, feedback is crucial for the effectual monitoring the activities of aircraft that may help to detect the errors. Feedback is also essential, to make human-in-the-loop by updating the mental model of the pilot and provide him to take control easily when needed. Autopilots work by physically, so pilot has the subtle information from the physical movement of the control wheels. In this case, feedback was available; however it was insufficient to attend pilot's attention properly.

On the other hand, excessive rate of feedback may cause representing too much information that can cause detracting attention which is explained in the previous issue. Norman (1990) indicates that automation gives feedback but it will not give information about what it is actually doing. Therefore it leaves the pilot uninformed again and lumbers the pilot in obscurity.

Low observability is another problem of the automation. Woods et al. (1994) point to that problem is not based on only the inadequate feedback; it is actually the required effort of the pilot's to monitor and process the information.

As automation does not function correctly all the times, pilots need to be taking over the control. In order to interfere successfully to unexpected or erroneous system behavior of the automation, pilot must determine the source of the problem quickly. This may be achieved only by appropriate feedback.

4.3.7 Pilot Skill Loss

Skill is not only the combination of operators' knowledge and performance it is also a fundamental aspect of human cognition (Norman, 1980). Wickens (1992) pointed out higher degrees of automation limits the pilot activities by doing most of the operations without pilots' participation. This changed the human role from active participant to passive observer as described in the Chapter 3 "Human Role in Automation". Therefore, this change in human operator's role also causes the degradation in manual skills when automation is used for a long time. Pilots' abilities may be rasped. Likewise, in the course of time, improving manual skills with time may not be enabled experienced as in traditional cockpits. Just like Norman (1993) concerns "technology can make us smart and technology can make us dumb".

The major difference between an expert and non-expert is the time. An expert has lots of time to do and an experienced pilot flies ahead of the plane whereas non-experienced pilot barely able to cope with (Norman 1980). An expert performs the minimum steps required for a certain mission while a non-expert follows indirect methods and performs more steps than required to complete the same mission. To become an expert, a non-expert needs time and practice. Unfortunately, as Bainbridge (1983) indicated physical skills degrade in course of time when they are not used.

4.3.8 Glass Cockpit Design Concept

Another alteration derived from the automation is the new environment in the cockpit. There are many advantages of glass cockpit design about usability. New design allows to display colored graphics, to present only the information needed for a specific operation, to enlarge text sizes so increase the readability and to make color coding whereas; the traditional cockpits has cluttered design as all the information has to be displayed all the time, fairly small text sizes and very little if any use of color or graphics (Figure 4.15).

Figure 4.15: Change in Cockpit Design

During a flight mission, pilot uses different combinations of data. Although, it is enough to display only the data in use an electromechanical instrument has to be in view all the time which makes the cockpit very crowded. Glass Cockpit allows an unnecessary value to be disappeared temporally. Before, each data had to be displayed during the flight mission continually, with the advanced technology it is now enough to display a data when it exceeds a particular value or when it is needed. For example there is no need to display the instruments of IFR (Instrument Flight Rules) during a VFR (Visual Flight Rules) flight. This simplification of flight deck, allows pilot to focus on the most needed information during a specific mission.

The new cockpit design allows pilots to reconfigure the displays according to their needs. This flexibility of displays serves several possibilities in the information presentation. Pilots can select the information which should be displayed in a display. They can both display primary flight controls that are displayed in the PFD page and navigational information in the ND pages at the same time.

However, new cockpit philosophy may cause some problems at the same time. Glass cockpit needs feedback from the pilot via the CDU. Again the pilot needs to know the exact place where the information is implemented in the architecture of the CDU pages (it should beneficial to be remembered that CDU may have more than 200 pages).

One of the goals of Human Factors is to provide designing appropriate controls and displays and workplace layout for a good interaction between the pilot and the automated systems. However, although the contributions toward preventing the types of errors of past, typing errors termed as “knobs and dials” seem to be not completely vanished yet (Wiener, 1993). The following example of two-engine Nord 262 at Los Angeles can be given an example to “knobs and dials” problem.

> “Narrative: One engine was burning more fuel than the other. So we tried crossfeeding fuel to correct the imbalance. We were distracted with other duties and inadvertently crossfed too long, so we were not able to correct the fuel imbalance as much as desired before landing. The indicator light for crossfeed on this airplane is located in a position on the cockpit panel that is down low and difficult to see. I consider this a design defect. It should be placed at eye level to make it easier for pilots to monitor the crossfeed status. (ASRS No. 121913)” (Wiener, 1993, p.30)

In this example, pilots shut downed the wrong engine because of an indicator which is located in a position that pilots cannot see. In addition to this there are also keyboard problems in the cockpit. As Wiener (1989) concerns after long-period times of human factors researches and application, there are more than two or three keyboard types - so different layouts - in a glass cockpit that causes human error.

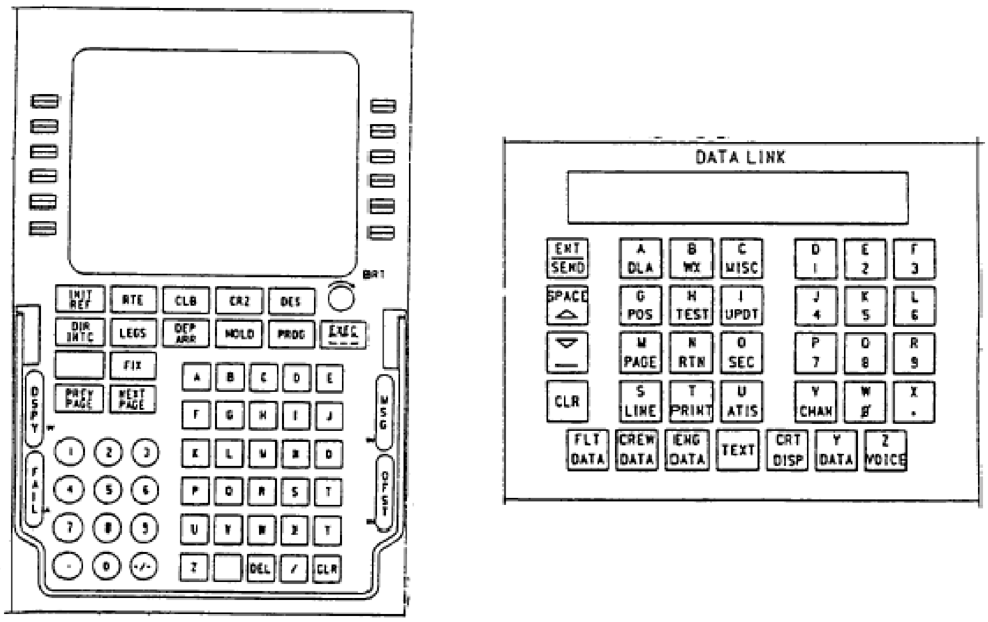

Figure 4.16: Two types of Keyboard in a glass cockpit

The un-standardization of design may cause serious problems in automated systems. Every system actually adapting to different interfaces is difficult for pilots and this may lead to number of errors as result of the pilots moving from one aircraft to another (Singer, 1999). Standardization of hardware is also desired to reduce training and maintenance costs (Wiener, 1989).

Wiener (1993) points out that the keyboards are highly vulnerable to finger error. These problems does not have to be seen when they are created, also they can lie dormant in the system for hours after they created until they become active. The following ASRS report is an example of faulty keyboard data entry.

> “Narrative: while preparing for departure, the captain loaded incorrect position coordinates in the IRS pos. Instead of a correct position of approximately N 50 deg 15 mins, E 00 deg 01 mins, he loaded N 50 deg 15 mins W 00 deg 01 mins…..The problem was discovered on initial departure when radar told us we weren't proceeding on the proper course. The problem was discovered quickly and no conflict occurred. We switched to manual nav. However, we couldn't continue our ocean crossing and diverted to Shannon, Ireland, where we made an overweight landing….. (ASRS No. 150785)” (Wiener, 1993, p.31)

In this situation pilots just could not perform their missions; however, such conditions may give rise to many serious problems.

Moreover, it is difficult for pilot to accomplish other tasks while pressing buttons or keys. The pilot has to take the risk to go with a division of attention. Remain head down while accomplishing most button keyboard inputs. Setting the automation of coordination where he wants to go rather than fly to that coordinates manually, looses the awareness of external environmental factors (Baron, 1988).

Further, some orientation problems also may occur with pilots transferring from traditional cockpit to glass cockpit. An example can be given for the disorientation of pilots between controls that they used to be and the new designed controls. In an aircraft modernization program that the author is included in, the heading scale knobs changed with push buttons. Before the modernization pilots used to knobs that turn 360 degree clockwise or counterclockwise and by the turn of the knob, heading bug turns to that side. They are used to this system so that when they are talking about setting a degree they turn their hand as turning a knob as a reflex. By the modernization instead of knob, push buttons are used; upper button is used to increase the degree by turning bug to the right, lower button is used to decrease the degree by turning bug to the left.

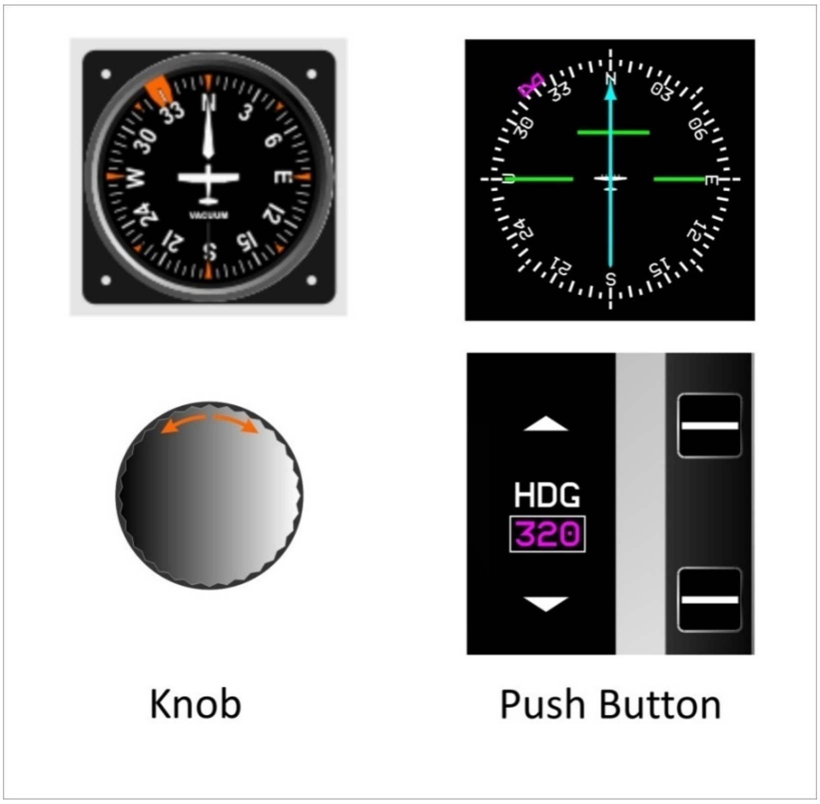

Figure 4.17: Button Design Problem

However, pilots concerned about the orientation of the increment-decrement keys and the direction of the heading bug. They wanted to change the graphical view of the keys arrows like the graphic of the knob. Designers intended to use the universal principle that the up key means the clockwise movement and down key means the counterclockwise movement as described[10] in the MIL-STD-1472F

[10] Clockwise movement of a rotary control, or forward, upward or rightward movement of a linear control shall produce a clockwise movement of circular scale pointers and an increase in the magnitude of the setting (MIL-STD-1472F, p.10).

Human Engineering Design Criteria Standard. Of course, this orientation problem is relevant for the pilots transferring from analog cockpit to glass cockpit; however it should be considered that in Turkey aircrafts established in 60’s are still in use in military operations and many pilots gets their first training with traditional cockpits.

4.3.9 Amount of Automation

With the rapid growth in microprocessor technology, some designers tend to design complex systems based on the rationale that systems can operate without human contribution (As it is discussed previously, this design goal cannot be actualized as the automated system needs human feedback and also needs human to substitute in case of malfunctions). If this complexity cannot be restrained then the pilots may have difficulties in performing their duties. On the other hand, some designers became aware of the sophistication of automated systems so simplification arises as an alternative to automation (Wiener, 1993). According to that approach simplification rather than complicated automation may also achieve the same goal.

Lee and See (2004) claim that an appropriate communication between pilots and glass cockpit depends on how well the operation capabilities of the automated system are expressed to the user and this can only be done by simplifying the automation or making its operations clear.

The potential difficulty of over-automation is that it degrades the situation awareness of the pilots with complicated systems and insufficient feedback. Increases boredom (Woods et al., 1995) so reduces the job satisfaction of the pilots and reduces monitoring (Parasuraman et al., 2000). Norman (1990) on the other hand, stresses that the problem in glass cockpit is not the over-automation, but the lack of feedback. He proposes that it is possible to reduce the problems of automation through appropriate design considerations such as giving feedback to operator and ensuring interaction with the operator in an effective manner whatever the automation level.

According to a survey of Tenney et al. (1995) pilots flying with A-320, MD-11 and B747-400 did not complained about the over-automation problem even they claimed that welcome more automation. However instead of a fully autonomous level of automation, they indicated that they would be more comfortable with a shared pilot automation performance level.

In addition, Sarter, Woods & Billings (1997) also claim that the unexpected consequences of the automation is not the result of over-automation or human error, the responsible agent is the design which allows for interaction problems between human and the automated system. Billings (1997) supports this argument and he says that the development in the automation of aircraft cockpits may have gone too far too quickly, without understanding its possible effects on pilots.

These two sides of approaches are also found supporter in the aircraft manufacture. Wiener (1993) compares the two aircraft manufacturer; The Douglas and the Boeing. He declares that whereas the design philosophy of Douglas is to remove the pilot from the loop (automation takes the decisions automatically and does not ask the pilot's approval), Boeing's approach is not to bypass the pilot (automation informs the pilot and gives the eventual decision to the pilots).

4.3.10 Change in Human Error

Change in human error is the consequences of all other factors that have just been explained in this chapter. This is the major ironies (Bainbridge, 1983) of the automation of the systems.

Although the major aim in the glass cockpit is to eliminate the human from the loop, human is still in the system from designing to operating the automated system. "According to international civil aviation authorities, because of refinements over the years the number of accidents caused by the machine has declined, while the number caused by humans has risen proportionately" (Sheridan, 1992, p.241).

Systems like GPWS, TCAS and TAWS are used improve the situation awareness of the pilot and eliminate the human error, however they "do not prevent the original error; but they do prevent it from maturing into an accident or incident" (Wiener, 1993, p.3). Automation is hoped to remove human error by replacing the human who makes errors inevitably with inerrable machines where Wiener (1993, p.4) indicated that "… this may be overly optimistic, and that automation merely changes the nature of error, and possibly increases the severity of its consequences". Briefly, automation may create more serious problems while eliminating small errors seen in traditional cockpits (Wiener, 1993).

Designer anticipates an interface design according to his/her mental model. Barriers are created to obstruct the faults on the extent of the interface designer's anticipations. However it is impossible to estimate all the situations in a system in which human is in the loop. In addition to that, designers have implemented more information onto displays and more options into flight management systems by the help of the automation. This hamper the pilots to master the whole system so with lack of knowledge pilots may make mistakes (Wiener et al., 1999).

Besides, new system creates new human errors. As automation interactively works with the pilots, it needs the pilot to give input to the flight management system. Depending on these inputs, FMS makes calculations and performs its mission. Thus, this system is open to human errors. In order to prevent this types of errors, system designers creates some barriers, however this design barriers are also depended to the prescience of another human; “the designer”.

Sometimes automation’s excellence does not fully solve the problem of human error. As mentioned in the social processes of the human, if the pilot trusts the automation – that works perfectly – more than required, he/she may leave tracking the automation, so leave the system undefended to failures.

On the other hand, in a simulation study Wiener et al. (1991) compared the performance of crews who flied with two types of aircraft in the same family – one of the aircrafts; DC-9, has a traditional cockpit and the other one; MD-88, has a glass cockpit – in a LOFT (Line Oriented Flight Training) session. They recognized that there were no statistically considerable differences in the severity of errors performed by the pilots of both aircrafts.

4.4 HUMAN – CENTERED AUTOMATION

The unanticipated problems of automation are associated with technology-centered automation by some human factors researchers. Designers tend to apply automation where it is feasible. Norman (1993) said that “people propose, science studies, technology conforms” to call attention to technology centered automation design. Thus human suffers from interaction problems at this cycle.

