COCKPIT DESIGN AND HUMAN FACTORS

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A DISSERTATION REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR

EXECUTIVEBACHELOR OFBUSINESS ADMINISTRATION

(AVIATION OPERATIONS) OF

UNIVERSITY OF PETROLEUM &ENERGY STUDIES, INDIA

CENTRE FOR CONTINUING EDUCATION

UNIVERSITY OF PETROLEUM & ENERGY STUDIES, DEHRADUN

Acknowledgement

This is to acknowledge with thanks the help, guidance and support that I have received during the Dissertation.

I have no words to express a deep sense of gratitude to the management of the SPEEDWINGS AVIATION ACADEMY for giving me an opportunity to pursue my Dissertation, and in particular Mrs. DAISY.T, for her able guidance and support.

I must also thank Mr. MANOJKUMAR K S & Mrs. ARYA SOMARAJAN for their valuable support.

I also place on record my appreciation of the support provided by Mrs. ANZA and other staff of SPEEDWINGS AVIATION ACADEMY.

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Declaration by the Guide

This is to certify Mr VIGNESH GOPAL, a student of Executive BBA (Program), Roll No 500031540 of UPES has successfully completed this dissertation report on "**COCKPIT DESIGN AND HUMAN FACTORS**" under my supervision. Further, I certify that the work is based on the investigation made, data collected and analyzed by him and it has not been submitted in any other University or Institution for award of any degree. In my opinion it is fully adequate, in scope and utility, as a dissertation towards partial fulfillment for the award of degree of Executive BBA.

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Date:30-10-2014

Place:KOLLAM

Table of Contents

ABBREVIATIONS AND ACRONYMS

EAA - East African Airways Corporation

KCAA - Kenya Civil Aviation Authority

ICT - Information Communication Technology

LCC - Low Cost Airlines

SITA- Societe Internationale de Telecommunications Aeronautiques"

STB- Simplifying The Business

ATAG- Air Transport Action Group

FDI - Foreign Direct Investment

ATM - Air Traffic Management

EXECUTIVE SUMMARY/ ABSTRACT

A cockpit or flight deck is the area, usually near the front of an aircraft, from which a pilot controls the aircraft. Most modern cockpits are enclosed, except on some small aircraft. The cockpit of an aircraft contains flight instruments on an instrument panel, and the controls that enable the pilot to fly the aircraft. In most airliners, a door separates the cockpit from the aircraft cabin. After the September 11, 2001 attacks, all major airlines fortified their cockpits against access by hijackers. The efficiency and robustness of pilot-automation interaction is a function of the volume of memorized action sequences required to use the automation to perform mission tasks. This paper describes a model of pilot cognition for the evaluation of the cognitive usability of cockpit automation.

The evolution of cockpit design is credited to the advancement of Human Factors as a formal discipline. The definition of HF by Koonce (1979) reads "The study of the human's capabilities, limitations, and behaviors and the integration of that knowledge into the systems we design for them with the goals of enhancing safety, performance, and the general well-being of the operators of the system"

CHAPTER 1

INTRODUCTION

INTRODUCTION

The introduction of automation on the flight deck of modern airliners has contributed to improved range, performance, and safety (Funk, 1997). Whereas this automation has reduced the *physical workload* of the pilot, it has increased the *cognitive workload* of the pilot (Woods, Johannesen, Cook, & Sarter, 1994; Billings, 1997; Federal Aviation Administration, 1996; Bureau of Air Safety Investigation - Australia, 1999; Air Transport Association, 1999). Investigations by researchers of modern flight-deck operations have identified the complexity of learning and using cockpit automation. Pilots described the experience of learning to use this automation as "drinking from a fire hose" (BASI, 1999), and only achieve skilled and efficient use of the system after 12 to 18 months of line experience (Polson, Irving, Irving, 1994). Several studies and surveys of pilots have consistently revealed that pilots have difficulty in using the features of the automation during line operations due to "gaps in their knowledge of how that automation works" (ATA 1999, FAA 1996). These and other studies cited the need for more training (BASI, 1999; Feary, et. al. 1998, Hutchins, 1994).

In a study of the cognition required to perform 102 mission tasks using the B777 Flight Management System (FMS) and it's Multi-Function Control and Display Unit (MCDU), Sherry, Polson, Fennell, & Feary (2002) found that 74% of the these tasks required training of *memorized action sequences* to complete the task. This directly contributes to the "fire hose effect" during training. Also, 46% of the tasks that were classified as occurring infrequently (i.e. less than once in every 20 flight legs) required the *recall of memorized action sequences*. Infrequent use of memorized action sequences results in erosion of pilot's skill (Javaux, 2000), and directly contributes to perceived complexity during line operations.

This paper describes a model of pilot cognition that is designed to be used by engineers developing cockpit automation to maximize the efficiency and robustness of the pilot-automation interaction. At the root of this approach is the *minimization of memorized action sequences* that must be trained and then recalled during line operations. This paper discusses five classes of user interface characteristics that lead to training and recall of memorized action sequences:

(1) Input devices require significant reformulation of the mission task into sub-tasks or alternative representations in order to use the automation

(2) Absence of labels, prompts, and/or organizational structure, require pilots to remember action sequences to access desired input devices (or information) in the hierarchy of cockpit displays

(3) Absence of prompts that define the format for data entry require pilots to memorize correct formats

(4) Absence of labels or prompts to identify how and where to insert the entry

(5) Representations and content of feedback displays require significant mental calculation or memorization to infer the intentions of the automation and to verify and monitor the long-term effects of the current commands.

The cockpit of an airliner is designed for the specific task of providing a safe and efficient interface with the operators, nowadays, often two pilots. Despite the similar tasks performed by all crews, designs vary greatly between manufacturers and hardly any standards exist for the interface methods.

The present methods of validating cockpit designs rely mostly on subjective statements and evaluations of a limited number of test pilots. These results in design solutions that have been approved for use without a realistic operational test and without objective or global agreed upon minimum acceptable performance levels. Unlike the technical system approval process that follows strict international standards and testing criteria, the Human Factors interface evaluation lacks such standards.

The evaluation and approval process today comprises several review phases with the appropriate feedback for change. The timing of the feedback is directly related to the effort and cost of each change. This constraint causes many manufacturers to defer design changes and instead apply “Band-Aid” fixes in the form of procedures, limitations and special training to overcome design weaknesses identified at the final stages of approval.

Design decisions regarding cockpit interface have always been made based on subjective statements of test pilots. Test pilots rely on the certification regulations, company design philosophy and own previous experience (Singer, 1992; Singer & Person, 1996). The design is scrutinized in reviews, flight tests and certification tests and is formally approved before it is allowed to enter service. And yet, most accidents lately have occurred despite this process. Based on this rationale it could be claimed that the test pilots have not been doing a good enough job. Blaming the test pilots for design deficiencies in cockpit interface would be unfair without highlighting the present process, its methods and tools. The result of an evaluation of a design is only as good as the tools used and the methods applied.

1.1 OVERVIEW

A model of pilot's cognition for studying aviation pilot automation interaction, developed by Sherry, Polson, Feary, & Palmer (2002),. Pilot cognition is described by five discrete steps (Reformulate, Access, Format, Insert, and Verify & Monitor). These steps are referred to as "RAFIV" in the remainder of the paper.

(1) Reformulate the mission tasks into tasks and data that can communicated to the automation. Pilots create a mental description of the how the automation will be used to perform a given task. For example an ATC clearance must be converted into a set of data that can be entered into the automation (Palmer, Hutchins, Ritter & van Cleemput; 1992). Once a description on how to use the automation has been defined, the pilot must perform actions to transfer the description to the automation via a sequence of actions.These actions have been divided into three steps (Polson, Irving, Irving, 1994):

(2) Access the right user-interface: Once a description on how to use the automation has been defined, the pilot must access the right page (e.g. hierarchy of MCDU pages), panel (e.g. Mode Control Panel), or display (e.g. multi-function synoptic displays). The access step identifies the actions that must be taken on the user-interface to display the fields for data entry (e.g. Vertical Revision page on the Airbus) or orient pilot's attention to the correct input device (e.g. Mode Control Panel LNAV button).