While technology centered automation focus on implementing technology if it is feasible, a new approach is considered while applying named “Human Centered Automation” by a noted human factors specialist Charles E. Billings. According to Billings (1991) the automation should be designed to support the communication between human operator and automation by considering the human’s properties, limitations and expectations instead of just applying the feasible technology. This means that, the technology-centered approach tends to automate tasks as fully as technically feasible, *Human-centered* approach tends to automate an extent that balances efficiency with safety and ensure a proper role for the human in the working system. Ideally, in a Human-centered approach, designers should take into account the impact of the role allocated to the human operator of the system by introducing new technology. Designer should accept human operator and the automated system as a whole.

Sarter, Woods & Billings (1997) underlined that human-centered automation is not against the technology, the main concern of design philosophy is to use high technology for operational requirements and operator’s needs.

Billings (1991) suggested a number of extensive principles for Human-Centered automation as:

- The human operator must be in command.
- The operator must be involved.
- Human operator must be adequately informed.
- Automated systems must be predictable.
- Automated systems should monitor the human.
- System agents should have intentional knowledge of other agents

•Training, learning and operation of automation should be simple
•Only automate functionalities if there is a need.

Although Human-centered approach is accepted and emphasized its importance by designers, human factors researchers and authorities, there are still problems in the implementation of philosophy to design. This gap between human-centered intentions and application shows that there is a misunderstanding about concept or inability in implementation (Sarter, Woods & Billings, 1997). Sarter et al. claim that the probable reason is the difference in mentality of the developer who creates the design and the user who operates it. According to the developers' eye view design is apparent simplicity that the design is created to support the human performance with its benefits. On the other hand, the practitioners' eye view design is in fact complexity. They may face with the complicated factors that can emerge from the real operation of the system.

CHAPTER 5

FIELD STUDY

In order to gather information about how pilots react to the problems that is argued in literature intensely, a questionnaire is prepared. The questionnaire is sent to pilots via the internet survey site: QuestionPro (http://www.questionpro.com/). Volunteers were requested to return the survey within two weeks however because of inadequate participation this duration has been extended to four weeks.

Participants are selected randomly. The identity of participants is guaranteed to be concealed as the responses would come from the mediator survey site. An explanation of intent of the survey was done to the participants before they started filling the questionnaire. Questionnaire is prepared in Turkish in order to being understood easily, however some of the terminology is also written in English as it has not an equivalent Turkish word in common parlance such as MFD, CDU or button pusher.

Pilots are actively flying with commercial planes like Airbus 320-321, Airbus 330-340, Boeing 737 and Boeing 777 were recruited for this survey. A total of 39 pilots (17 of them are A320 aircraft pilots, 4 of them are A330 aircraft pilots, 8 of them are B737 aircraft pilots, 5 of them are B777 aircraft pilots) completed the survey. The remaining pilots are not classified as they fly with Cessna that does not contain glass cockpit. The sample includes no female. Distribution of the pilots and aircraft types is shown in Table 5.1.

Table 5.1: Number of Pilots attended the Survey

Aircraft Type	**Number of Pilots**
A320	17
A330	4
B737	8
B777	5
Cessna(C402B)	5

The mean age of pilots is 34.6 with a range of 26 to 47. Subjects averaged 6.01 years of commercial flying experience and 10 numbers of pilots had a military experience (Table 5.2).

Table 5.2: Biographical Data for Pilots

	Average
Age	36.4
Total years in commercial	6.01
Total years in military	11.3
Total Hours Flying	4110
Pilot in Command	2614

Questionnaire consisted of 3 parts is included in the Appendix;

First part consists of the demographic data of the pilots such as age and past flight experiences. There are 7 questions from question-1 to question-7. The aim of getting demographic information is to take a view about pilots' past experiences and how these experiences influence their attitudes.

In demographical data questions, pilots are asked to answer the aircraft type that they fly as each aircraft types has a different interface design, different environmental design and different automation design philosophy. By asking flight hours of pilots, it is expected to analyze if responses to the questions differ according to experience or not. Further, military service is another question which is asked to learn if military experience makes difference in response as pilots may get a different training in the military.

Second part contains a Likert-type attitude scale which deals with the attitudes of pilots on cockpit automation related issues. There are 43 questions from question-8 to 35-h.

Likert-Scale is used to measure the attitudes of participants on a particular statement. As the scale format is familiar to the population it is easy to design and apply. An odd number of response options varying from "strongly disagree" to "strongly agree" are offered to the participants for a statement and it is wanted respondents to choose their strength of agreement with each of the statement.

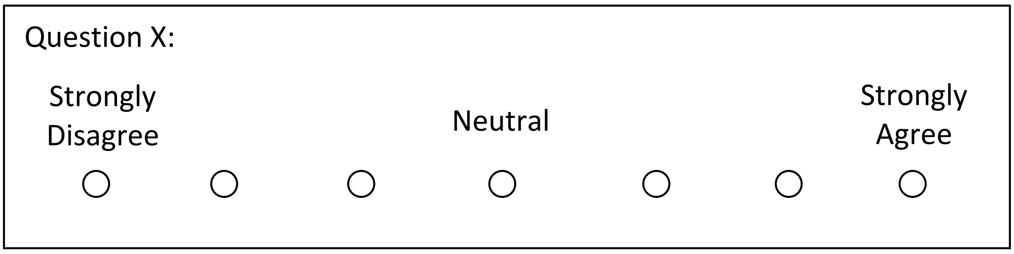

Figure 5.1: Likert-type Attitude Scale

The middle point of the attitude scale is ambiguous as it causes dilemma about the meaning. It may mean that pilot may be really neutral or undecided, not have an opinion or even not want to reply this question. Jacoby and Matell (1972) asserted that with the increase in the number of the steps in the attitude scale, the possibility of participants' selecting the mid-point category decreases. Furthermore, because pilots are expert users and they have high awareness about the survey topic, a Likert-type scale with 7 alternatives has been wanted pilots to answer. It is expected that this strategy would degrade the risk of selecting the Neutral option.

Questions showed in Table 5.3 are created from the problems of automation which are described in the chapter "Human Factors Issues of Automation". Pilots were asked about their opinions on the problems which were determined in each issue. Some of the questions were derived from the NASA Langley Research Center's Survey of Pilots of Advanced Automation Aircraft on Philosophy Issues related to Design and Use of Flight Deck Automation (Pew, Rogers and Tenney, 1995) by modifying according to the content of this survey.

The main factor of creating a good interaction between pilots and glass cockpit is the pilot to be accepting his/her new role. A common belief is that younger people are adapted to technology easily than elders. So Question 9 is asked to learn if younger pilots catch on to the glass cockpits faster than older pilots. Further an automated system makes most of the works

Trust is the key factor of automation use. Therefore, Question 26 and 27 are asked pilots to learn how much they trust their automation. And, Question 35-e and 35-h are asked, if they concern they will be reluctant to take over the control when needed as a consequence of overtrust.

Cognitive conflict is occurred when automation does something different than pilot's expectation. In Questions 10 and 11 pilots are asked to learn if there is conflict between their expectation and automation operation. Being reliable and predictable indicates that most of the factors affect conflict in cockpit. So Question 10 and 11 are asked to measure reliability of the automation.

Most of the automation overload problems are appeared because of warnings which may alert pilot continuously even necessary or not and unknown modes and features. So Question 12, 35-d and 13 are asked to learn pilots' attitudes on amount of information displayed in glass cockpits. Since amount of information affect simplicity of automation directly, Question 34-c is asked to pilots.

In order to explore human factors issue of workload as in literature there is a belief that workload is decreased in normal situations whereas increased in busy situations, participants are asked to rate physical and mental workload level respectively and total workload in Question 14, 15, 32 and 33.

Much of the workload contributions are based on managing the automation. So Question 8 is asked to learn if programming the FMS through CDU causes spending much time. Increasing workload is a success of automation if achieved on the other hand too low automation is also a risk as it may cause boredom. Therefore Question 34-f is asked to learn if pilots concern about such a problem.

In order to create awareness of aircraft's situation, pilots should know what automation is doing when autopilot/flight director is in control. So Question 16 and 34-d are conducted to pilots. Further, it is important that to what pilots are focused on when they are flying, because if they are focused on controlling automation rather than flight, they cannot figure out situation of automation and cannot detect system errors. Therefore, Question 31 and Question 35-b are asked to pilots.

Feedback is the main factor to figure out the situation awareness. Therefore in order to understand if the automation gives sufficient feedback, Question 18 and Question 34-e are conducted to pilots.

In literature there is a common belief that automation causes degradation in pilots' skills. In order to measure skill degradation, Question 21 and Question 20 are conducted to pilots. Besides, if skill is degraded, pilot cannot take over the control when needed, so Question 17 is asked.

Since much of the design problems are come in view because of the use of CDU, in the Design title Question 22, 23 and 35-g are asked to learn pilot attitudes on design problems. Further 34-c and 34-f are to gather information about the design concept of glass cockpits.

Amount of automation may cause some human factors issues so pilots are asked Question 28 and 29 to learn how pilots react to amount of automation in current glass cockpits.

One of the promises of automation is to decrease the human error in cockpit. Pilots are asked if automation could achieve this promise in Question 24 and if achieved how it would decrease human error in Question 34-h and Question 34-i. Further, Question 25 is conducted to pilots in order to analyze the statement that automation creates new human errors while decreases older ones.

Table 5.3: Survey Questions

Issue	Question
New Roles of Pilot	**Q9** Younger pilots catch on to the new systems (like the CDU) faster than older pilots.
	Q19 Sometimes I feel more like a "button pusher” than a pilot.
	Q30 When using automation; I feel: controlling the aircraft/ managing the automation
	Q35-a I am concerned that automation could lead to: **difficulty in learning to operate** Low concern/ High concern
	Q35-c I am concerned that automation could lead to: **need for new skills** Low concern/ High concern

Table 5.3 (Continued)

Issue	Question
Cognitive Conflicts in the Mental Model	**Q10** In the automation, there are still things happened that surprise me.
	Q11 Sometimes automation does something different than I expected.
	Q34-a **I think automation is;** **Dependable-Reliable-trustworthy** means that the automation does what it is supposed to do and never does what it is not supposed to do.
	Q34-b **I think automation is;** **Predictable** (means that the automation behaves as expected (i.e., it is clear what it is going to do).
Information Overload	**Q12** There are still modes and features of the automation that I don't understand.
	Q35-d I am concerned that the overall amount of information available on my aircraft is too much.
	Q13 Automation gives incessant warnings even it is necessary or not.
	Q34-c **I think automation is;** **Simple** (means that it is easy to understand and use (i.e., it is straightforward to learn and operate to do).

Table 5.3 (Continued)

Issue	Question
Workload Dilemma	**Q14** Automation frees me of much of the routine, mechanical parts of flying so I can concentrate on "managing" the flight.
	Q8 I spend more time setting up and managing the automation (CDU, FMS) than I would hand-flying or using a plain autopilot.
	Q15 Automation does not reduce total workload, since there is more to monitor now.
	Q32 According to classical cockpits, physical workload in automated aircrafts relative to that in conventional cockpits, is much lower / much higher
	Q33 According to classical cockpits, mental workload in automated aircrafts relative to that in conventional cockpits, is much lower / much higher
	Q35-f I am concerned that automation could lead to: **workload extremes (high and low)** Low concern/ High concern
Situation Awareness (SA)	**Q16** I always know what mode the autopilot/flight director is in.
	Q34-d **I think automation is;** **Comprehensible** (means that one can figure out what the automation is doing and what needs to be done to operate it).
	Q31 When using automation; My attention is focused on the flight/automation
	Q35-b I am concerned that automation could lead to: **difficulty in detecting system errors** Low concern/ High concern

Table 5.3 (Continued)

Issue	Question
Insufficient Feedback	**Q18** Automation does not give sufficient information about what it is doing.
	Q34-e **I think automation is;** **Informative** means that the automation imparts knowledge to the pilot (e.g., information about the airplane, automation, problems, operations, etc.).
Skill Loss	**Q21** I can fly the plane as smoothly by hand as with the automation.
	Q17 I am concerned that automation could lead to: **difficulty in recovering from an automation failure** Low concern/ High concern
	Q20 I am concerned that automation could lead to: **degradation of pilot skills** Low concern/ High concern
Glass Cockpit Design	**Q22** It is difficult to use the CDU and MFDs.
	Q23 It is difficult to find what I am looking in the pages of MFD or CDU.
	Q35-g I am concerned that automation could lead to: **data entry errors** Low concern/ High concern
	Q34-f **I think automation is;** **Adaptable** (means that displays, control devices, etc., are re-programmable within a wide range of pilot preferences and needs)
	Q34-g **I think automation is;** **Flexible** means that an appropriate range of modes and levels are available to the operator (e.g., from manual control to autonomous operation).

Table 5.3 (Continued)

Issue	Question
Human Error	**Q24** I make fewer errors in the automated aircraft than we did in the older models.
	Q25 Whereas automation reduces the errors that I did in the traditional cockpits, new human errors have been occurred in the glass cockpit.
	Q34-h **I think automation is;** **Error-resistant** means that the automation keeps pilots from committing errors (e.g., disallowing inputs when automation can detect entry is wrong).
	Q34-i **I think automation is;** **Error-tolerant** means that the automation can detect and reduce the effects of error, given that some errors will inevitably occur.
Automation Use	**Q26** I feel safer in glass cockpit / I think my glass cockpit aircraft is safer than analog ones.
	Q27 I know automation always works properly.
	Q35-e I am concerned that automation could lead to: **Complacency** Low concern/ High concern
	Q35-h I am concerned that automation could lead to: **reluctance of crew to take over from automatics** Low concern/ High concern
Amount of Automation	**Q28** As I look at aircraft today, I think they've gone too far with automation.
	Q29 I look forward to more automation - the more the better

Third part includes one open-ended question; that pilots can express their opinions and some other opinions which are not foreseen in the content of this thesis. This part will not be used for statistical data, will be accepted as further opinion from the pilots.

Main purpose of the open-ended questions is to gather detailed information from the pilots. This gathered data is subjective data that includes the experiences and opinions of the pilots with their own words. All the responses will not be given in the thesis, only the selected opinions and comments that are attractive, unusual or distinctive will be given.

5.1 Results

As noted previously, data collected via the internet survey has been discussed one by one for each of the problems. Responses from pilots who fly with Cessna that does not contain glass cockpit have been ignored in the statistical data offered.

5.1.1 New Roles for the of Pilot

Questions 9, 19, 30, 35(a) and 35(c) are asked to pilot to evaluate their attitudes on their new roles.

Table 5.4: New Roles Issue Response Statistics

Issue	Question #	Response #	Mean	Standard Deviation
NEW ROLES	9	34	6	1.128
	19	33	2.545	1.502
	30	34	4.941	1.632
	35-a	30	5.167	1.931
	35-c	30	5.567	1.547

According the results of the pilots' comments there seems no critical problem in usage related to new roles. Adaptation is claimed as high and the role of the pilots has been accepted by pilots by a majority.

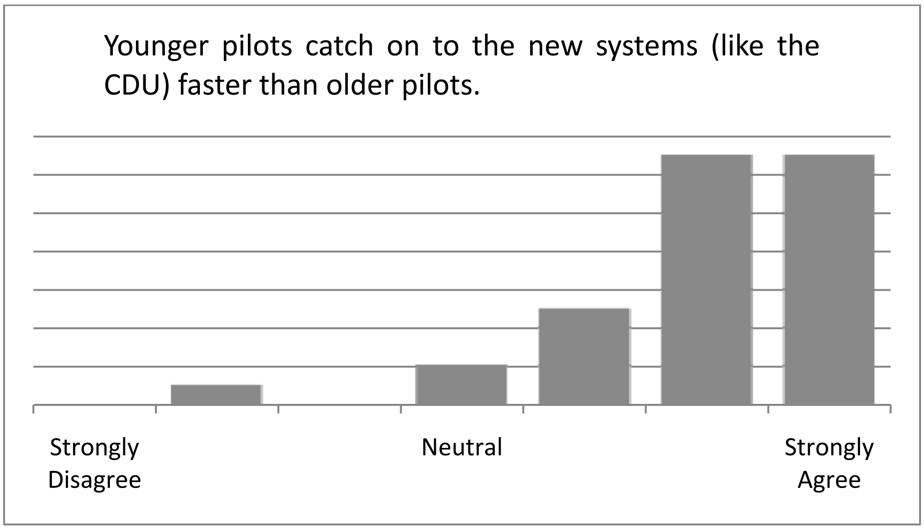

Figure 5.2: Question 9

In response to question 9, there is a common sense through the pilots that younger pilots can adapt to these new systems such as CDU and MFD easily rather than older ones. When responses are examined with respect to age, it is observed that younger pilots are really more moderate than elder pilots as seen in Table 5.5.