(3) Format Data for Entry: Once pilots have formulated the information to be entered into the displayed page, altitude widow, dialog box, etc., the pilots must format and enter the data (e.g. MCDU scratchpad typing).

For example, the entry of a lateral route offset is <Side L or R><distance in nm.>. The format step described here is more specific than the Designate step of the Polson, Irving, and Irving (1994) model.

(4) Insert Data: Once the data is formatted the pilots takes actions to insert the data in the correct location. For example an entry in the MCDU scratchpad is inserted by selecting the line select key adjacent to the MCDU page field for the entry. Once the entry has been made and the automation commands the aircraft trajectory, the pilot must verify and monitor the progress of the aircraft trajectory to satisfy the mission tasks goals input to Step 1

(5) Verify & Monitor: The pilot must verify that the automation has: (1) accepted the pilot entry, (2) is performing the intended task within the envelope of acceptable performance, and

(3) the task is satisfying the mission goals (Fennell, 2002). This step involves scan and intensive scrutiny of the PFD, ND, and MCDU.

❖ PILOT PERFORMANCE

Each of the RAFIV steps required to complete a task is performed by the pilot by either *recalling* the appropriate action from long-term memory or by *recognizing* the appropriate action from salient visual cues in the environment such as, button labels or prompts on the user-interface (Polson, Sherry, in preparation).

- Training Time for Recall Steps: Steps of the RAFIV model that rely entirely on the recall of memorized action sequences for completion (i.e. steps without any visual cues) require *2 to 10 times* more time to train to competence than steps with visual cues (Kieras, 1997). Once the memorized action sequence is described, repetitive drill and practice is required to master the skill.
- Reliability of Recall Steps: Steps of the RAFIV model that rely entirely on the recall of memorized action sequences and are performed infrequently, will exhibit *less than 50% probability* of completion (Franzke, 1995; Kitajima, SotoPolson, 1998). "If you on't use it, you will lose it."

❖ Anthropometry in Aviation

Anthropometry is an integral part of ergonomic design, for aircraft designers anthropometry is not limited to the measurements alone but also who the targeted users and operators are. It is not feasible to design a cockpit for every individual in the world; rather a normal distribution is used where an aircraft is designed for the 5th to 95th percentile of the intended population (NASA, 1978). (Note that this is not the same as the middle 90% of the population)

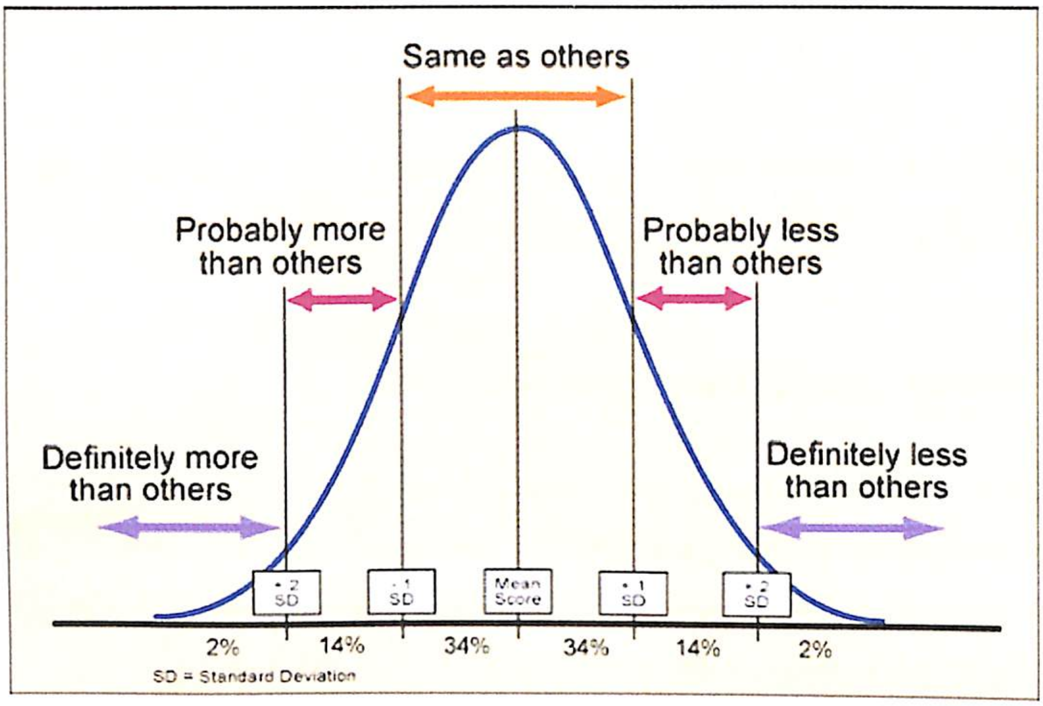


Fig: Distribution of the 5th-95th percentile (image embedded from Web answers on 12 August 2012)

Anthropometry considerations in aviation include

Body dimensions	Clothing (including gloves, shoes) of crew uniform
Hand size	Size, location and layout of button, switches, levers and small controls. Maintenance access for engineers
Length of arms and legs	Reach envelope for control locations
Sitting eye height	Seat adjustment to establish correct eye datum
Sitting height, sitting knee height and thigh thickness	Control column yoke clearance, desk and console design
Standing height	Ceiling and door height limitations, overhead panel reach
Sitting elbow rest height/	Armrest location

length	
Body width and thickness	Fuselage, passageway, door and hatch size limitations
Thigh length	Seat length
Foot size	Foot location, space and controls (rudder and brakes)
Muscle strength	Control feedback forces (real or artificial). Service and maintenance requirements. Portable equipment weights

1.2 BACKGROUND

The General Aviation Manufacturers Association (GAMA) sponsored the effort to develop a single document containing best HF practices and guidance for Part 23 cockpits/flight decks. This document is follow-on of that work completed on revision of AC 23.1309-1C and AC 23.1311-1A and supports a systematic consideration of HF aspects in aviation design. Systems continue to increase in complexity. This has resulted in a need for improved pilot machine interfaces to reduce the degree to which incorrect pilot actions contribute to accidents. This document is intended to facilitate optimization of designs to give these systems enhanced HF interfaces. Utilization of the guidelines in this document should result in improved safety and resolution of human factors issues early in the design process. This document has potential benefit to the small aircraft manufacturing community in that it provides:

1. Information developed from several companies who have many years of experience in developing and applying human factors design to their aviation products. Users of the best practices that are described in this document will benefit from previous design efforts and lessons learned in applying those practices.
2. Utilization of the human factors guidance and evaluation methodology described in this publication will aid in development of a standardized approach for all industry developers and evaluators.

3. Utilization of the best practices described in this document will lead to safer error tolerant designs. This should result in a reduction of aircraft accidents and incidents. This is a living document and it may require future revisions to stay abreast of new approaches and techniques that could be used in designs and as a result of field experience gained from use of the document. A form is included at the end of this publication in Appendix G that may be used to submit comments to GAMA. The contributors to this document are listed in Appendix F. They include representatives from industry and the FAA.

1.3 PURPOSE OF THE STUDY

The purpose of this document is to provide manufacturers of small aircraft and systems with human factors (HF) recommendations for the design of cockpits/flight decks and their associated equipment to enhance overall aircraft safety. This document should be useful to manufacturers as they proceed through the design, development and evaluation efforts. The guidelines in the document address issues relevant to new generation products, as well as to existing products and their use in new and existing cockpits/flight decks. This document will be helpful to manufacturers seeking certification of their products because it is consistent with the newly developed Federal Aviation Administration (FAA) and Industry Guide to Product Certification published in January 1999.

1.4 RESEARCH HYPOTHESES

In my project hypotheses is cockpit design and human factors. A cockpit or flight deck is the area, usually near the front of an aircraft, from which a pilot controls the aircraft. Most modern cockpits are enclosed, except on some small aircraft. The efficiency and robustness of pilot-automation interaction is a function of the volume of memorized action sequences required to use the automation to perform mission tasks. This paper describes a model of pilot cognition for the evaluation of the cognitive usability of cockpit automation. A research hypothesis is the statement created by researchers when they speculate upon the outcome of a research or experiment. Every true experimental design must have this statement at the core of its structure, as the ultimate aim of any experiment. The hypothesis is generated via a number of means, but is usually the result of a process of inductive reasoning where observations lead to the formation of a theory. Scientists then use a large battery of deductive methods to arrive at a hypothesis that is testable, falsifiable and realistic. This is too broad as a statement and is not testable by any reasonable scientific means. It is merely a tentative question arising from literature reviews and intuition. Many people would think that instinct and intuition are unscientific, but many of the greatest scientific leaps were a result of 'hunches'. The research hypothesis is a paring down of the problem into something testable and falsifiable. In the aforementioned example, a researcher might speculate that the decline in the fish stocks is due to prolonged over fishing. Scientists must generate a realistic and testable hypothesis around which they can build the experiment.

Measurements can be in the form of

- Static measurements: Measurements when the body is still. (E.g. sitting height)
- Dynamic measurements: Measurements when the body is moving (e.g. a pilot's reach envelope for the overhead panels)
- Contour measurements: Measurements of the body (e.g. head circumference or waist size).

A hypothesis must be testable, but must also be falsifiable for its acceptance as true science. A scientist who becomes fixated on proving a research hypothesis loses their impartiality and credibility. Statistical tests often uncover trends, but rarely give a clear-cut answer, with other factors often affecting the outcome and influencing the results. Whilst gut instinct and logic tells us that fish stocks are affected by over fishing, it is not necessarily true and the researcher must consider that outcome. Perhaps environmental factors or pollution are causal effects influencing fish stocks. A hypothesis must be testable, taking into account current knowledge and techniques, and be realistic. If the researcher does not have a multi-million dollar budget then there is no point in generating complicated hypotheses. A hypothesis must be verifiable by statistical and analytical means, to allow a verification or falsification. In fact, a hypothesis is never proved, and it is better practice to use the terms 'supported' or 'verified'. This means that the research showed that the evidence supported the hypothesis and further research is built upon that. A research hypothesis, which stands the test of time, eventually becomes a theory, such as Einstein's General Relativity. Even then, as with Newton's Laws, they can still be falsified or adapted. Scientists must generate a realistic and testable hypothesis around which they can build the experiment. This might be a question, a statement or an 'If/or' statement. Some examples could be: Is over-fishing causing a decline in the stocks of Cod in the North Atlantic? Over-fishing affects the stocks of cod. If over-fishing is causing a decline in the numbers of Cod, reducing the amount of trawlers will increase cod stocks. These are all acceptable statements and they all give the researcher a focus for constructing a research experiment.

CHAPTER - 2

LITERATURE REVIEW

LITERATURE REVIEW

During the war, flying advanced in that aircraft were required to fly without visual cues, such as at night or in cloud, furthermore pilots were not only required to manoeuvre the aircraft but to navigate, fire weapons, deliver troops and perform other various duties. As the requirement for increased roles for the pilot were increased, so were the number of controls and instruments in the cockpit. As written by Salas and Maurino (2010) "More and more information placed inside the aircraft supplemented or replaced cues outside the aircraft". This trend continued onto airliners up to the 1970's until the number of instruments, knobs and controls outgrew the cockpit.

The increased number of flight and engine instruments resulted in the contrary to what designers had intended. There was limited integration of controls and instruments, and instead of increasing awareness to the pilot, workload and stress levels were increased. Wiener and Nagel (1988) summarized that "crew system designs and flight station layouts have frequently ignored the limitations and capabilities of the human operator".

Literature reviews use secondary sources, and do not report new or original experimental work. Most often associated with academic-oriented literature, such as a thesis, dissertation or peer-reviewed journal article, a literature review usually precedes the methodology and results section. Literature reviews are also common in a research proposal or prospectus. Its main goals are to situate the current study within the body of literature and to provide context for the particular reader. Literature reviews are a staple for research in nearly every academic field. A systematic review is a literature review focused on a research question, trying to identify, appraise, select and synthesize all high quality research evidence and arguments relevant to that question. A meta-analysis is typically a systematic review using statistical methods to effectively combine the data used on all selected studies to produce a more reliable result.

2.1 REVIEW AREA BROAD

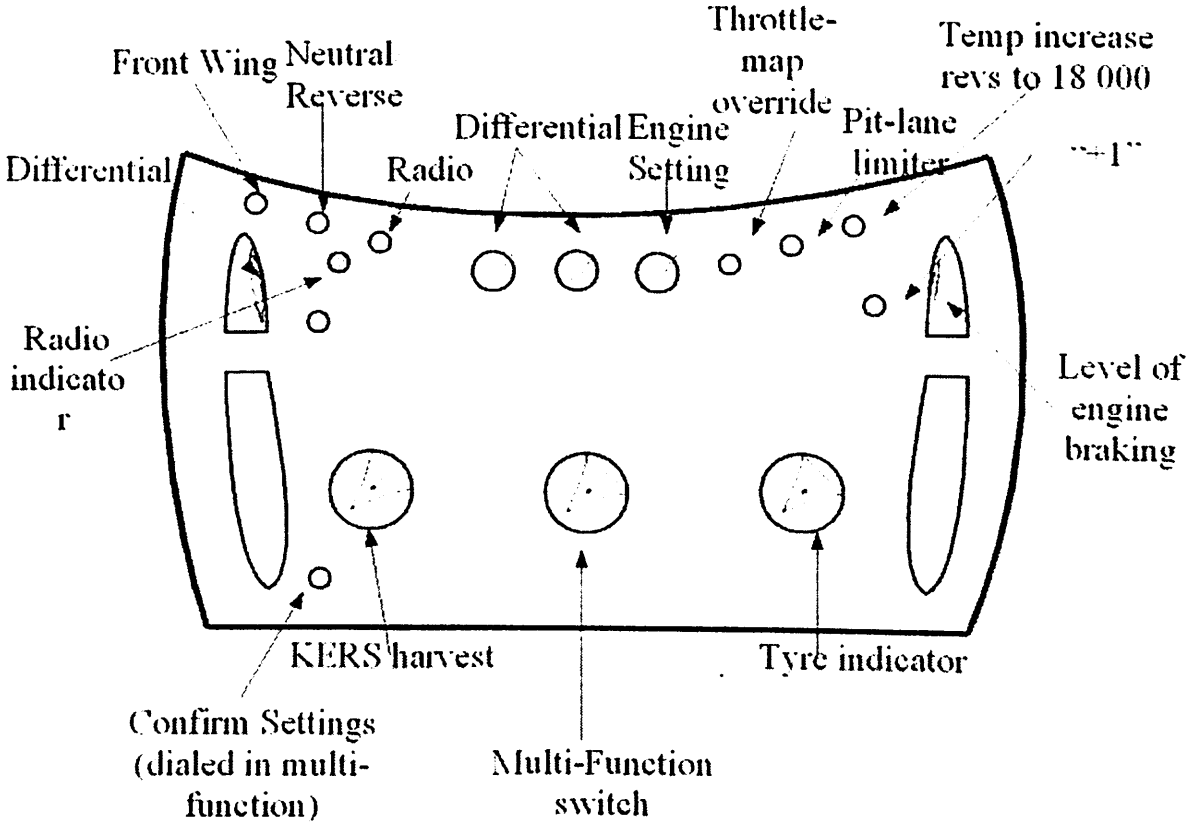
The complexity in instruments displaying aircraft systems and performance resulted in high stress levels and error rates. Examples of this were missed signals, misinterpreted information and limited detection and recognition of a number of instruments by the flight crew (Weiner and Nagel, 1988).