Table 5.5: Adaptation to New Roles

Age	Response Mean of New Roles Issue	Response Mean of Question-9	Response #
25-32	5,536	6,333	9
32-37	4,528	6,444	9
37-43	4,125	5,625	8
43-47	4,896	5,5	8

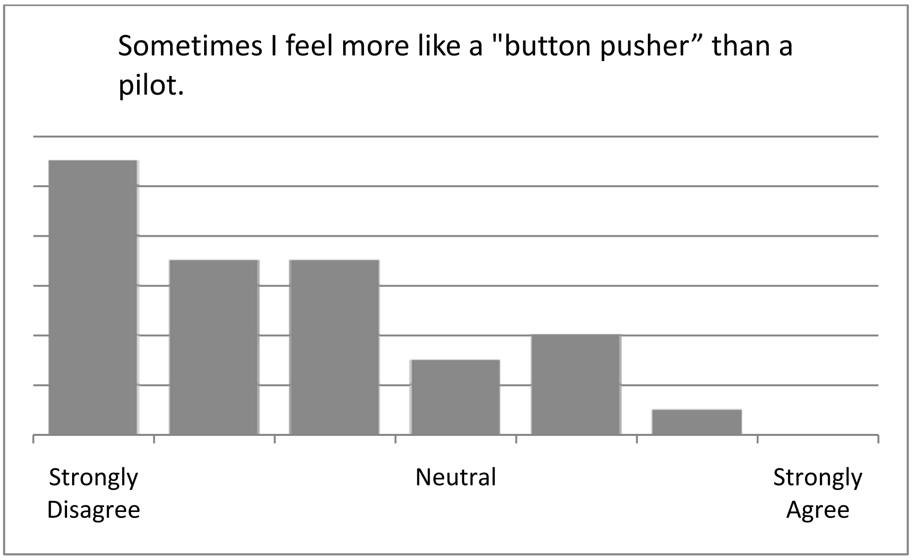

Figure 5.3: Question 19

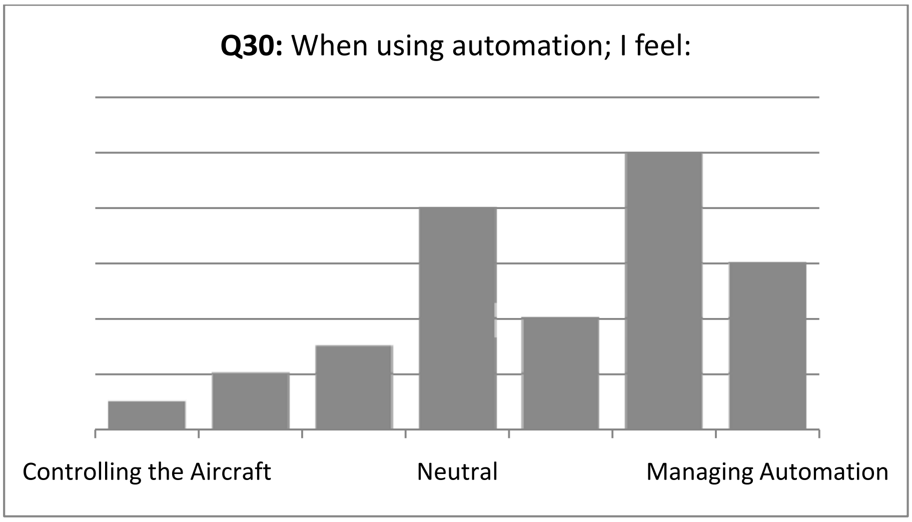

Figure 5.4: Question 30

Question 30 is asked to find out the understanding of pilots about their new role; "supervisor". Pilots are focused on managing the automation rather than flying (Figure 5.4). As a result they may have some troubles such as missing the evidence of what automation is doing and when needed difficulty in taking over the control. Nevertheless they do not report such a problem neither in Design Issue problems nor in Situation Awareness Issue.

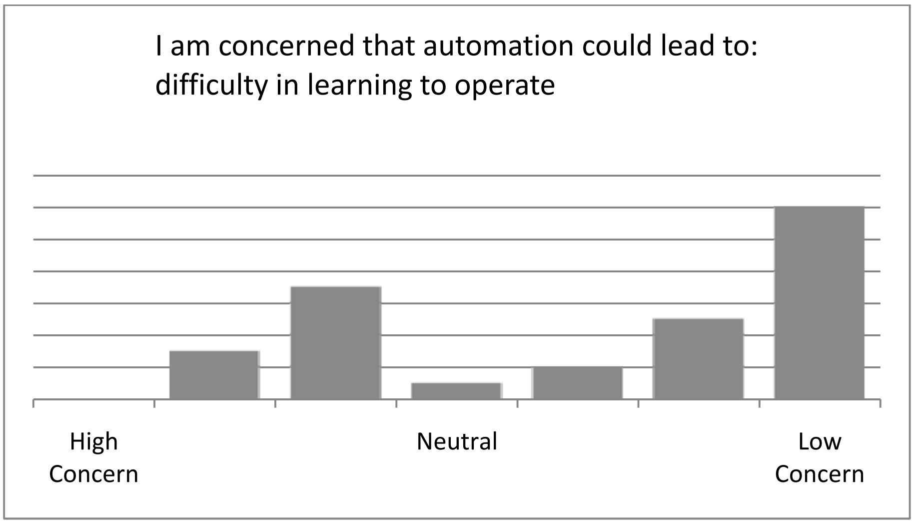

Figure 5.5: Question 35(a)

It is clear that pilots trust themselves in accordance to automation. Conflict is less and automation is claimed to be learned easily. Automated systems do not require extra abilities rather than traditional practice (Figure 5.6).

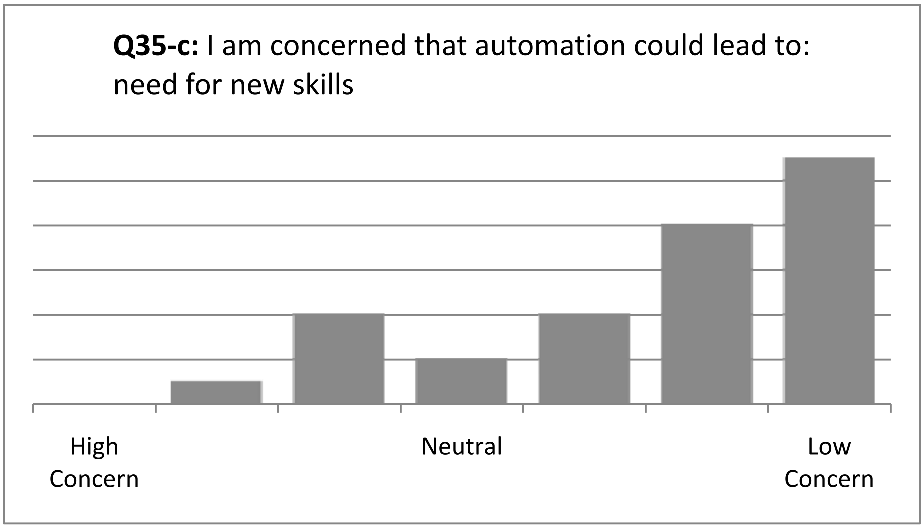

Figure 5.6: Question 35(c)

Pilots have a continuous communication with automation; moreover they are not slave of it. This communication does not pacify pilots on the contrary pilots still manage and command on it.

5.1.1 Automation Use/Misuse

While asking the Questions 26, 27, 35(e) and 35(h), it is intended to learn how the automation use habits of pilots.

Table 5.6: Automation Use Response Statistics

Issue	Question #	Response #	Mean	Standard Deviation
AUTOMATION USE	26	34	5.265	1.797
	27	34	5.647	1.368
	35-e	30	3.733	1.818
	35-h	30	3.533	2.063

It is a common belief in literature that the automated aircrafts are safer than the traditional ones. However some serious accidents may occur even so it is safer in the abstract. Although some of the pilots concerns about the safety, generally subjects agree that the glass cockpits are safer than analog ones. Nonetheless, while there are some concerns on safety of automation, the reliability of automation is highly accepted by pilots in Question 27.

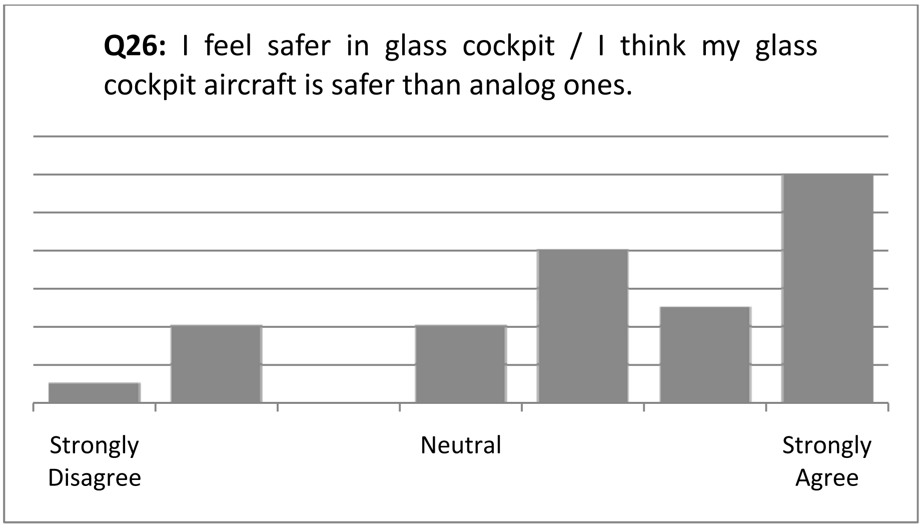

Figure 5.7: Question 26

Pilots trust that automation always works properly. This may cause misuses as they may give up monitoring and controlling the automated functions.

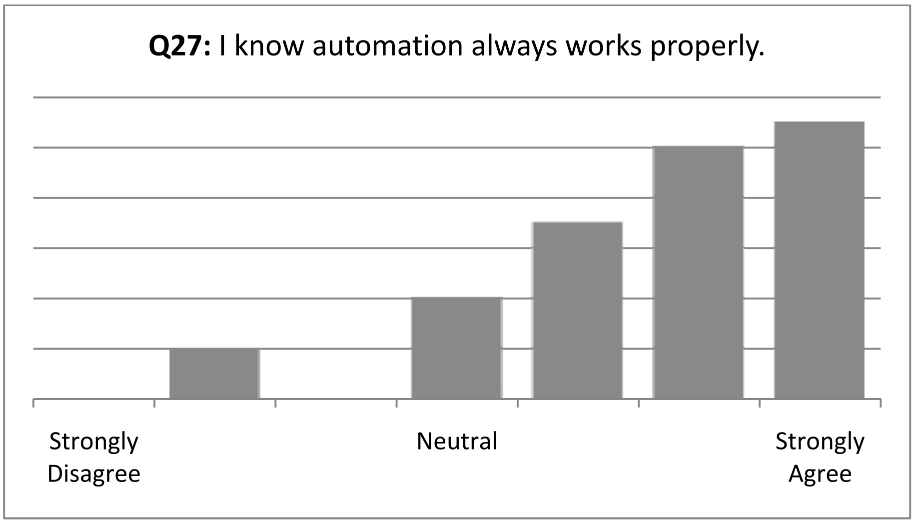

Figure 5.8: Question 27

Questions 35(e) and 35(h) shows that generally pilots concern about the automation may cause complacency so pilots may create reluctance of crew to take over from automatics. However they are still glad to use automation in their cockpits.

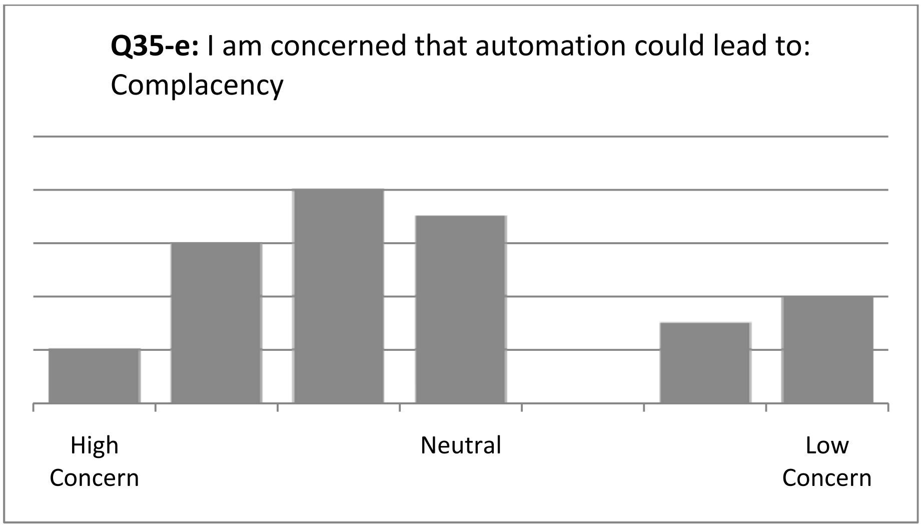

Figure 5.9: Question 35(e)

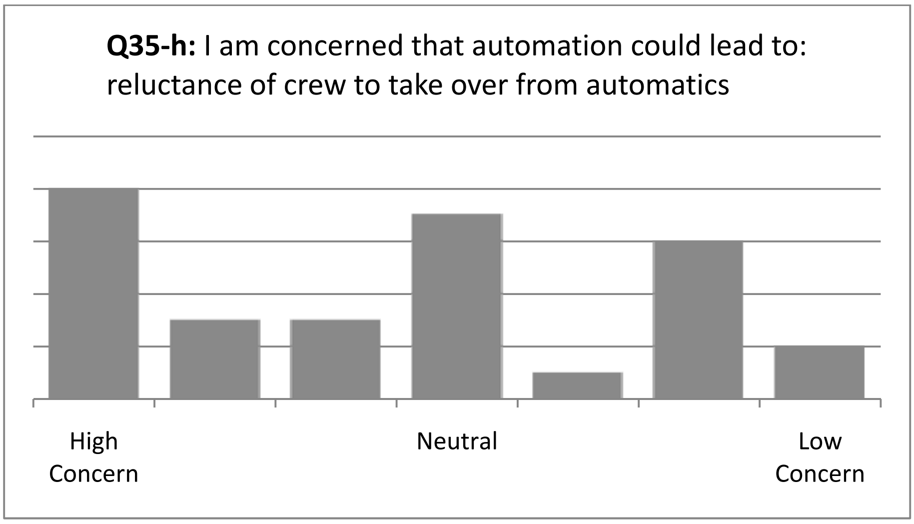

Figure 5.10: Question 35(h)

5.1.2 Cognitive Conflicts in the Mental Model of Human and the Operation of Automation

Questions 10, 11, 34(a) and 34(b) are asked to pilot to evaluate their attitudes on cognitive conflicts in the mental model of human and the operation of automation in cockpit.

Table 5.7: Cognitive Conflicts Issue Response Statistics

Issue	Question #	Response #	Mean	Standard Deviation
COGNITIVE CONFLICTS	10	34	3.824	1.8
	11	34	3.794	1.855
	34-a	31	6	1.183
	34-b	31	5.935	0.854

According to question 10, a group of pilots have commented that they have faced with surprises where others have not. At the first sight, it can be thought that it is caused due to differences in usage styles however subjects are line pilots and they are strictly dependent to regulations. Before a routine flight; route, amount of cargo and fuel are determined. Indeed some airlines may execute regulation that how much automation has to be used during the flight. If the question 34(a) and question 10 is considered together, automation does what it is supposed to do and never does what it is not supposed to do, yet it may cause surprises.