Data shows that there was an increasing trend in the number of displays (Instruments & gauges) up until the 1980's where there was a sharp decrease (Wiener & Nagel, 1988). The reduction of the number of instruments in cockpit designs coincided with the perception and human information processing focus that dominated the HF era in aviation around that same time (Salas and Maurino, 2010). It also coincided with the introduction of next generation aircraft such as the Boeing 757/767 and A310. In modern next generation cockpits the studies of these HF topics are reflected in design. There is not only a significant reduction in the number of instruments but the display of information in the form of glass cockpits reflects the improved understanding of the human cognitive process and the application to this in design of the systems (the objective of HF).

❖ Design eye position/ Eye Datum

The design eye position, also known as eye datum or design eye reference point (DERP) is one of the key aspects of cockpit design. A pilot should be able to view all the main cockpit instruments while maintaining a reasonable view of the outside world with minimal head movement (FAA, 1993). The instruments should be located high enough for easy viewing but low enough so that it does not obstruct the view of the runway ahead during takeoff and landing. The aircraft designer will first allocate a design eye position and from there build the cockpit around it, factoring in the reach envelope the designer can then position the controls, switches and dials to cater for the 5th to 95th percentile of pilots (Coombs, 1999).

In order to operate the aircraft as intended it can be seen that all pilots must use the same reference datum. This is normally achieved by adjusting the seating position in both vertical and fore/aft axis. Some aircraft will also have adjustable rudder pedals and/or control yoke/joy stick to ensure the pilot's view is in alignment with the design eye position. To highlight the significance of the design eye position, sitting just 1 inch below the reference point on a Boeing 767 will result in losing 40 meters of ground vision during final approach.



❖ Workspace Constraints

Rarely does the cockpit design take precedence over the aircraft fuselage shape. A compromise therefore exists between the ergonomics and anthropometry of the cockpit and the aerodynamics and strength of the aircraft body. Nevertheless, the cockpit should be designed to be as spacious as possible. One way to achieve this is by de-cluttering the cockpit, position of a particular control will be based on the importance and frequency of use as well as whether the requirement exists between having it duplicated or shared (Enol, 2012). For example, the throttle levers, which are shared controls, are limited to be positioned somewhere in the middle of the cockpit so that it is accessible by both crew. Should a control be off-centered beyond the reach of one crew (such as the flap lever on some aircraft), then the pilot on the respective side will be solely in charge of manipulating that particular control. While this may create additional complications during unfavorable scenarios, due to workspace constraints it is not practical to duplicate all the controls and certainly not have all the controls in the middle of the cockpit.

Pilot Comfort

Airline pilots remain seated for an extended period of time, long haul routes are often in excess of sixteen hours. While the importance of seat comfort itself is explanatory, there is also big emphasis on designing a seat that offers sufficient back support (Roskam, 2002[15]). More information on aircraft seat ergonomics can be found here.

Humidity and illumination can also affect pilot comfort. Most large aircraft cockpits have a separate environmental control panel for pilots to regulate the ambient temperature. The difference in isolation due to the large windscreens often means that the cockpit will require a different setting than the rear cabin. The illumination on the left and right side of the instrument panel should have the ability to be adjusted independently to suit the individual pilot.

❖ FIVE COMMON DESIGN ERRORS AND HOW TO AVOID THEM

This section describes each of the five classes of design errors with examples, and strategies to avoid this phenomenon.

(1) INPUT DEVICES THAT REQUIRE REFORMULATION OF THE MISSION TASK INTO SUB-TASKS OR ALTERNATIVE REPRESENTATIONS

The most usable automation provides direct features for the completion of mission tasks. When the automation does not directly support the task, the pilot must reformulate the task into alternative tasks or a sequence of sub-tasks that the automation can perform (Palmer, Hutchins, Ritter & van Cleemput, 1992). This behaviour relies on the use of memorized actions. This is time consuming and attention demanding, and therefore subject to increased training times and reduced reliability.

Tasks Supported by the MCDU/FMS	Tasks not Supported by the MCDU/FMS
Alignment of ADIRU Position Flightplan/Route Planning Aircraft Performance Computations Direct To Holding Pattern at PPOS Lateral Route Offset Missed Approach/GoAround Descend Direct Descend Now	Climb through intermediate altitude constraint Descend to crossing restriction Change departure/arrival runway Adjust climb speeds to achieve desired climb gradient Crossing radial with altitude restriction

Sample of tasks supported and not supported by the MCDU/FMS (From Sherry, Polson, Feary, & Palmer, 2002) Table 1

For example, tasks that are supported directky include: Direct to a Waypoint (enter waypoint ICAO identifier into Line Select key 1L on the MCDU LEGS page), Hold at Present Positon (Hold Page), and Descend Now (Line Select Key 6R on the DEScent MCDU page). In contrast, the basic mission task to descend to cross a waypoint at a specified altitude and speed cannot be performed directly by the automation. [Note: entry of a speed and altitude constraint at the specified waypoint in the flight plan does not guarantee that the aircraft will be commanded on an appropriate trajectory.] Instead the pilot must compute and command the required rate-of descent using distance (or time) to the waypoint, ground speed, and altitude remaining. Furthermore, the pilot must determine the appropriate combination of airspeed, vertical speed, airbrake setting, pitch attitude and/or thrust to achieve the desired rate-of-descent and maintain within the safe operating envelope of the aircraft. The only way to mitigate this class of design error is to *understand the mission tasks* and *provide automation to support the pilot in executing these tasks*. Several researchers (e.g. Vakil & Hansmann, 2000) have proposed including the mission task analysis as the starting point of the design process. For example, Riley (1998) designed a cockpit user-interface to accept Air Traffic Control commands as inputs. In addition to the definition of the mission tasks, a critical element of the design process is the definition of the internal representation of the environment and the mission that is held by the automation. For example, the LEGS and RTE lists represent the flight plan as a sequence of legs and a sequence of procedures and airways respectively. The list structure of these representations determines the manipulations required by the pilot to make flight plan changes. Vicente (1999) provides a structured approach for deriving internal representations using a control engineering paradigm; (a) understand the plant (i.e. environmental constraints), (b) identify potential sources of disturbances, (c) define control objectives (i.e. mission goals), and (d) provide the means to control to these goals.

The following definitions are derived either from specific sources or from the accepted understanding of a meaning due to common usage. When a recognized source for a specific definition is available, it will be indicated at the end of the definition. More information pertaining to HF subjects as discussed in this document may be obtained from a list of "Reference and Related Documents" contained in Appendix A. Appendix C contains a list of acronyms that are used in this document.

Backup Display or Data Source is the display of a parameter or selection of a different data source when the pilot elects to use it in lieu of the primary display or data source of that parameter. (Source: committee consensus) **Basic-T** is the standard arrangement of flight instruments displaying attitude, altitude, and airspeed and heading information. (Source: 14 CFR PART 23.1321.)

Design Eye Box is a three-dimensional volume of space surrounding the Design Eye Reference Point that designers and evaluators use to determine the acceptability of display and control locations. The design-eye-box is defined as a 2-½ inch sphere centred on the Design Eye Reference Point that encompasses the eyes of a pilot from the expected user population when properly seated at the pilot's station. (Source: Committee consensus)

Design Eye Reference Point is a single reference point in space selected by the designer where the midpoint between the pilot's eyes is assumed to be located for design purposes when the pilot is properly seated at the pilot's station. The reference point is the centre of the design-eye-box. (Related terms include 'operational eye position' and 'flight eye position'). (Source: AC 25.773-1)

Expected User Population refers to the physical characteristics and operational experience of a cross section of the user population that will be expected to pilot an aircraft. The population definition should account for critical dimensions that are pertinent to the operation of the system under consideration. (Source: committee consensus)

Function (as used in systems design) is a characteristic action required to be performed or to be accomplished by one or more of a system's elements: human, hardware or software. A function may be defined at *any level* of a system. It may be further decomposed to *any number of lower levels* of functionality (e.g. sub-function, sub-sub-function, etc.) relative to the originally defined system requirements. Functions are then allocated, based on the system design, to be performed by the human, hardware, or software component.

NASA TLX Evaluation is a multi-dimensional subjective workload rating technique. This method requires the evaluator to perform two types of evaluations to obtain a measure of workload. The first method requires the evaluator to select from a series of paired words or phrases to determine which one of the two best describes the impression of workload for the task. The second part requires the evaluator to rate each of those same word phrases using a scale to indicate their singular contribution to workload.

Primary Display is the display of a safety of flight parameter that is located in front of the pilot. A Primary Flight Display (PFD) is an example of a primary display.

Primary Field-of-View is based upon the optimum vertical and horizontal visual fields from the design eye reference point that can be accommodated with eye rotation only. With the normal line-of-sight established at 15 degrees below the horizontal plane, the values for the vertical (relative to normal line-of-sight forward of the aircraft) are +/-15 degrees optimum, with +40 degrees up and -20 degrees down maximum. For the horizontal visual field (relative to normal line-of-sight forward of the aircraft),

❖ HUMAN-CENTERED DESIGN CONSIDERATIONS

Innovative Design Leading to Improved Safety

This document provides HF guidance that will enhance the ability of manufacturers to use the advances made through new technology to economically produce and certify innovative designs improving operational safety. It is necessary to note that innovative designs, in and of themselves, do not ensure improved safety. However, appropriate implementation of new designs using new technologies will produce the desired safety improvements.

Human Centred Design Process

Certification programs can derive benefits from the application of a human centered design process. The designer should develop a process to ensure that HF is considered throughout the design, development and evaluation stages of the program. One such approach is described in ARP-4033. The HF design process should be an internal company activity that is in place prior to the design being started. These HF design criteria need to be addressed during the conceptual phase of the design to produce timely certification approvals. Overall, the Human Cantered Design (HCD) goal is **to optimize the composite system design as installed in an aircraft; not just the design of an individual product or subsystem.** A consistent human-system interface for the pilot should result from the process of developing a systems solution.

HUMAN FACTORS IN PRODUCT DEVELOPMENT & EVALUATION

The designer's task is to address HF issues and considerations, both with respect to the specific system being developed, and to the operational use of the aircraft and its systems. A goal of the design team is to ensure that the aircraft and its systems are safe, easy to learn and The level of involvement of human factors expertise in the test and evaluation of the system is one of the most important determinants of a successful product development effort. This section provides guidance related to conducting human factors assessments. Test and evaluation methods may be used for entire cockpits, integration of new system components into existing cockpits, or single individual components without reference to a specific cockpit.

Purpose of a Human Factors Evaluation

The purpose of conducting a HF evaluation is to ensure that the HF criteria are correctly addressed. This is accomplished by data collection and testing regarding the adequacy of the system design and operational characteristics in the performance of tasks and functions associated with the system/component. For a system that provides an interface for human interaction, such as a control panel or display screen, human performance becomes an essential part of overall system performance. It is therefore essential that human factors designers conduct early evaluations of the capability of the human and system to perform the intended functions.

Design & Evaluation Teams

As systems continue to become more complex and integrated, the need for HF considerations becomes even more critical to ensure safe aircraft operation. History has substantiated the benefit of developing teams comprised of different disciplines when designing, developing and evaluating complex systems. Essential to an effective and well-balanced design team is adequate representation of human factors expertise with adequate authority to ensure HF principles are considered in the design. Such a team should be composed of display designers, control designers, human factors specialists, flight test pilots, customer pilot population; and flight operations, manufacturing/quality, training and certification personnel.

Human Factors Coordinator

It is desirable that a single individual or one office in a particular organization, with adequate organizational authority to ensure HF considerations are addressed, be identified and held responsible for the direction and coordination of human factors activities and participation in design reviews. These individuals should have some formal training in human factors principles and several years of experience, particularly in the application of human engineering principles and practices in the design, development and evaluation of aircraft systems/products.

Benefits

An evaluation plan can provide many benefits to a design and development organization including:

- Serving as a checklist to assure proper project planning has been performed with regard to the evaluation of the functions involved, the product and sequences of events,
- Assuring that a thorough review of applicable user, operational and environmental requirements and related design guidance have been accomplished,
- Providing a "road map" for project progression from beginning to end, Assisting in efficient project management,
- Aiding in the early identification and resolution of HF-related issues,
- Reducing misunderstandings and last-minute difficulties both inside and outside the design organization, and
- Reducing program costs and schedule impacts.

Design Goals and Activities

A HF evaluation plan should be developed early in the design program to ensure that human factors expertise is available and functioning during the conceptual development phase and throughout the life cycle of the system. The plan should address the processes and methods that will be employed to verify the design concept. Some of the specific goals and activities that need to be addressed in the human factors plan relative to the evaluation of a system (including the human pilot) are listed below.

Goals:

– The pilot is capable of operating the provided functions without exceptional skill or ability and without excessive effort, either physical or mental (requirements fall with normal range of human capabilities).

– The design is suitable for the intended use by the pilot (human operator).

– The design is intuitive to the point that no training is required to use it.

Early Analysis

Prior to development of the plan, human factors experts and representative users should be involved in analysis of system operational, conceptual and design requirements. The type of analyses that may be conducted include: high-level cognitive/behavioural task-analysis procedural evaluations (complexity, number of steps, nomenclature, etc), reach analysis via computer modelling, time-line analysis for assessing task demands and workload, or other methods depending upon the issue being considered. The goal of this effort is to identify key HF issues and areas that need to be addressed in the HF evaluation plan. The evaluation plan should focus on those areas and issues that appear to be the most problematic. Usually, these areas are comprised of complex and/or frequently performed tasks subject to error, which could have detrimental operational consequences if performed incorrectly.

Tailoring the Plan

Installation of a new or modified system or device that results in a different human-vehicle interface or human tasking will need to be assessed for its human-performance implications. The level of assessment will vary proportional to the degree of change of the physical characteristics and operational procedures for a given control/display interface device. The primary concern should be what effect the new operation will have on human tasking and overall system performance. All assessments should begin with some type of high-level analyses to identify changes in pilot tasking with the new system. For systems that have very little effect on the human vehicle interface, for example replacing a standard analogue fuel indicator (needle) with a digital readout of fuel remaining, the level of analysis may be quite limited. In some cases, a simple description of the change, rationale for the modification and any underlying human tasking/performance assumptions would suffice. Modifications that significantly change the human-vehicle interface will require a more thorough analysis to ensure that all of the key human factors issues have been identified. There are certain attributes and characteristics of a component that should be considered when deciding which level of evaluation to use and how representative it is of the test article and test setup (fidelity). The list that follows is by no means comprehensive, but includes some of the more important issues that need to be considered.

- **Independence & Interaction**

  An independent, stand-alone system that does not interact with other aspects of the pilot interface in the cockpit would most likely require little analysis or evaluation. However, for components that are more integrated with other systems in cockpit and/or with higher levels of interaction and that perform functions critical to safe flight, more in-depth evaluations with greater fidelity will need to be conducted.

- **Novelty**

Technology that is more mature and in wide use with a proven track record would most likely require minimal analysis and/or evaluation. However, new or novel applications of existing technology also should be subject to more rigorous test and evaluation methods.

- **Complexity/Automation**

Complex manual and automated systems impose demands on the pilot that are difficult to envision and understand. Consequently, more sophisticated and realistic testing must be employed to understand and identify human-system interface and performance issues. Tests should be performed using the system's normal and backup or reversionary modes of operation.

- **Criticality**

Highly critical systems that could affect the safety of the flight if misinterpreted or operated incorrectly should be tested in realistic environments (high-quality simulation or flight testing).

- **Dynamics**

Highly dynamic control or display features need to be evaluated under conditions that replicate the expected dynamic flight environment.

- **Training Requirements**

Products that are relatively simple to learn and operate in the cockpit would most likely require little analysis or evaluation. A goal is to make the system as simple to use as possible such that little or no training is required. Training should not be used to compensate for design shortcomings. However, some products will likely require a significant amount of training to operate and the interfaces will probably need to be evaluated in an environment that replicates the full spectrum of activities in which the pilot may be involved.