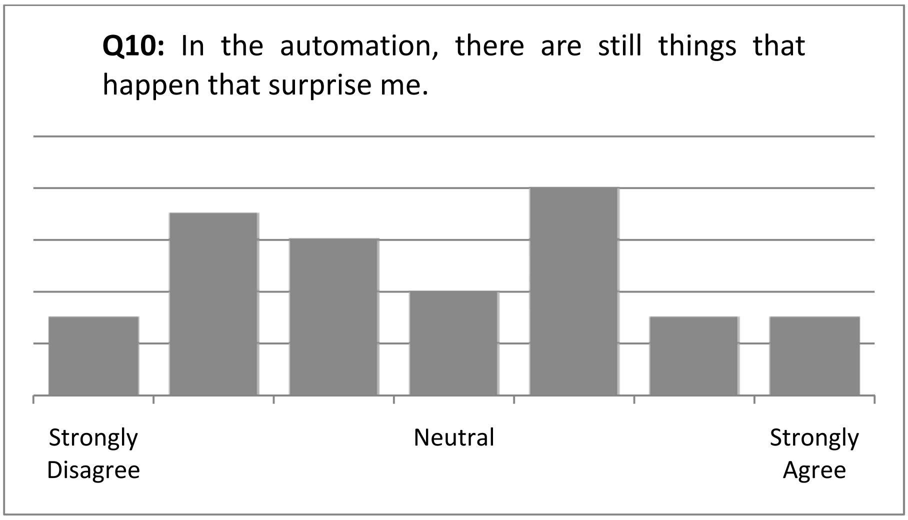

Figure 5.11: Question 10

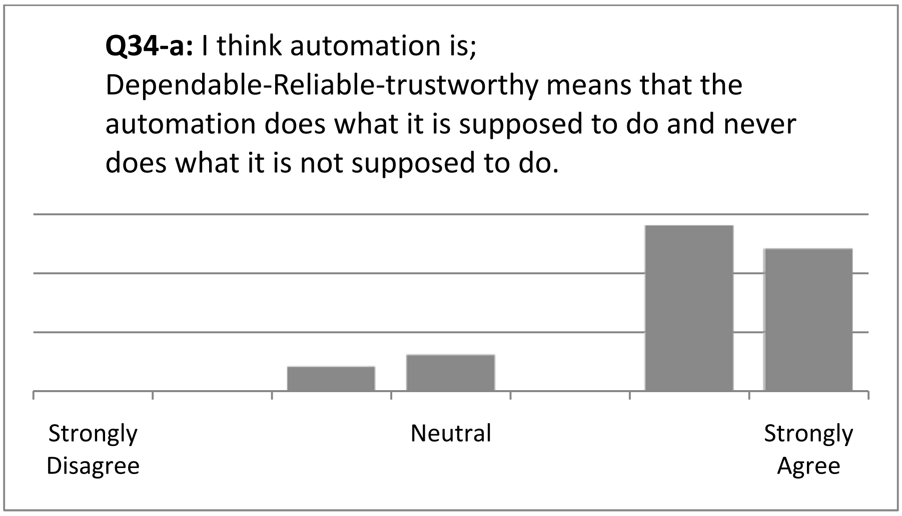

Figure 5.12: Question 34(a)

Question 11 and Question 34(b) are control questions one another. In the question 11 some of the pilots find the automation surprising where others do not concern about this problem. However, in the Question 34(b) the majority of the pilots regard as the automation predictable that means the automation behaves as expected (i.e., it is clear what it is going to do).

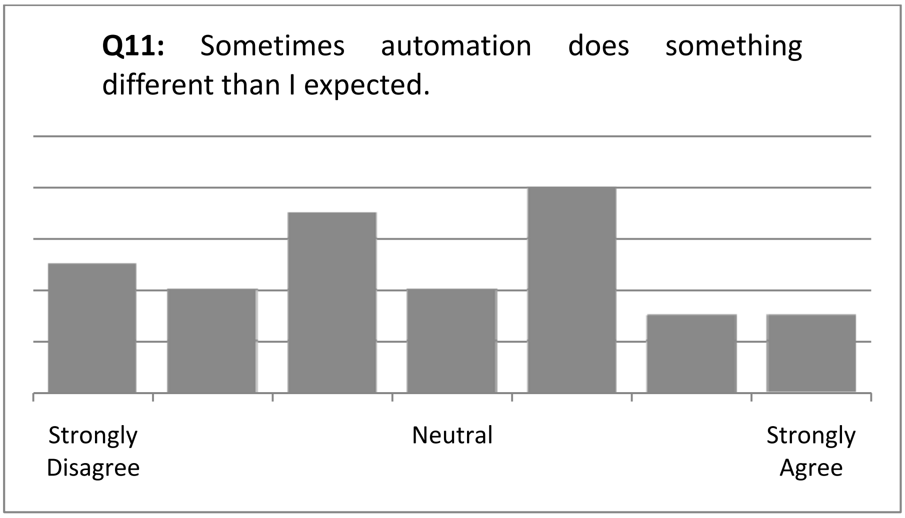

Figure 5.13: Question 11

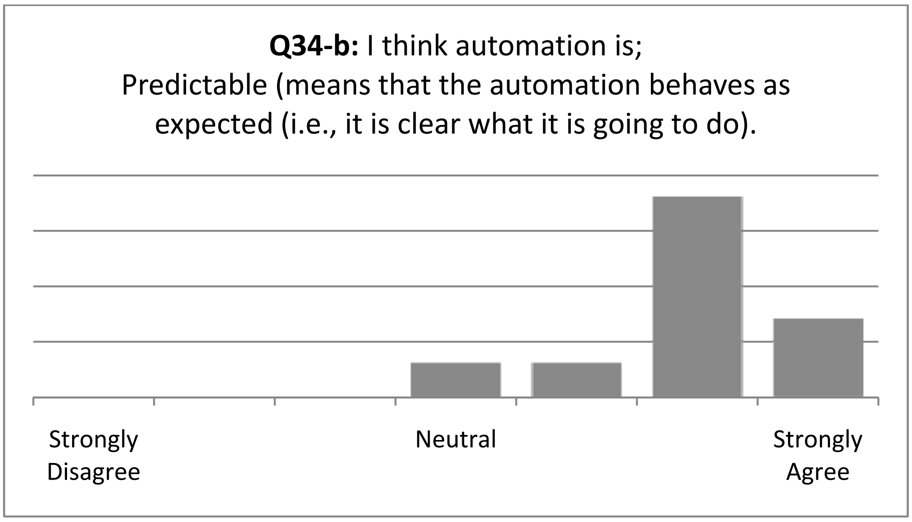

Figure 5.14: Question 34(b)

5.1.3 Information Overload

Questions 12, 13, 34(c) and 35(d) are asked to pilot to evaluate their attitudes on information overload.

Table 5.8: Information Overload Issue Response Statistics

Issue	Question #	Response #	Mean	Standard Deviation
INFORMATION OVERLOAD	12	34	3.882	2.012
	13	34	2.529	1.502
	34-c	31	5.548	1.362
	35-d	30	5.367	1.752

As the automation has many features and modes pilots are trained on these features, but according to Question 12 they do not master the whole system. This may be caused because they do not have sufficient information other than the features that they are interested in.

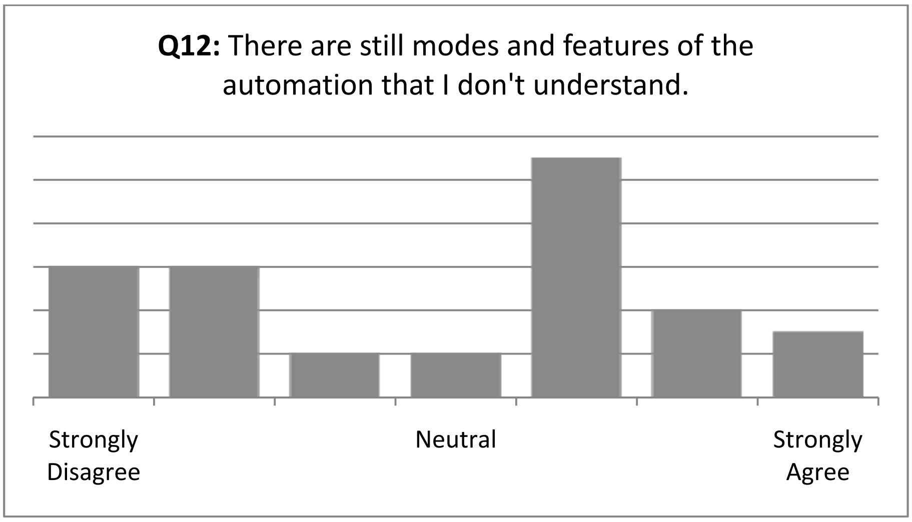

Figure 5.15: Question 12

According to the author's experience with pilots, the common expression is that automated aircrafts may be too noisy that disturbs and makes unmotivated the pilots during flight mission. Although the literature claims that the aircrafts is too noisy because of the alerts, subjects stated conversely in Question 13 (Figure 5.16).

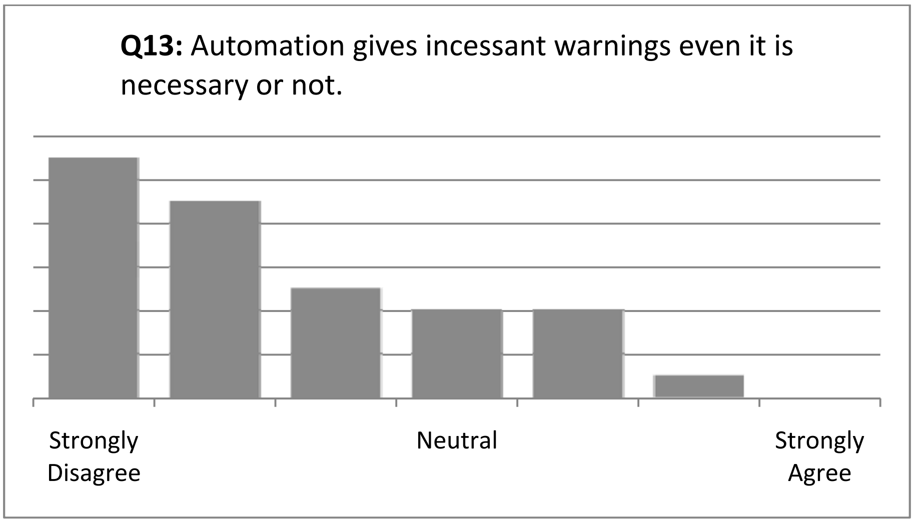

Figure 5.16: Question 13

In the Question 34(c) most of the subjects believe that the automated glass cockpits are simple that means it is easy to understand and use (i.e., it is straightforward to learn and operate to do).

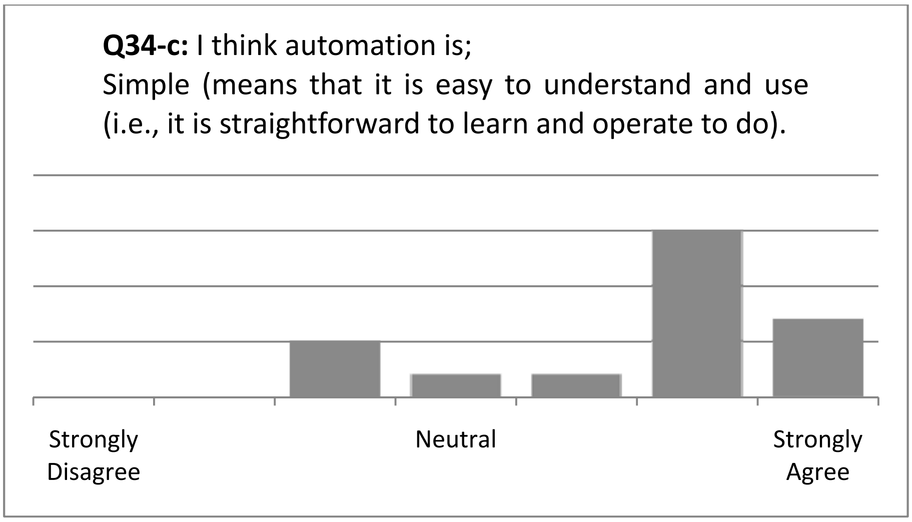

Figure 5.17: Question 34(c)

Although half of the pilots emphasize that there are still modes and features of the automation that they do not know, in the Question 35(d) they believe that the amount of information available on the aircraft is not too much.

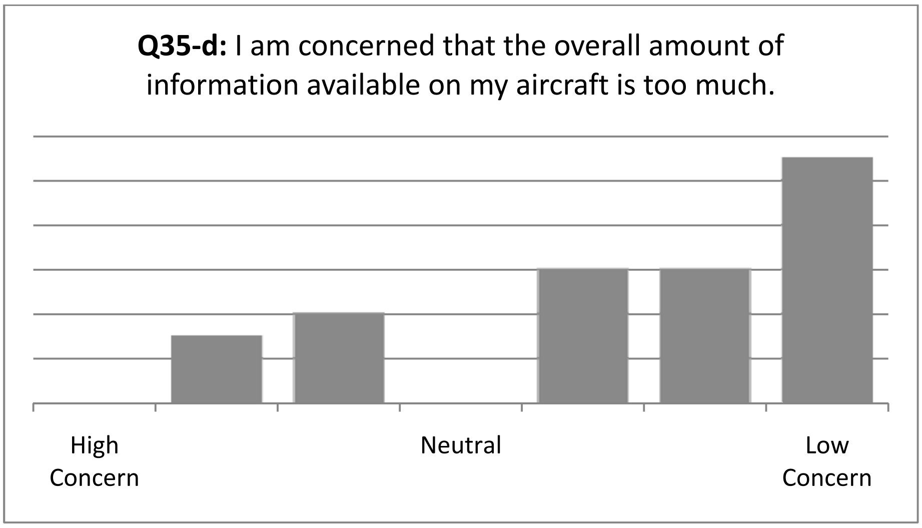

Figure 5.18: Question 35(d)

5.1.4 Workload Dilemma

In Questions 8, 14, 15, 32, 33 and 35-f, respondents were asked to rate workload level of both physical and mental for glass cockpits in comparison with analog cockpits.

Table 5.9: Workload Issue Response Statistics

Issue	Question #	Response #	Mean	Standard Deviation
WORKLOAD	8	34	2.324	1.718
	14	34	6.324	0.945
	15	34	2.294	1.447
	32	34	1.882	1.343
	33	33	3.455	1.502
	35-f	30	4.933	1.964

In order to make an automated flight, pilots have to set the FMS through CDU. However, so as to set the FMS pilots have to enter lots of data and enter into many pages. Therefore, it is expected that they may spend too much time while setting the FMS and their workload may increase. However, subjects are against to this statement and they do not think that they spend more time setting up and managing the automation than they would hand-flying or using a plain autopilot (Figure 5.19).

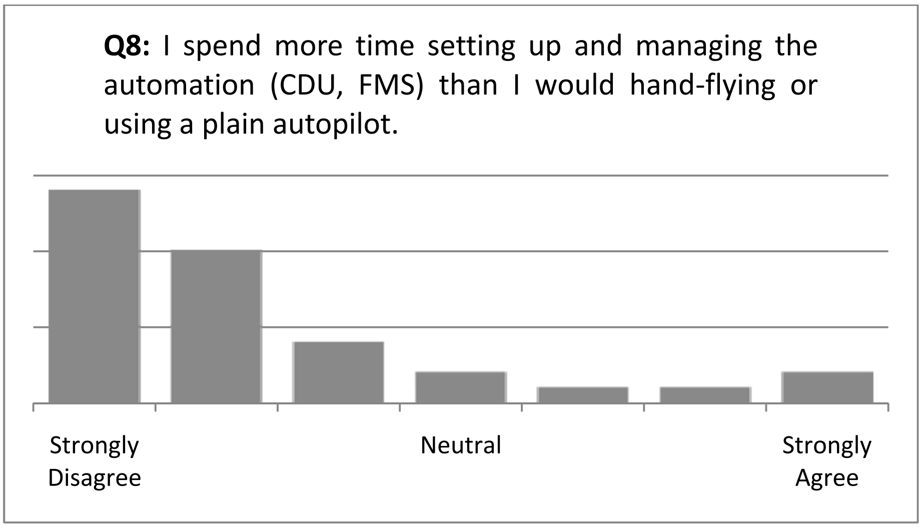

Figure 5.19: Question 8

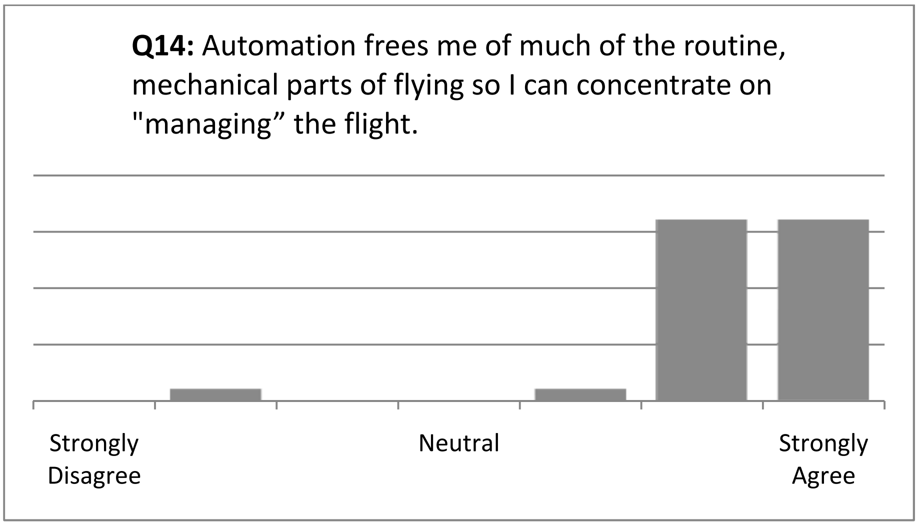

Figure 5.20: Question 14

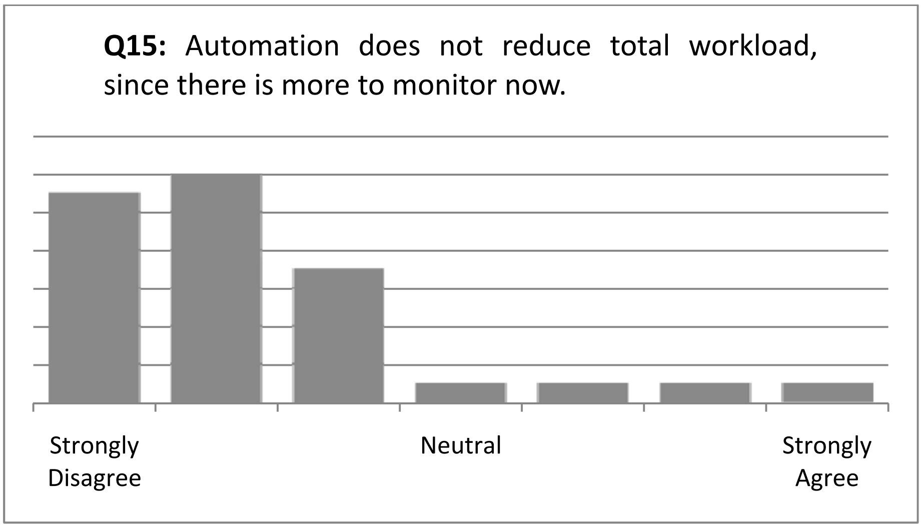

Figure 5.21: Question 15

In the question 32, subjects believe that the physical workload is decreased absolutely. According to subjects in the Question 33, mental workload also decreased with some concerns. The results confirm the common belief that glass cockpit automation has decreased physical workload more than mental workload.

The statement decrease in workload is also supported in the Question 14 and Question 15. Pilots believe that they could be freed much of the routine parts of flight and could concentrate on flight. When looked at the subjects using different aircrafts, there is not a remarkable change in the situation.

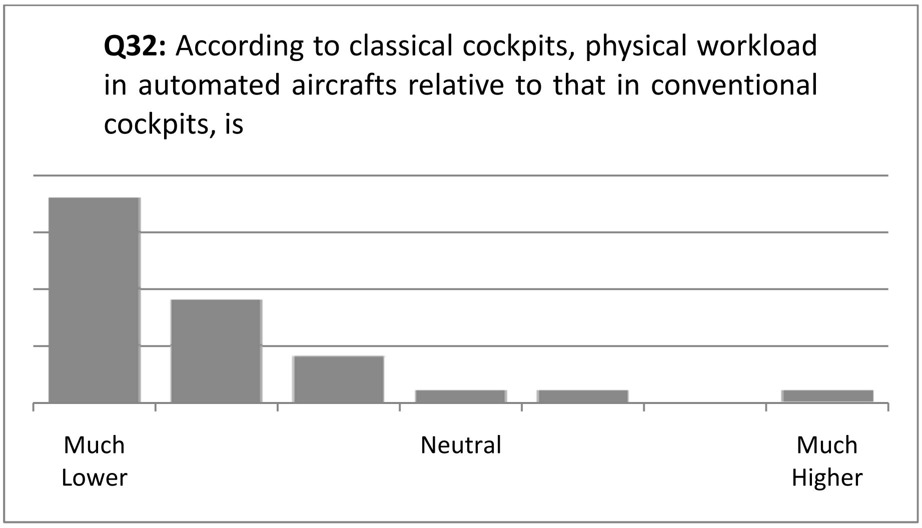

Figure 5.22: Question 32

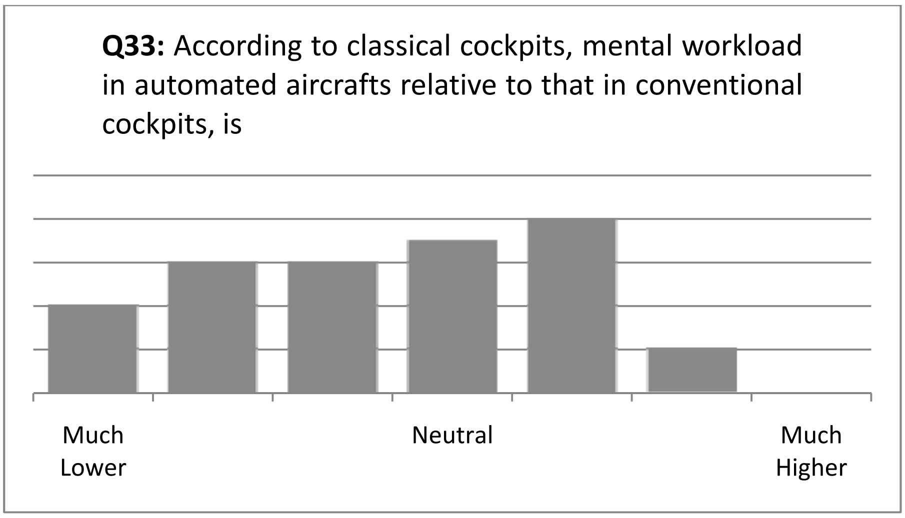

Figure 5.23: Question 33

Too much or too low workload is not desired by designers as both cause reduction on performance. The main goal to ask question 35(f) is to get information about pilot attitudes on workload variation. As it can be understood from the Figure 5.24 although some concerns, generally the subjects do not believe automation could lead to workload extremes.

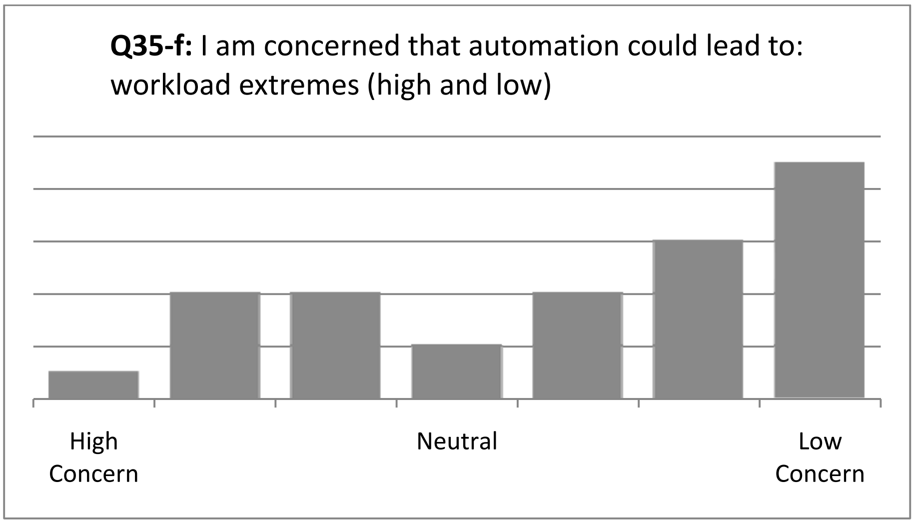

Figure 5.24: Question 35(f)

5.1.5 Situation Awareness (SA)

Questions 16, 31, 34-d and 35-b are asked to get an opinion about the situation awareness of pilots.

Table 5.10: Situation Awareness Issue Response Statistics

Issue	Question #	Response #	Mean	Standard Deviation
SITUATION AWARENESS	16	33	6.455	0.666
	31	34	3.029	1.732
	34-d	31	5.355	1.427
	35-b	30	5.3	1.878

Although the literature mentions that pilots cause various serious accidents because of mode confusion, subjects are against to this belief and they think that they are always aware of what mode the autopilot or flight director is in. However, according to the author of this study, subjects must have felt that Question 16 examines their flying skills; therefore they strongly agree the statement "I always know what mode the autopilot/flight director is in".

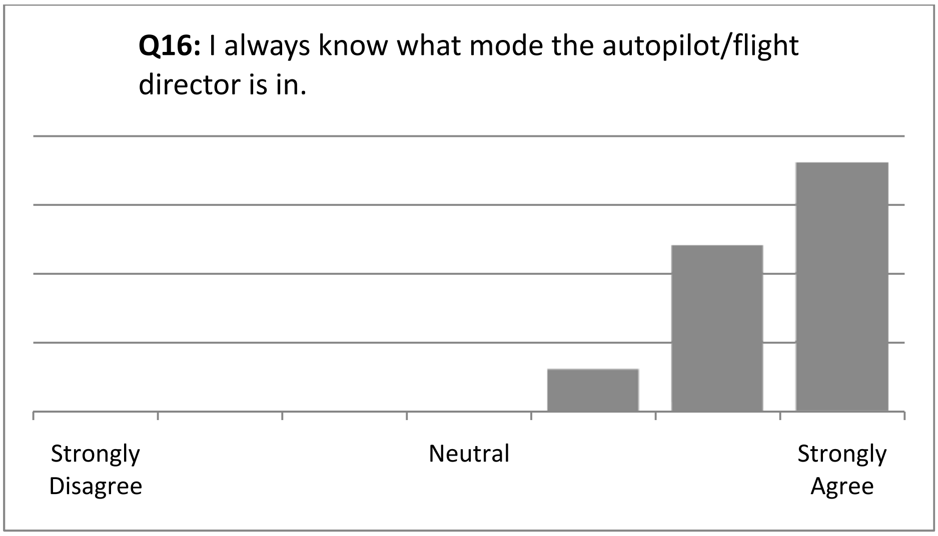

Figure 5.25: Question 16

Although before pilots declared that they manage the automation rather than fly the aircraft in the Question 30, they strongly emphasize that they focus on flight in the question 31. So, there is inconsistency between Question 30 and Question 31.

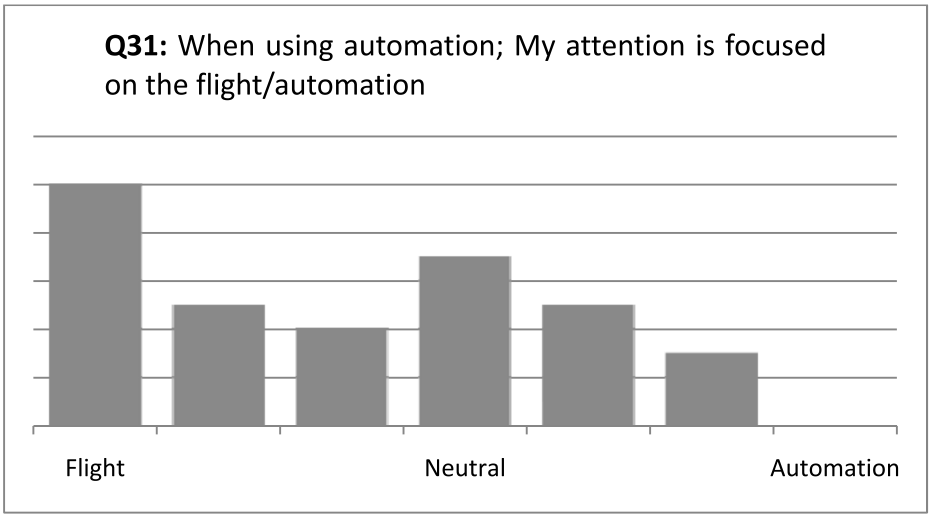

Figure 5.26: Question 31

In the Question 34(d), it seems to be the common tendency is that the automation is comprehensive that means one can figure out what the automation is doing and what needs to be done to operate it.

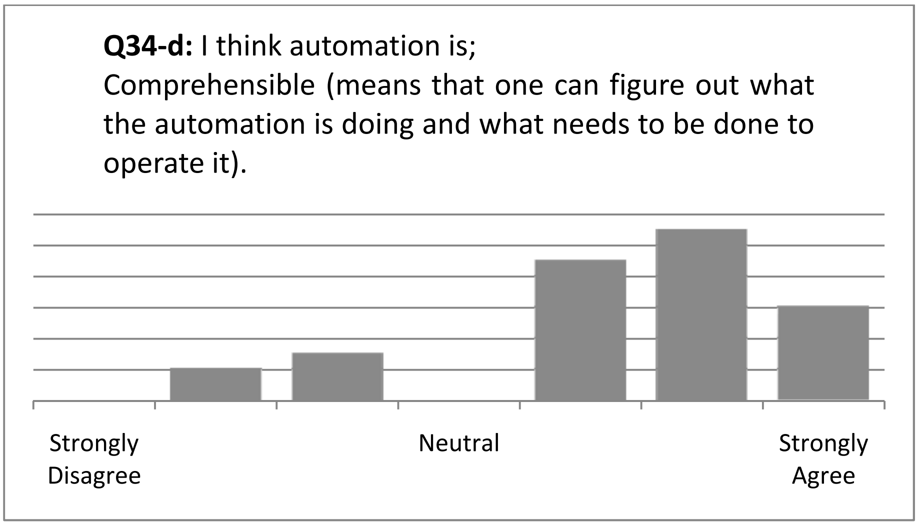

Figure 5.27: Question 34(d)

In the Question 35(b), pilots are asked that the automation could lead to difficulty in detecting errors. Most of the pilots declared that they are not concerned about this problem however some of them concern that this might be a big problem.

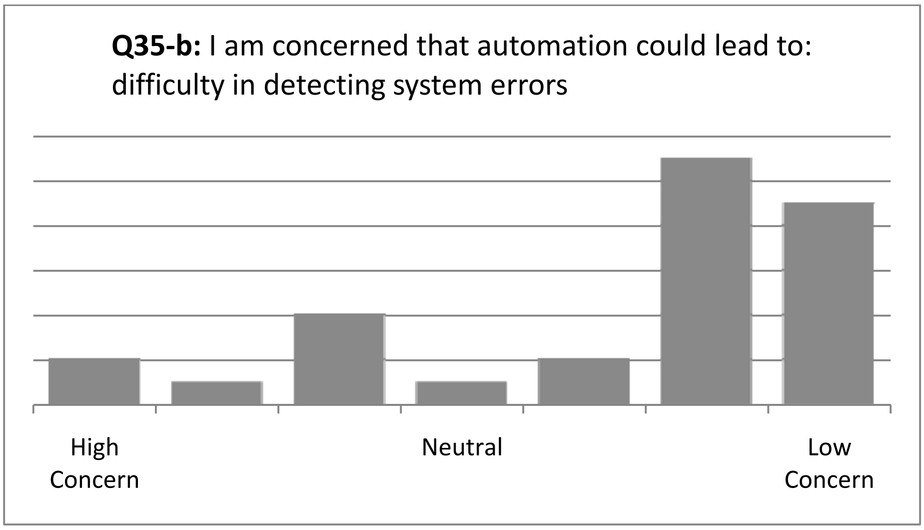

Figure 5.28: Question 35(b)

5.1.6 Insufficient Feedback

Questions 18 and 34(e) are asked to get information about the level of feedback that the automation gives to pilot.

Table 5.11: Insufficient Feedback Response Statistics

Issue	Question #	Response #	Mean	Standard Deviation
INSUFFICIENT FEEDBACK	18	34	2.559	1.44
	34-e	31	5.903	1.044

Feedback is very important as pilot has only the opportunity to monitor what automaton is doing. If there is not sufficient feedback, pilot cannot figure out the operations of automation and cannot take over the control in case of failure. Responses to Question 18 and 34(e) are coherent as they both claim that automation gives sufficient feedback to pilots.

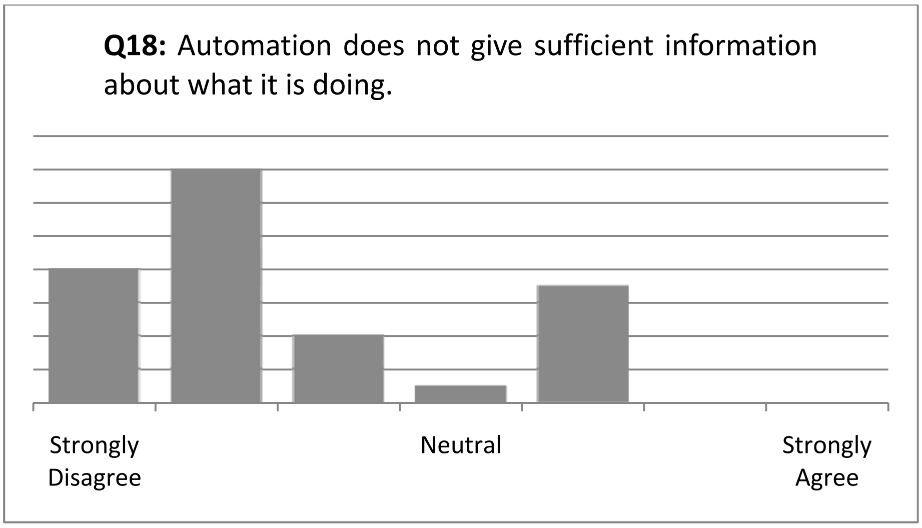

Figure 5.29: Question 18

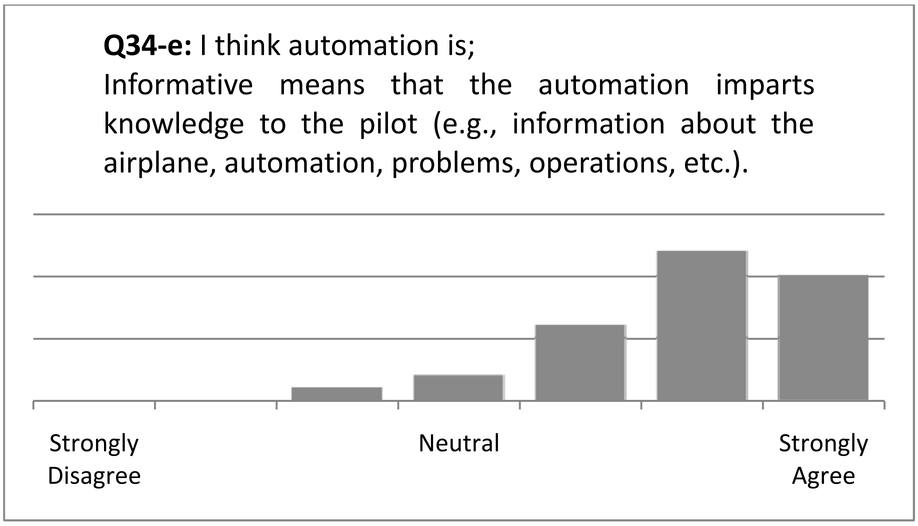

Figure 5.30: Question 34(e)

5.1.7 Pilot Skill Loss

Questions 17, 20, and 21 are asked to pilot to evaluate their attitudes on skill degradation.