- **Subjective Criteria**

Requirements that have specific, objectively measurable criteria can often employ less sophisticated and involved test and evaluation methods. As more subjective criteria are used to qualify the system interface and performance, more integrated and representative testing will need to be conducted to compensate for the greater uncertainties associated with subjective evaluations.

The design team should refer to the above list when developing the HF test and evaluation plan. Once the system function under examination has been categorized in these areas, tests should be selected that are commensurate with the level identified in the above areas. The information presented in Table 6.1 provides a high-level summary to define the level of effort and test fidelity required to evaluate an HF design based on the categorization of the attributes and characteristics.

Level of Interaction, Novelty, Complexity/Automation, Criticality, Dynamics, Training Requirements and/or Subjective Criteria

Low	Moderate	High
-System Description & Drawing Review, - Visual/Manual Access Study, - Procedure Evaluation, - Task Analysis, and/or - Bench and/or Flight Tests	- System Description & Drawing Review, - Visual/Manual Access Study, - Procedure Evaluation, - Task Analysis, and/or - Bench Tests -Part-task - Demonstrations using: -Electronic Models, -Mockups, -Simulators, and/or -Actual Aircraft on the Ground	- System Description & Drawing Review, - Visual/Manual Access Study, - Procedure Evaluation, - Task Analysis, and/or - Bench Tests - Demonstrations using: -Electronic Models, -Mockups, -Simulators, and/or -Actual Aircraft on the Ground - Comprehensive, Full-task, Integrated Evaluations conducted in: - High Fidelity Simulators, and/or in - Actual Aircraft and Flight Environment

Table 6.1- Guidance for Defining the Level of Human Factors Test & Evaluation Required

Human Factors Evaluation Plan

A well-written evaluation plan provides a structured, consistent approach that documents the assessment, identification and resolution of HF issues. The plan describes the evaluation objectives, the evaluation approach, test equipment, data collection and analysis techniques to be used. The purpose of a human factors evaluation plan is to define an evaluation approach for determining the acceptability of a specific aircraft or subsystem function. The evaluation plan defines how human factors testing and evaluation will be conducted. This evaluation should be conducted from a human-machine interface perspective of the operational functions of a system as the development of the products occurs. HF issues need to be considered in periodic design reviews of the products. Methods to take early corrective action for revisions to the product requirements and the design data need to be in place as HF issues are addressed and solutions resolved. This plan should consider appropriate operational issues and scenarios. This will include such items as defined mission of the aircraft, operational environment, expected weather during operation, etc. If it is planned to install the system in various aircraft categories and sizes, there also needs to be an evaluation to determine if versions of configurations need to be addressed. The plan needs to cover the design from conception throughout the life cycle of the system. A key aspect of this process is to identify design and/or operational deficiencies that may degrade human-system performance.

The use of testing to discover design and operation deficiencies can provide valuable information about the impact these deficiencies will have on pilot-system performance and aircraft safety. Based on the results of these evaluations, decision-makers can better determine whether the system is acceptable as is, or if modifications are necessary. Further tests and evaluations may be required to determine the adequacy of alternative configurations or of modifications incorporated to address specific design and operation deficiencies. To guide this process a structured, comprehensive test and evaluation plan should be developed.

The plan should include methods to take early corrective action for resolution of issues identified during the evaluation. This may include deficiencies to the product and any design modification. At the end of a development program, a report(s) should be completed documenting the history of the HF evaluation. A summary of the results, conclusions and recommendations should be generated. The report should be clearly and succinctly written in terms appropriate for upper-level management to enable them to determine that HF criteria have been met. Although an HF program plan may vary in form and content, there are certain elements that should be included and addressed in any plan. This plan should be at an overview level supplemented by detailed documents, test methods, checklists, etc. as necessary for a particular program.

❖ HUMAN FACTORS DESIGN AND EVALUATION GUIDELINES

The human factors evaluation should concentrate on the cockpit/flight deck as a whole. This may mean that evaluations include individual components, as well as an evaluation of the integrated system. When considering HF evaluation, the appropriate operational requirements need to be considered in addition to the specific evaluation at the cockpit/flight deck level. The design and evaluation best practices guidelines provided in this section have been divided into the following two sub-sections:

- ✓ Systems and Equipment Design Guidelines.
- ✓ Functional Integration Guidelines.

The Systems and Equipment Design Guidelines sub-section focuses on specific and individually defined topics. These items may be assessed by inspection or measurement of physical characteristics such as size, shape, position, brightness, etc. of the displays and controls in an aircraft that provide the human interface to the cockpit. However, they may require the use of the following types of assessment tools.

1. Workload analysis and task performance analyses can take on several formats with several different techniques. They can focus on a subsystem (e.g. hydraulic system control); on a collection of subsystems (e.g. avionics suite); or on the entire cockpit. These evaluations are recommended for new installations or as appropriate for retrofit installations into existing cockpits. Because the human-machine interface usually involves consideration of several factors, these analyses will usually include a number of variables for computing the results.

2. The results of tests conducted on a sample of the user population and characteristics may be necessary. If it is possible, it is preferred that human performance be objectively measured. Measured performance data may be used to document the human performance of the tasks that the subsystem or system requires. The data for any of these approaches may be taken in part-task simulators, full-motion simulators, or on actual aircraft as defined in the HF evaluation approach to be used.

The Functional Integration Guidelines sub-section focuses on topics that are the result of placing sub-systems or systems in the same cockpit. They are often the result of introducing new levels of integration of previously separate display or control functions. In any case, most of the issues related to integration will require the use of the assessment tools and sample population methods noted above. In some instances redundant information may be presented in more than one section. This has been done intentionally to reflect important aspects of one particular criterion to one or more other criteria.

WHAT IS A CHECKLIST?

The major function of the flight deck checklist is to ensure that the crew will properly configure the airplane for any given segment of flight. It forms the basis of procedural standardization in the cockpit. The complete flight checklist is sub-divided into specific task-checklists for almost all segment of the flight, i.e., PREFLIGHT, TAXI, BEFORE

LANDING, etc.; and in particular before the critical segments: TAKEOFF, APPROACH, and LANDING. Two other checklists are also used on the flight-deck: the abnormal and emergency checklist. This paper will address only the normal checklist. We believe that normal checklists are intended to achieve the following objectives:

1. Provide a standard foundation for verifying aircraft configuration that will attempt to defeat any reduction in the flight crew's psychological and physical condition.
2. Provide a sequential framework to meet internal and external cockpit operational requirements.
3. Allow mutual supervision (cross checking) among crew members.
4. Dictate the duties of each crew member in order to facilitate optimum crew coordination as well as logical distribution of cockpit workload.
5. Enhance a team concept for configuring the plane by keeping all crew members "in the loop."
6. Serve as a quality control tool by flight management and government regulators over the flight crews.

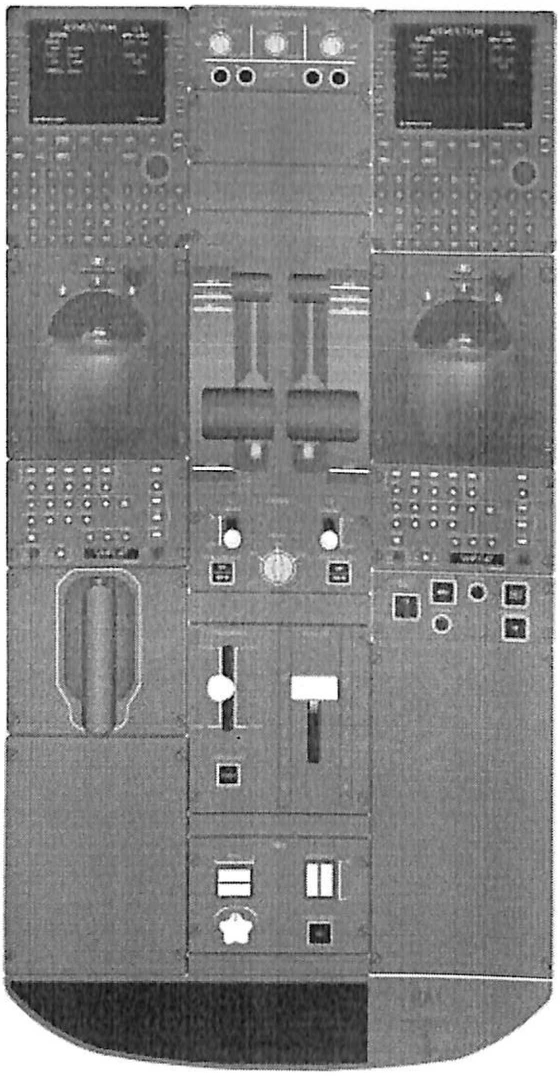
In many cockpits, the addition of new systems to an already existing highly complex interface, have resulted in the inability of the crew to cope with critical conditions. The implementation of the multi modal interface has in some cases been done in an unstructured way and without evaluating the full consequences of the combination of outputs (Woods, 1995; Mårtensson, 1995).