Table 5.12: Skill Loss Issue Response Statistics

Issue	Question #	Response #	Mean	Standard Deviation
SKILL LOSS	17	34	6.412	0.609
	20	34	4.382	1.875
	21	34	5.824	1.424

Automation may cause some skill degradation as noted in the literature. However, subjects believe that in an emergency case they can easily notice the situation of the aircraft and transfer from automation to manual flight (Question 17). In addition, they believe that they can fly the plane as smoothly by hand as with the automation (Question 21).

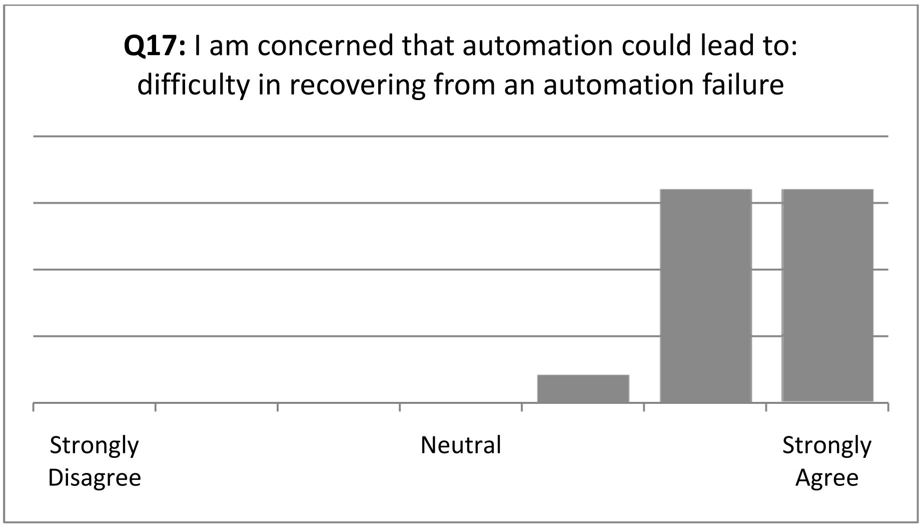

Figure 5.31: Question 17

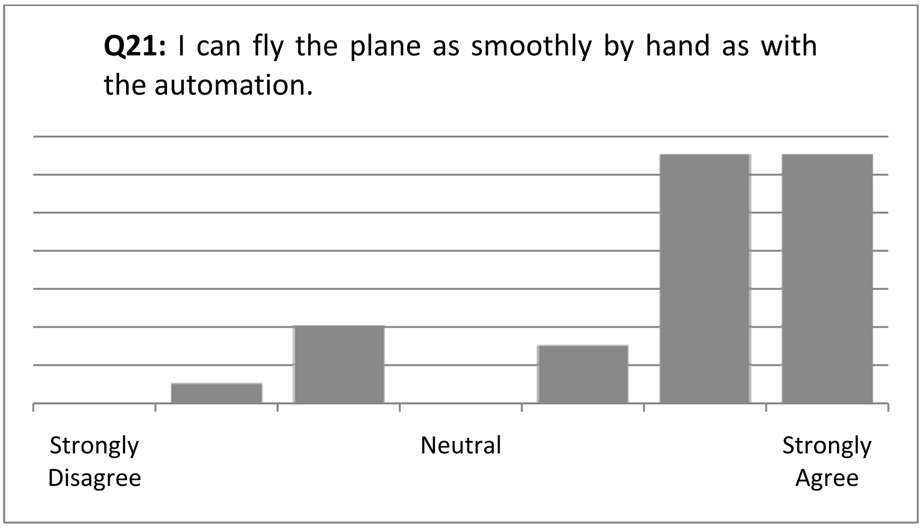

Figure 5.32: Question 21

On the other hand, when the question is asked directly, half of them support the belief that automation could lead to degradation of their skills. They share the concern of being ineffective with the automation.

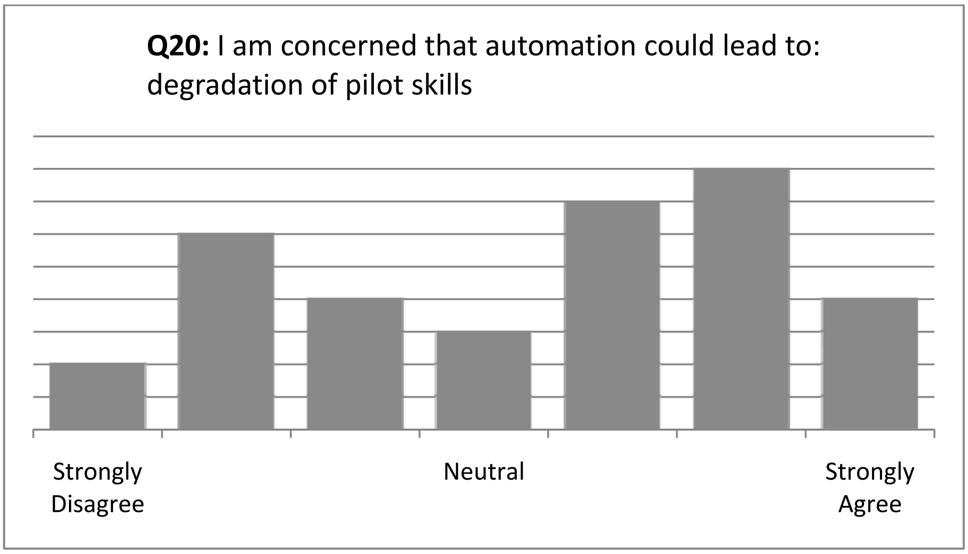

Figure 5.33: Question 20

5.1.8 Glass Cockpit Design

Questions 22, 23, 34(f), 34(g) and 35(g) are asked to pilot to learn their attitudes on their new design.

Table 5.13: Design Issue Response Statistics

Issue	Question #	Response #	Mean	Standard Deviation
DESIGN	22	34	1.412	0.609
	23	34	2.324	1.408
	34-f	31	6.258	0.729
	34-g	31	6.194	0.749
	35-g	30	3.533	1.737

The major problem with the glass cockpit design is the use of MFDs and CDUs. Generally pilots have difficulty while adapting to this new controlling systems. However, in the Question 22, pilots emphasize that use of CDU and MFD is easy.

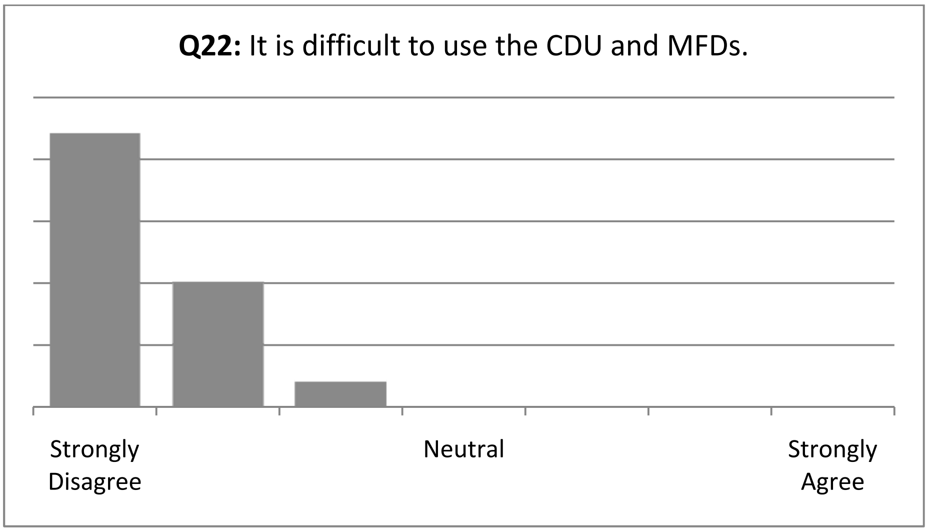

Figure 5.34: Question 22

Although pilots remarked that they do not know all the parts of the FMS at Question 12, they declared that they can find what they are looking in the pages of MFD or CDU. There is a discrepancy between these questions. This may be caused because they generally look for data that they know.

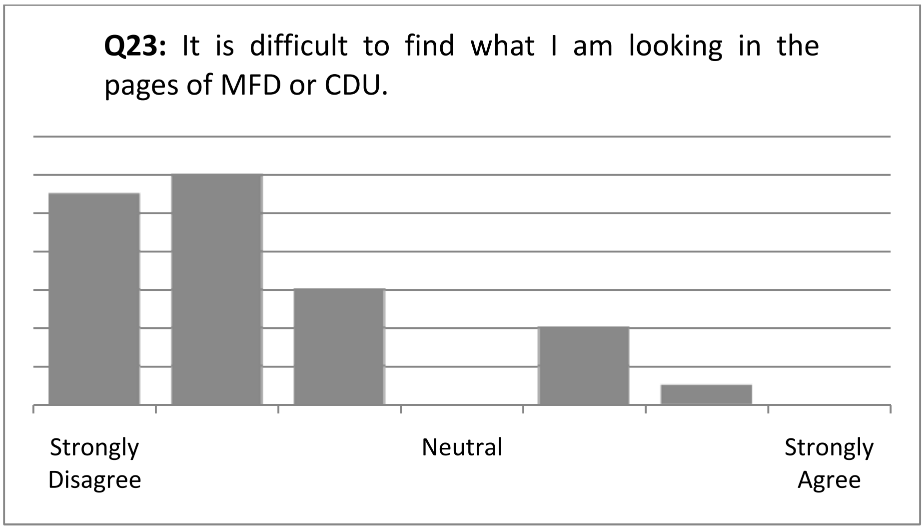

Figure 5.35: Question 23

Pilots have to enter some data to set up the FMS and during this data entry some typing errors or other errors (e.g. completion function of FMS, accepts ROZO instead of ROMEO) may occur. The Figure 5.36 supports this argument; more than half of the pilots concerns about data entry errors.

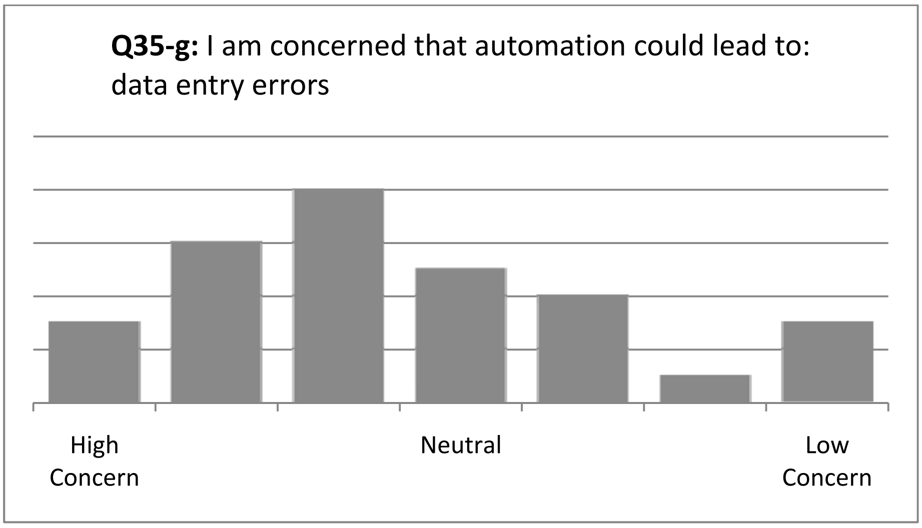

Figure 5.36: Question 35(g)

The most practical feature of the glass cockpit design is the flexibility of its components. They can be adapted to the needs of operations and expectation of operator. Thus, in the Question 34(f) subjects agreed that automation is adaptable means that displays, control devices, etc., are re-programmable within a wide range of pilot preferences and needs.

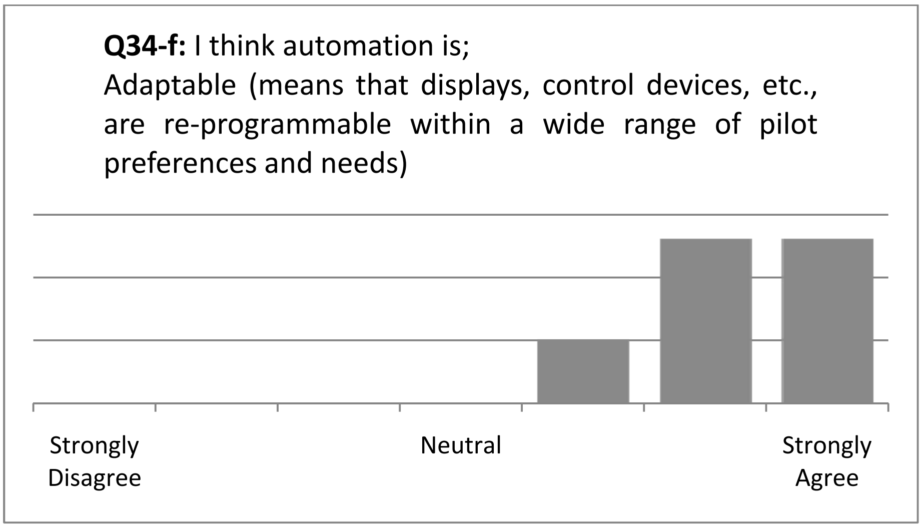

Figure 5.37: Question 34(f)

According to the Human-centered design approach selection of automated flight or manual flight should be leaved to pilot's decision. Albeit human factors researchers thought that there are some problems about the flexibility of design, subjects agree on that the automation is flexible. Ironically, generally airlines firms have regulations how the pilots shall use the automation.

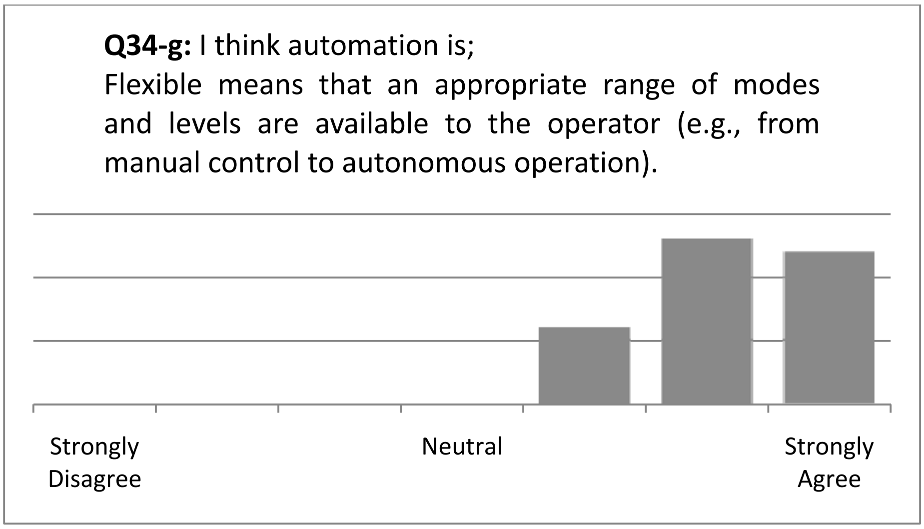

Figure 5.38: Question 34(g)

5.1.9 Amount of Automation

In the Questions Q28-29, subjects were asked to rate the amount of automation is too much or too low on their current aircraft.