2.6 Evaluating

❖ Evaluating Novel features

The introduction of new and novel controls and displays into the cockpit has resulted in new potential risks when using them. Novel features could be new hardware such as a *Cursor Control Device* (figure 3) or the new operational use of existing controls and displays for a more complex task (CDU at the top of figure 2). The resulting error risks, workload increase and training requirements are all issues that must be addressed when introducing such designs (JAA, 2001). Due to the higher level of automation and complexity of such installations, the use of a classic subjective evaluation by a test pilot has great limitations. The new designs must be evaluated for logic, feedback and error tolerance in both normal and failure conditions. In addition, the failure cases where the highly automated system misleads the crew could have unanticipated consequences. In order to overcome the shortcomings of the existing regulations, temporary guidance material has recently been introduced (JAA, 2001).

Figure 2: A typical layout of modern cockpit controls (Do728)



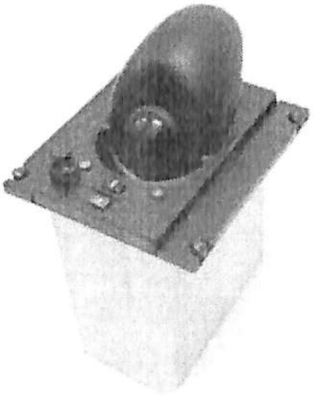


Figure 3: Novel cockpit controls – Cursor Control Device (CCD) (Do728 - Honeywell International)

❖ "Band-Aid" fixes

The present method of evaluating a commercial cockpit design is based on contractual requirements, time and scope constraints and the trend to minimize certification risks. Unlike the large manufacturers, the majority of the airframe manufacturers have infrequent new projects, limited research resources and compressed test schedules (Singer, 1992; Singer, 2000). In contrast to most military projects, commercial ones usually allow only two years for design and one year for development and certification flights (Singer & Persson, 1996). Due to these time constraints, very little experimentation is done for validation of new design features and approvals are made based on "Good Engineering Practices". In many cases the evaluations are done using paper mock-ups or early prototypes and the final result is forced through the certification process as "Good Enough". Despite test pilot protests, error-prone design features are approved due to the lack of a "Certification Paragraph" that could be used to enforce a change. Test teams are often faced with a more or less finished design and have very little room to mandate changes.

The constraints above have contributed to cockpit design solutions that lack a formal validation and therefore probably incorporate deficiencies that might cause or facilitate crew errors (Courtney, 1999). Some would claim that such error risks will usually be captured by other safety nets such as procedures and training but how reliable are these nets? This has been explored by many including representatives of the certification authorities (Newman, 1997).

❖ Training to cover for design flaws

When the design finally enters service, it often lacks the full means of training and documentation. The manufacturer of a new aircraft is required to comply with the airworthiness regulations but much more is needed for the efficient use in service. Training requirements for the crew are not part of the mandatory *Airplane Flight Manual* (AFM) and usually require extensive work by training centres and airlines to be made complete. A training simulator might not be available prior to introduction into service and detailed design philosophy and training needs are not specified. This issue, when not taken into account during initial evaluations, may contribute to extra risks due to errors made by the new users.

The general goal of training is to improve response reliability and robustness of failure management and increase anticipation of alarm situations to the point of creating an ideal alarm less environment. There seems to be a gap between designers and training pilots when it comes to the level of system understanding required. Addressing the training issues early in the design process and publishing a clear system philosophy to the users will help eliminate such gaps.

❖ Inadequacies of the evaluation methods presently used by industry

The following examples illustrate the process used by the aircraft industry to show compliance with the present design requirements. These examples illustrate the typical small scale manufacturer and do not criticize the larger manufacturers that usually have more leverage to force tailor-made designs. Furthermore, the role of the test pilot in each method is highlighted for discussion reasons.

❖ Cockpit ergonomics

One of the first tasks of the test pilot in a new project is to evaluate mock-ups and prototypes of the cockpit and its levers. For flying the aircraft, the most important control features in a cockpit are the primary controls usually called the control-column or control-wheel. In most commercial aircraft (Airbus 320/340 family is an exception), pitch and roll are determined by the pilot by moving a control column forward and aft and rotating a control wheel left and right. The position and size of the wheel is central in the design of the whole cockpit and requires a thorough and systematic evaluation throughout the design and development process. The designer must assure the full travel of the controls when a pilot is seated, that the cockpit displays are not significantly obscured by the controls in any position and ensure the crew ability to egress the cockpit.

All of the above can be evaluated in a partial cockpit mock-up. By selecting evaluation pilots of different sizes and percentiles (including some with extreme combinations) the ability to use the full travel of the controls and reach the rest of the cockpit functions is evaluated. Since the pilot seat can be adjusted in several degrees of freedom, it is essential to determine that all evaluations are done using the pre-determined position that is equivalent to all pilots. A Design Eye Point, a three-dimensional position in the cockpit, is defined as a point where it is assumed all pilots can position themselves and perform all duties (FAA, 1998). This position is also the one determining the other display positions and the field of view available out of the cockpit windows. Even though full travel of the controls can be determined in such a mock-up, the forces required for moving the controls are not fully defined (for reversible controls) until the flight test phase. The smaller the size of the control wheels, the less it obstructs the pilot's view. On the other hand, a small wheel results in a shorter moment arm between the pivot and the pilot hands thus requires higher forces (Singer, 2000).

❖ Avionics systems integration

The integration of the different avionics units into a cockpit is a demanding and frustrating phase in testing and certification. Since not all systems are fully defined yet, many features are only preliminary and the full interface logic is not complete. The level of dependency between sensor data, logic and displays is very high and requires a very systematic approach. In today's integrated cockpits it is no longer possible to visualize the outcome of all input combinations. Even though the primary logic is usually defined, many secondary effects might be overlooked. Lacking an effective evaluation tool, the system engineer is faced with the need to make subjective engineering judgments without a thorough validation process.

At this phase the test pilots are often asked to contribute with an interpretation of system operational aspects, opinion on the ease of use and the risks of error. Due to the lack of evaluation tools the pilots usually revert to previous experience which results in subjective evaluations and isolated proposals. In most cases common sense results in a good design, but the validation process is missing. Pilots are very highly biased to previous experience that might not be relevant to the new design. Personal bias is known to be a dominant issue in selecting warning text messages for example.

One of the most complex and time-consuming processes when developing an advanced commercial aircraft is to define the system feedback logic and display interface. With the increased complexity of aircraft systems and the reduction of the number of crewmembers that operate the aircraft in service, cockpit design philosophy has to be revaluated. In the past, each system had dedicated dials and warning lights which the crew was to monitor and understand. With the limited number of systems, each having only few parameters that could give a direct feedback to the pilot, workload during malfunction was reasonable and pilot options limited.

With the introduction of advanced glass-cockpit aircraft using highly automated engines and flight control systems, the situation changed. The systems were integrated in such a way that one failure could cascade into multiple failures of other systems. In addition, the sensing and monitoring features became more capable and could display the detailed faults and system status.