Table 5.14: Over Automation Response Statistics

Issue	Question #	Response #	Mean	Standard Deviation
OVER AUTOMATION	28	34	3.676	1.981
	29	34	5.176	1.114

While some of the pilots agree that the automation has gone too far, others does not agree this belief. When the aircraft types that pilots use are considered, there is not a distinguishable change in responses. On the other hand, although some of the pilots think that automation has gone too far, most of the pilots look for more automation and they believe that the more automated the aircraft then it is better.

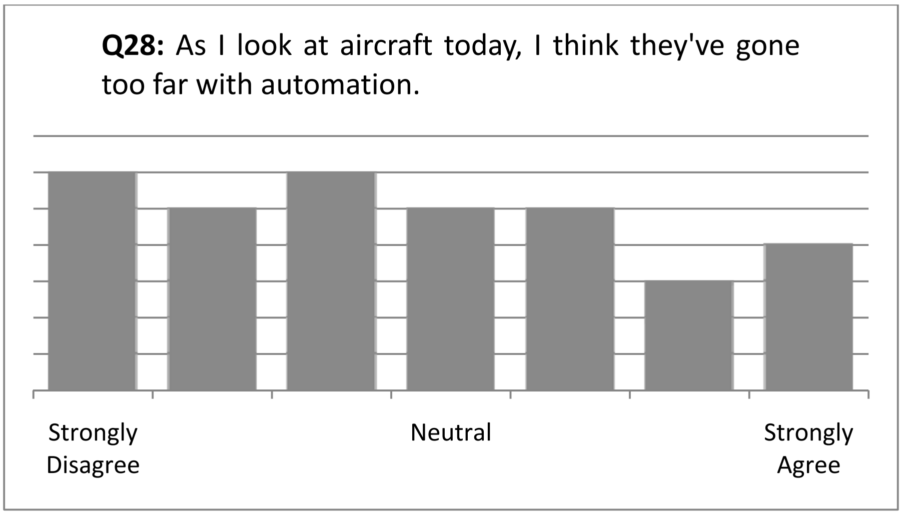

Figure 5.39: Question 28

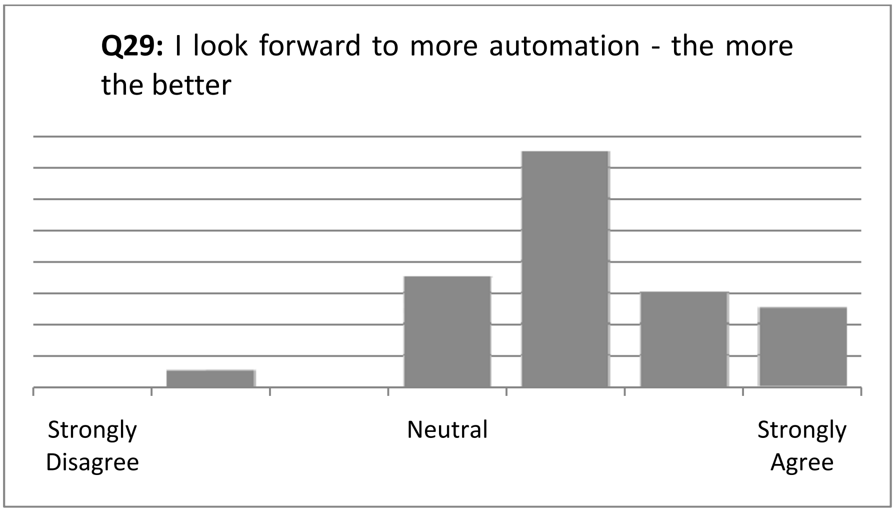

Figure 5.40: Question 29

5.1.10 Change in Human Error

Questions 24, 25, 34(h), and 34(i) are asked to pilot to evaluate their attitudes on change in human error.

Table 5.15: Human Error Response Statistics

Issue	Question #	Response #	Mean	Standard Deviation
HUMAN ERROR	24	34	5.676	1.173
	25	34	3.882	1.552
	34-h	31	5.742	1.437
	34-i	31	4.839	1.809

A common belief of pilots is that they make fewer errors in the automated aircrafts than they did in the older ones (Question 24). This situation is also supported in the Question 34(h) where automation is believed as error resistant. Moreover, automation is applied to reduce the amount of human errors in the existing systems.

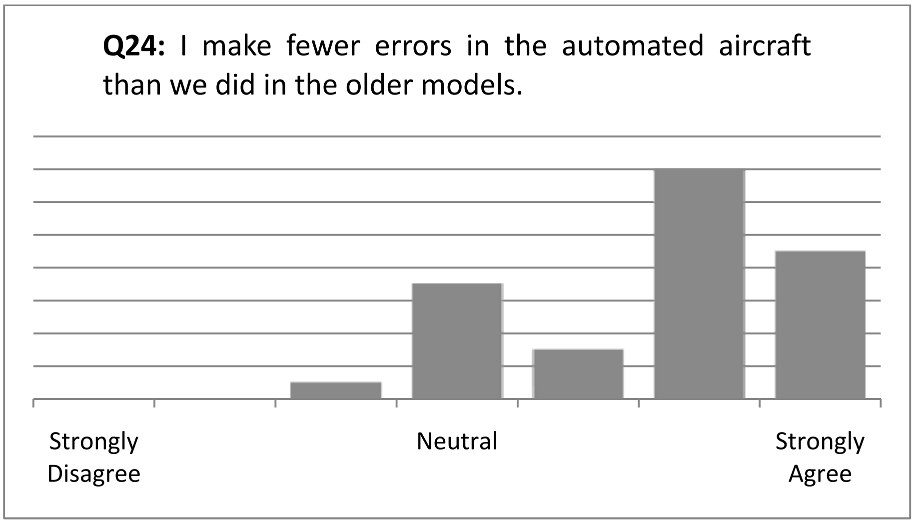

Figure 5.41: Question 24

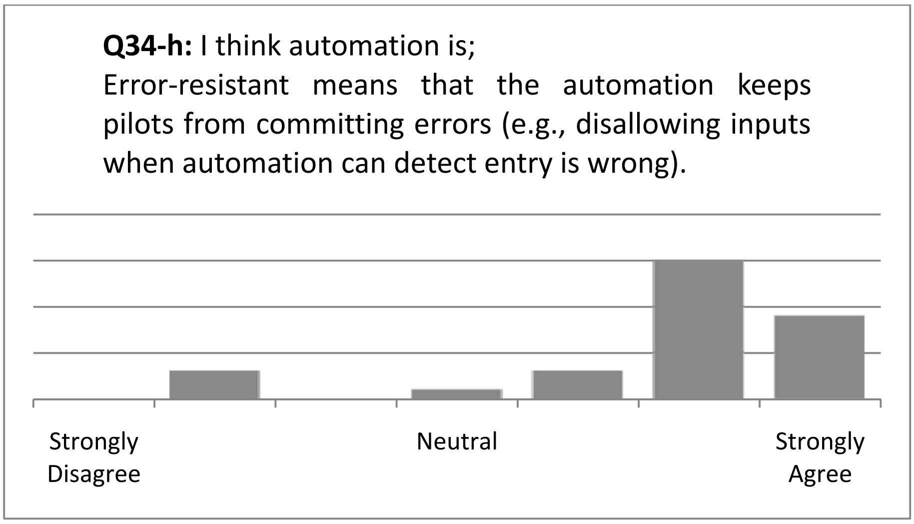

Figure 5.42: Question 34(h)

On the other hand, new use scenario creates new error types as seen in question 25. Subjects concern about the new errors that have been occurred in the glass cockpits.

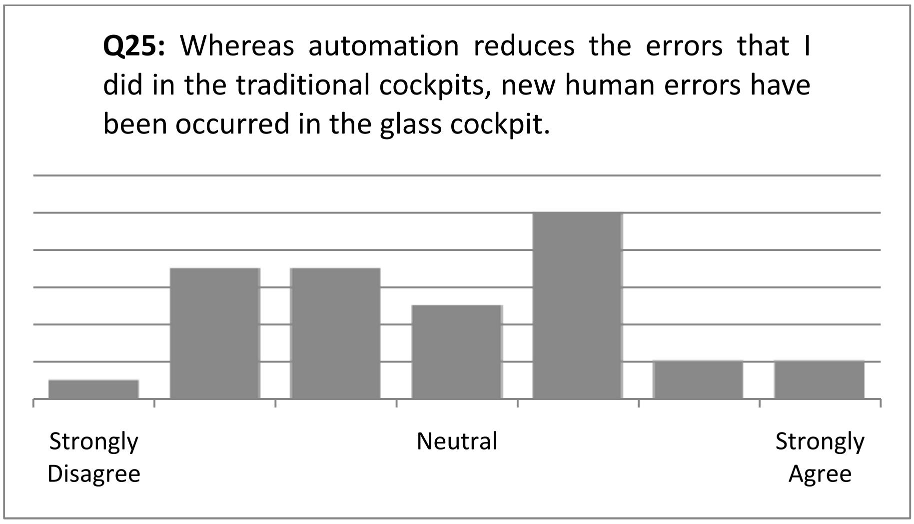

Figure 5.43: Question 25

If the human errors are accepted as inevitable, automation is expected to tolerate these errors. In the question 34(i), some of the subjects believe that automation could not tolerate human error; on the contrary a majority of the subjects declares automation is error-tolerant that means the automation can detect and reduce the effects of human error.

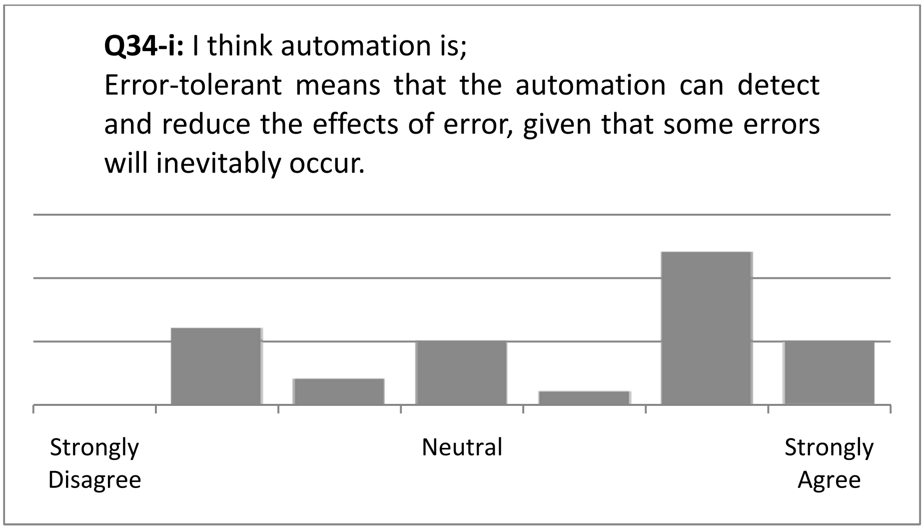

Figure 5.44: Question 34(i)

5.2 Reliability Analysis of Questions

Each issue question set has been analyzed by Cronbach's Alpha Analysis which is a statistical measurement tool to verify a set of items under a group are related with each other, in order to measure the internal inconsistency between the questions under the same issue title. Cronbach's alpha is ranged from "0" that means there is a significant correlation between items to "1" that means each item serves same results.

In order to prepare the responses for Cronbach's alpha analysis, responses are firstly processed in Microsoft Excel spreadsheets. Responses were numbered from 1 for Strongly Disagree to 7 for Strongly Agree. Each response has been analyzed and responses that belong to questions which have a negative meaning have been reversed from the way they appeared in the questionnaire by subtracting its value from 8. SPSS 11.5 is used to measure the Cronbach's alpha in this study. Cronbach's alpha results of the overall test reliability have been shown in the Table 5.16.

According to the results, Automation Use and Amount of Automation issues have a negative degree of Cronbach's alpha, and cannot be optimized by removing question that would be used to increase or decrease the Cronbach's alpha. The reason why alpha value of Automation Use is low is probably because in issue questions both positive (Q26 and Q27) and negative (Q35(e) and Q35-(h)) questions are used together. However, when these pairs analyzed together it is seen that alpha values are still low. In addition, Amount of Automation issue is observed that has a discrepancy in its questions. However as there is only two questions in this issue, an optimization cannot be done.

Although Cronbach’s alpha value of New Roles issue is high, Question 9 is removed from the question block. It is because Question 9 is asked to measure automation usage with respect to age, but this question cannot achieve its goal. As the goal of the question can be achieved by demographic questions, this question is ignored in reliability analysis. Question 35(d) which is asked in the extent of Information Overload issue is eliminated from issue question block as it has not correlated with other questions and has acted differently. Albeit pilots declare that they do not master whole system, they do not complain about excessive amount of information in Question 35(d). As a result, Cronbach’s alpha value of this issue is increased from -0.458 to 0.548. Further, Question 14 is eliminated from the question block of Workload issue and alpha value is increased from 0.3066 to 0.4156. Elimination is because it is thought that the statement “manage” is perceived wrongly.

It is seen that other issues has a high alpha value except Skill Loss. Albeit this issue does not have a high value, it is accepted having a correlation somewhat as it has a positive aspect. Consequently, it can be said that questions in determined issues are correlated in itself except Automation Use and Amount of Automation issues and specification of issues is reliable.

Table 5.16: Cronbach's Alpha values of Issues

	Cronbach's Alpha	Optimized Cronbach's Alpha	Optimization Comment
NEW ROLES	0.6915	0.7914	Q9 is removed from analysis items
COGNITIVE CONFLICTS	0.7633	0.7633	
INFORMATION OVERLOAD	-0.458	0.5482	Q35-d is removed from analysis items
WORKLOAD	0.3066	0.4156	Q14 is removed from analysis items
SITUATION AWARENESS	0.6172	0.6172	
INSUFFICIENT FEEDBACK	0.7203	0.7203	
SKILL LOSS	0.3234	0.3234	
DESIGN	0.6205	0.6205	
HUMAN ERROR	0.6097	0.6097	
AUTOMATION USE	-0.18	-0.18	reliability analysis is failed
AMOUNT OF AUTOMATION	-0.0586	-0.0586	reliability analysis is failed

Based upon the Cronbach's alpha values given in the table, all the issues can be considered to be reliable somehow except for Automation Use and Amount of Automation. Therefore, these issues are not considered in the next analysis that would assess the correlation between the issues. Table 5.17 shows the correlation and significance values of the issues which are the results of The Pearson correlation coefficient calculated with SPSS 11.5.

Table 5.17: Correlation Matrices

		NEW ROLES	COGNITIVE CONFLICTS	INFORMATION OVERLOAD	WORKLOAD	SITUATION AWARENESS	INSUFFICIENT FEEDBACK	SKILL LOSS	DESIGN	HUMAN ERROR
NEW ROLES	Pearson Correlation		0,334	0,627**	0,390*	0,549**	0,457**	0,442*	0,565**	0,333
	Sig.(2-tailed)		0,062	0,000	0,027	0,001	0,009	0,011	0,001	0,063
	N		32	32	32	32	32	32	32	32
COGNITIVE CONFLICTS	Pearson Correlation	0,334		0,684**	0,411*	0,282	0,654**	0,241	0,483**	0,233
	Sig.(2-tailed)	0,062		0,000	0,020	0,119	0,000	0,185	0,005	0,199
	N	32		32	32	32	32	32	32	32
INFORMATION OVERLOAD	Pearson Correlation	0,627**	0,684**		0,381*	0,576**	0,657**	0,445*	0,652**	0,325
	Sig.(2-tailed)	0,000	0,000		0,031	0,001	0,000	0,011	0,000	0,070
	N	32	32		32	32	32	32	32	32
WORKLOAD	Pearson Correlation	0,390*	0,411*	0,381*		0,267	0,464**	0,087	0,681**	0,235
	Sig.(2-tailed)	0,027	0,020	0,031		0,139	0,007	0,634	0,000	0,195
	N	32	32	32		32	32	32	32	32
SITUATION AWARENESS	Pearson Correlation	0,549**	0,282	0,576**	0,267		0.567**	0,459**	0,692**	0.375*
	Sig.(2-tailed)	0,001	0,119	0,001	0,139		0,001	0,008	0,000	0,034
	N	32	32	32	32		32	32	32	32
INSUFFICIENT FEEDBACK	Pearson Correlation	0,457**	0,654**	0,657**	0,464**	0,567**		0,545**	0,714**	0,334
	Sig.(2-tailed)	0,009	0,000	0,000	0,007	0,001		0,001	0,000	0,061
	N	32	32	32	32	32		32	32	32
SKILL LOSS	Pearson Correlation	0,442*	0,241	0,445*	0,087	0,459**	0,545**		0,372*	0,457**
	Sig.(2-tailed)	0,011	0,185	0,011	0,634	0,008	0,001		0,036	0,009
	N	32	32	32	32	32	32		32	32
DESIGN	Pearson Correlation	0,565**	0,483**	0,652**	0,681**	0,692**	0,714**	0,372*		0,544**
	Sig.(2-tailed)	0,001	0,005	0,000	0,000	0,000	0,000	0,036		0,001
	N	32	32	32	32	32	32	32		32
HUMAN ERROR	Pearson Correlation	0,333	0,233	0,325	0,235	0,375*	0,334	0,457**	0,544**	
	Sig.(2-tailed)	0,063	0,199	0,070	0,195	0,034	0,061	0,009	0,001	
	N	32	32	32	32	32	32	32	32	

*. Correlation is significant at the 0.05 level (2-tailed). / **. Correlation is significant at the 0.01 level (2-tailed).

The main aim to analyze the correlation between human factors issues of cockpit automation is to assess if any of the independent units might have a common basis from the pilot's point of view. Each issue has been calculated with each other respectively and the strength of a linear relationship between the variables has been examined. Some of the items which have a high correlation marked as statistically significant, that means correlation results are unlikely to have occurred by chance.

All the correlations display a positive aspect, it is clear that items are definitely related with each other. The highest correlation found in the two Insufficient Feedback and Design items with others except Human Error item. It should be noted that there is no negative relationship between the dimensions. However all of the item correlations have not a high significance value in general although expected.

Nonetheless, the major point is that although Human Error item is expected to have a significant correlation with all of the other items, it is clear that item is only correlated with Skill Loss and Design items. It was anticipated that Human Error item would have an intense correlation with all of the other items.

An interesting finding across this analysis is that Situation Awareness and Cognitive Conflicts items do not make correlation with each other. However, these two items should be correlated with each other as they trigger one another in practice.

The correlation between Situation Awareness and Workload items also is of interest. In literature, it is a common aspect that when the situation awareness increases, workload would decrease as pilot will not make extra effort to understand the situation. On the other hand, in this survey, these two items are not correlated significantly.

A negligible pattern of responding has been found for pilot's demographical data. Responses display almost no statistically significant difference according to military experience, flight hour as a pilot in command or total flight hour. Nonetheless, there are some interesting findings in demographical question's statistics. When the effect of flying experiences on pilot attitudes is examined by comparing survey responses of the pilots flying with different aircraft types, it is found that B737 aircraft pilots generally response more positive than other pilots except Cognitive Conflicts and Workload issues. Further, when the age of pilots is considered, younger pilots generally have a more positive attitude on automation especially in role adaptation, situation awareness level, interface and environmental design and human error level. Besides, pilots fly with B777 aircraft perceive more workload than others.

Table 5.18: Response according to Demographical data

		NEW ROLES	COGNITIVE CONFLICTS	INFORMATION OVERLOAD	WORKLOAD	SITUATION AWARENESS	INSUFFICIENT FEEDBACK	SKILL LOSS	DESIGN PROBLEMS	HUMAN ERROR
AIRCRAFT TYPE	A320	4,35	4,98	4,82	5,63	5,25	5,63	5,04	5,61	4,94
	A330	4,94	5,56	5,33	5,35	5,69	5,63	4,92	5,55	3,75
	B737	5,55	5,10	5,80	5,60	6,05	6,10	6,27	6,16	5,75
	B777	4,93	4,93	4,86	4,69	5,55	5,43	5,29	5,49	5,50
MILITARY	MILITARY	4,99	5,06	5,19	5,49	5,44	5,44	5,00	5,40	4,50
	NOT MILITARY	4,64	5,07	4,99	5,34	5,51	5,74	5,38	5,77	5,25
FLIGHT HOUR (pilot in command)	0-1000	4,29	5,21	4,62	5,37	5,40	5,43	5,43	5,46	5,71
	1000-2000	5,18	5,10	5,60	5,28	5,80	5,90	5,33	5,98	5,23
	2000-5000	4,20	5,18	4,86	5,34	4,64	5,07	5,05	5,17	4,50
	5000-8000	5,58	5,50	5,56	5,60	6,00	5,83	5,44	5,73	4,58
	8000-10000	4,75	4,35	4,50	5,53	5,90	6,20	5,13	5,96	4,75
AGE	25-32	5,54	5,68	5,62	5,46	6,04	5,93	5,62	6,09	6,04
	32-37	4,53	5,11	5,11	5,09	5,43	5,72	5,67	5,42	4,81
	37-43	4,13	4,91	4,65	5,66	5,28	5,75	4,83	5,80	4,56
	43-47	4,90	4,63	4,88	5,38	5,31	5,25	4,96	5,43	4,91
TOTAL FLIGHT HOUR	250-2500	4,67	4,75	4,52	5,22	5,37	5,44	5,52	5,49	5,58
	2500-4000	5,57	5,79	6,29	5,20	6,14	6,21	5,62	6,00	5,00
	4000-7500	3,94	5,14	4,74	5,64	4,69	5,06	4,59	5,40	4,69
	7500-13000	5,04	4,64	4,88	5,44	6,04	6,14	5,48	5,89	4,82

CHAPTER 6

CONCLUSION

Glass cockpit automation has been implemented with best intends of designers such as increasing the safety, increasing accuracy of systems, increasing situation awareness of pilots, decreasing workload and decreasing the costs of the flight. It has actually provided undeniable contributions to aviation in precision, efficiency and safety; unfortunately it has also come along side effects.

With the advance of the cockpit technology, role of the pilots has been changed from active controller to supervisory control. Thus, in his new role human is responsible with monitoring and programming the automated systems and take over the control from automation in case of malfunctions. This seems to eliminate the existing human errors occurred in traditional cockpits. However, some poorly designed systems cause faulty interaction between pilot and the glass cockpit. Giving insufficient feedback isolates the pilots mentally and removes them out-of-the loop. Alienation from operations of the glass cockpit reduces the situation awareness so limits the ability of the pilots to cope with the failures. Workload is another problem of glass cockpits. A proper workload is needed for an appropriate level of human performance; automation may give rise to expose pilots to too much or too little workload. Automation design problems may also cause misuse or disuse as a result of over automation or creating over-trust.

Looking all these problems one can think that automation should not be implemented to cockpits, but it not like that at all. Contrarily, implementation is indeed encouraged as long as these problems are considered during design continuum. Although glass cockpits have experienced several accidents and many incidents related to pilot interface problems, this does not mean these aircrafts are unsafe. Actually they generally work very well in accuracy and efficiency.

On the other hand, in the survey which is done within this study, it is found that pilots have not perceived most of the human factors issues stated in the literature as a problem. Pilots participated in the survey have presented interesting results regardless of the literature findings. Since the aim of this survey is to find the negative effects of automation on pilots, it is expected that pilots would feel some concern about the automation. On the contrary, automation pleased them in many ways and it is seen successful by pilots.

According to the pilot's point of view, automation has positive contributions to flight experience. They accept the role that automation assigns to them and they do not think that there is a problem in this function allocation. There is a common belief among pilots that situation awareness has been increased successfully which is one of the promises of automation. Also, they do not recognize cognitive conflicts with the operation of the automation. Besides they are glad about current amount of automation, they declared that they welcome more automation. Although they concern about automation being skill degradation and complacency so would lead pilots to be reluctant to take charge over, they stand for using automation. They find automation is to be simple; however they accept that they do not master whole system. They believe use of CDU and MFDs is simple and the concept of the automation design is favorable for their operations. Another common response is about the reliability of the automation; pilots think automation is reliable and generally works properly, so they find automated systems predictable. Also, an interesting finding identified by respondents about the automation is that automation decreased the workload in the cockpit. Meanwhile, it is found that physical workload is decreased more than mental workload as expected. Pilots find interaction design of the glass cockpits successful. Insomuch that, according to one of the comment from pilots, if a failure occurs it will be because of the errors of pilots not the design of automation.

The most common concern identified by respondents about the automation is that automation leads to complacency as a result leads to reluctance of crew to take over the control from automatics. However they are still pleased of automation and welcome more. Besides, they are highly concerned about automation not to recover from failure. This problem may be occurred because of decrease in situation awareness, insufficient feedback or skill degradation. Yet, they do not report such a problem in situation awareness or insufficient feedback. In addition, pilots feel safer in glass cockpit rather than analog ones however, they concern that automation may create new errors while reducing current errors that they did in the traditional cockpits. And they do not believe that automation will tolerate errors by detecting and reducing the effects of error that they made during flight.

Aviation sector is being on the upgrade in Turkey. Analog aircrafts are modernized into glass cockpits or advanced automated glass cockpits are designed with current projects. However, there is not any reference for Turkish pilots' behavior of automation use though automation use can be affected by various factors such as motivational, social or cognitive processes. Therefore the purpose of this study is to present a general framework that will be useful in guiding research to understand human-computer interaction in glass cockpits and provide a source for systems designers in Turkey. This study may respond to at what level and how much a system should be automated, and what will be the consequences of this transition from analog to digital in view of pilots. How a pilot's information process and how he/she reacts to these problems. What should be done to reduce the problems of this transition? Consequently, this study makes designers being aware of what will be the consequences of glass cockpit automation from the pilot’s point of view and determines the possible problems beforehand. The author’s experience with this study may contribute to the design project in modernization of C130 Hercules aircrafts which has been continuing for Turkish Air Force.

Since participation of pilots was voluntary so as more question would have bored pilots, adequate amount of questions were not asked to pilots. Further studies should be encouraged in order to improve human factors studies in aviation in Turkey.

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APPENDIX A

QUESTIONNAIRE

Exit Survey »

Merhaba,

Pilotların kokpit otomasyonu ile ilgili düşüncelerini araştıran bir ankete davet edildiniz. Bu anketin amacı pilotlardan otomasyonun çeşitli etkileriyle ilgili düşüncelerini almaktır. Ankette "Sayısal Kokpit (Glass Cockpit)" ile ilgili 36 soru yönlendirilecektir ve yaklaşık 10 dakika sürecektir.

Bu ankete katılım tamamen isteğe bağlıdır. Anket süresinde istediğiniz bir anda anketten çıkabilirsiniz. Anket süresince herhangi bir kimlik bilgisi ya da kişiye özel soru yöneltilmemiştir. Bu anket tamamen sizin kişisel görüşlerinizden oluşmaktadır ve herhangi kurum ya da kuruluşu bağlamamaktadır. Elde edilen bilgiler istatistik bilgi olarak Orta Doğu Teknik Üniversitesi Mimarlık Fakültesi Endüstri Ürünleri Tasarımı bölümünde yapılan bir tez çalışmasında kullanılacaktır. Eğer herhangi bir sorunuz olursa Çiğdem Güneş'e ckoroglu@tai.com.tr mail adresinden ulaşabilirsiniz.

Zaman ayırarak bu teze katkıda bulunduğunuz için çok teşekkür ederim. Aşağıdaki "Devam" tuşuna basarak ankete başlayabilirsiniz.

Devam

2 %

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Yaşınız:

Cinsiyetiniz:

- Kadın
- Erkek

Uçak Tipi(Son uçulan uçak):

Ticari olarak uçulan yıl (yaklaşık):

Eğer varsa Askeri olarak uçulan yıl (yaklaşık):

Toplam Uçuş Saati (yaklaşık):

Uçan pilot (Pilot-in-Command)olarak toplam uçuş saati (yaklaşık):

21%

Lütfen aşağıdaki soruları son kullandığınız uçağı baz alarak cevaplayınız.

Otomasyonu ayarlamak ve yönetmek için manüel uçuştan daha fazla zaman harcıyorum.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
○	○	○	○	○	○	○

Genç pilotlar yeni sistemlere (CDU-Control Display Unit gibi) daha çabuk adapte oluyorlar.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
○	○	○	○	○	○	○

Otomasyonda halen beni şaşırtan durumlar oluşuyor.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
○	○	○	○	○	○	○

Otomasyon bazen benim beklediğimden bambaşka bir şey yapabiliyor.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
○	○	○	○	○	○	○

Otomasyonun halen bilmediğim mod ve özellikleri var.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
○	○	○	○	○	○	○

Otomasyon gerekli ya da gereksiz sürekli olarak alarm veriyor.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
☐	☐	☐	☐	☐	☐	☐

Otomasyon beni uçuşun rutin mekanik işlerinden kurtarıyor, dolayısıyla uçuşu yönetmeye yoğunlaşmamı sağlıyor.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
☐	☐	☐	☐	☐	☐	☐

Şimdi gözlenmesi gereken daha çok şey olduğundan otomasyonun toplam işyükümü azaltmadığını düşünüyorum.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
☐	☐	☐	☐	☐	☐	☐

Otopilotun / uçuş yönlendiricinin(flight director) hangi modda olduğunu her zaman bilirim.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
☐	☐	☐	☐	☐	☐	☐

Acil bir durumda, uçağımın durumunu hemen fark eder ve otomasyondan manüel uçuşa kolaylıkla geçebilirim.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
☐	☐	☐	☐	☐	☐	☐

Otomasyon ne yaptığıyla ilgili yeterli bilgi vermiyor.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
☐	☐	☐	☐	☐	☐	☐

Bazen kendimi bir pilottan çok sadece bir "düğmeye basan"(button pusher) olarak hissediyorum.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
◯	◯	◯	◯	◯	◯	◯

Çok fazla otomatik uçmaktan dolayı manüel uçuş kabiliyetlerimi kaybedeceğimden endişeleniyorum.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
◯	◯	◯	◯	◯	◯	◯

Acil bir durumda, manüel uçuşa geçmem gerekirse uçağı analog kokpitte olduğu gibi rahatlıkla uçurabilirim.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
◯	◯	◯	◯	◯	◯	◯

Sayısal kokpitin (Glass Cockpit) getirmiş olduğu yeni sistemleri (CDU-control and display unit ve MFD-multi functional display) kullanmakta zorluk çekiyorum.(tuş kullanımları, bilgi girme, okuma gibi

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
◯	◯	◯	◯	◯	◯	◯

MFD ve CDU sayfaları arasında aradığım bilginin olduğu sayfayı bulmakta zorlanabiliyorum.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
◯	◯	◯	◯	◯	◯	◯

Sayısal kokpitte(Glass cockpit) analog kokpitlere göre daha az hata yapıyorum.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum

Otomasyon geleneksel uçaklarda yaptığım hataları azaltırken, daha önce olmayan yeni hatalar yapmama neden oluyor.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum

Sayısal kokpitte (Glass Cockpit) kendimi analog olanlara göre daha güvende hissediyorum.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum

Otomasyonun doğru ve güvenilir çalıştığına inanıyorum.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum

Bugünün uçaklarına baktığımda, otomasyonun çok fazla olduğunu düşünüyorum.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum

Daha çok otomasyonun daha iyi olduğunu düşünüyorum.

Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum

Otomasyonu kulanırken;

Uçağı Uçurduğumu Hissediyorum			Nötr			Otomasyona Kumanda Ettiğimi Hissediyorum
○	○	○	○	○	○	○

Otomasyonu kulanırken;

Uçuşa odaklanıyorum			Nötr			Otomasyona odaklanıyorum
○	○	○	○	○	○	○

Fiziksel işyükü glass kokpitlerde, analoglara göre;

Çok daha az			Nötr			Çok daha fazla
○	○	○	○	○	○	○

Zihinsel işyükü glass kokpitlerde, analoglara göre

Çok daha az			Nötr			Çok daha fazla
○	○	○	○	○	○	○

92%

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Bence otomasyon;

	Kesinlikle Katılmıyorum			Nötr			Kesinlikle Katılıyorum
Tutarlı(Kendinden istenileni yapıyor)							
Tahmin Edilebilir(Kendinden bekleneni yapıyor)							
Basit(Kullanımı kolay)							
Anlaşılır(Nasıl çalıştığı kolayca bilinebilir)							
Bilgilendirici(Hareketleri konusunda bilgi verici)							
Uyarlanabilir(İhtiyaç ve tercihlere göre ayarlanabilir)							
Esnek(İsteğe göre manüel ya da otomatik kullanılabilir)							
Hata Önleyici(Pilotun hata yapmasını engeller)							
Hata Toleranslı(Oluşan hataları telafi edebilir)							

Otomasyonun;

	Endişe Ediyorum			Nötr			Endişe Etmiyorum
Kullanımını öğrenmede zorluğa neden olacağından							
Sistem hatalarını farketmede zorluğa neden olacağından							
Yeni kabileyetler gerektireceğinden							
Çok fazla bilgi içermesinden							
Fazla rahatlığa neden olacağından							
İşyükünü aşırı uçlara taşımasından(çok fazla ya da çok az)							
Data giriş hatalarına neden olacağından							
Pilotların otomasyondan görevi devralmakta gönülsüz olmasından							

Otomasyonla ilgili daha fazla görüşünüz varsa aşağıya ekleyebilirsiniz;

100%