The result was an overload of warning information in the form of audio and visual feedback to the crew at critical stages of the flight like in the case of the MD80 accident in Sweden 1991 (Mårtensson, 1995).

As a method of design, the manufacturer looks at the possible failure cases for each system, the expected effects, and the way the crew is expected to react and show compliance with the written requirements. In addition, test pilots are involved in the determination of the system interface suitability in all foreseeable conditions (displays, audio sounds and tactile feedback). Since the matrix of all combinations is endless, safety analysis is made to isolate the most probable failures and the ones with the most severe effects.

❖ Flight testing

Traditionally, flight test has always been assumed to be the best method to evaluate a system, since it is tested in *end-to-end* operations in actual flight conditions. Typically, following a ground test period on the aircraft prototype, the system is found safe to fly and the test teams are given the task to evaluate its usability in flight. Most test version systems have many deviations from the final product but the basic function is usually available. Therefore many restrictions are set on flight test configuration, limiting testing scale and exposure to less than the full envelope. Nevertheless, flight test is in many cases the best tool for the task.

The flight test technique used by the test pilots for evaluating control characteristics requires precision and patience. It is the pilot's task to help define the most critical conditions for the test to cover all foreseen future flight conditions. In many cases the flight test methods succeed in identifying problems and result in changes that make the control response acceptable for use in all foreseeable conditions. In several examples (Singer, 1992) the flight test method failed to give the expected results in time and the project suffered considerable delays. High fidelity simulation based on a more detailed aerodynamic model would allow an earlier fix and could contribute to a better initial product.

❖ Certification criteria

Any aircraft in service must meet rules and regulations set by the aviation authorities. In the Western world today, most countries follow the rules set by the *American Federal Aviation Administration* (FAA), the *Joint Aviation Authorities* (JAA) for most European countries, or close derivatives of these rules. The airworthiness rules guaranty that the aircraft will be designed to certain standards, and meet minimum system safety levels and aircraft control in all foreseeable conditions. In the case of large commercial aircraft (above 5.7 tons) the set of requirements are called *Federal Aviation Regulations Part 25* (FAR 25) or *the Joint Airworthiness Requirements* (JAR 25).

The fact that an aircraft is·built to the airworthiness standards does not clear it for operations. Separate requirements exist for each nation and type of operations that mandate the rules set for the airline regarding aircraft equipment; its use, crew training, duty time, maintenance etc. In the USA operational rules for airlines are regulated by FAR 121 or FAR 135 and in Europe by JAROPS. The mandatory FAR/JAR 25 paragraphs are usually very generic regarding new technologies. Nevertheless, when applying for approval of a new interface installation, several FAR/JAR rules must be complied with (Singer & Dekker, 2001 – Paper B). The vague rules and guidelines show the difficulties in showing specific compliance especially with the introduction of complex integrated systems. The terms ease, smoothness and costiveness used in the regulations are inherited from the traditional cockpits with mechanical levers, switches and buttons. In the domain of electronic screens and keyboards the FAR/JAR 25 (FAA, 1998) requirement is very vague since feedback from computers is rarely felt. How do these terms translate into software dialog on a modern display? Modern cockpits require almost no physical effort, but the means of measuring mental fatigue are not described and neither is the acceptable level stated. How should one use these requirements to determine reasonable concentration of fatigue when programming an obstinate FMS in difficult flying conditions? The system designer or evaluator is faced with the impossible task of showing that the installation provides convenient operation and prevents confusion and inadvertent operation. The term prevent, if interpreted as an absolute state, will make a design of a complex interface unrealistic. Labelling of controls is a straightforward rule regarding normal cockpit controls. But how does one define labels on an electronic display? When checking existing displays, it becomes clear that although partially addressed in the advisory material such as AC 25-11 (FAA, 1987), there is no standard and that more guidance on means of compliance is needed. For example, terms like effect of error should be used and what tests the design has to pass are shown. The requirement to function properly when installed is easy to evaluate on mechanical levers, but how can this be achieved with any certainty on an FMS? In the PC environment, display architectures have become standardized to some extent following the international standards for Visual Display Terminals (VDT) (ISO 9241, 1997-1998). Such guidelines are missing for cockpit interface systems like the FMS. How can one determine what is simplicity and how much training is needed for the crew to reach the level of ease stated in this requirement when existing practices, routines and vulnerabilities change as a result of the introduction of a new technology? In general pilot skill is not defined sufficiently and no criteria are stated as to the adequate levels required to operate a new novel system safely.

❖ Certification flights

The certification authorities are faced with a dilemma concerning the interpretation of the rules. Their task is to check compliance with regulations that are often outdated and irrelevant for the new design. General rules requiring *ease of use* for example, lack a fail/pass criterion that has been shown to be accepted by previous validation. The reliance on older design solutions is often used to approve new designs based on the so-called *Grandfather Rights*. When a manufacturer applies new design features that might reduce the susceptibility to human error, it is unclear what kind of certification credit these features might give the design. The lack of objective criteria results in the introduction of special conditions and issue papers that try to fill in the gaps in the regulations. Since these papers are usually ad-hoc, suggested requirements were not considered during the design phase and conflicts tend to rise. Certification flights of failure modes are usually done after a proper briefing, using a build-up approach and by trained crews. The certification pilots are then asked to extrapolate the results to an operational environment and the typical end user. These assumptions are subjective and may vary significantly between certification teams. The unpredictable results increase the project risk since early ruling is difficult to attain. Many high-risk certification tests are done in engineering simulators in order to expose the systems to the limits of the envelope. These tests require a simulation tool validated to satisfy the needs of the specific tests. The need to achieve high fidelity in simulation at an early stage of a new aircraft project may delay the use of the simulator and result in late or incomplete evaluations.

The current methods of validating the design and usability of a new cockpit are not sufficient when evaluating the new complex systems in a modern commercial aircraft. The following summarize these issues:

- Usability Tests are made on subsystems in isolation with the final design. The full extent of the system interface and complexity is seldom implemented in these tests.
- The tools used usually display static conditions and in many cases consist of a paper schematics or Boolean logic only.
- The evaluator, often a test pilot, is asked to answer in a subjective manner since objective criteria are often not agreed upon.
- New and novel features such as highly automated controls and displays, contain new potential risks that are difficult to identify and quantify using the traditional evaluation methods.
- The evaluator is asked to make predictions as to possible use and misuse by operators of different background and culture. This type of extrapolation and prediction of human behaviour is not the main expertise of a test pilot.
- Typical evaluation results are very subjective and difficult to substantiate in a manner accepted by design engineers and managers. The lack of clear and specific rules makes the task of the evaluator very demanding and places a very large burden on each decision.
- Evaluations are often made without the end user and only by very few evaluators that are also involved in the initial design. This causes a risk for bias that is not counterbalanced in a scientific way.
- Existing research methods are usually not implemented by the industry due to high cost in resources and schedule.
- Finally, when deficiencies are discovered in the final product, the fixes that can be made are often not design ones but rather more training, complex procedures and introduction of operating limitations.

❖ The paradox of information display

The highly automated systems in a cockpit are capable of collecting and presenting a vast amount of information regarding aircraft system status and predictions at a very high level of detail (Figure 5). The user on the other hand, has maintained the same capacity of perceiving, understanding and reacting to this information. This leaves the designer with a paradox of not being able to use all the system capabilities. The art of design becomes the ability to make the correct compromise between the type, quantity, and timing of information display. Not only is that task very demanding, it must be considered taking into account the dynamic change of flight conditions. The physical characteristics of each flight phase are known but still under debate are the combinations of atmospheric conditions, flight conditions and system failure modes to be used for validation. Since even these parameters can be quantified, it might seem like a solvable problem. The issue that has been the concern in recent years is more the ability to predict crew perception and workload due to the information that is displayed (Woods & Sarter, 1998). On the one hand, the pilots' request to be kept in the loop and have good situation awareness while on the other, only relevant information is wanted (Mårtensson & Singer, 1998). The definition of relevant information changes with stress and workload and has been found difficult to determine.

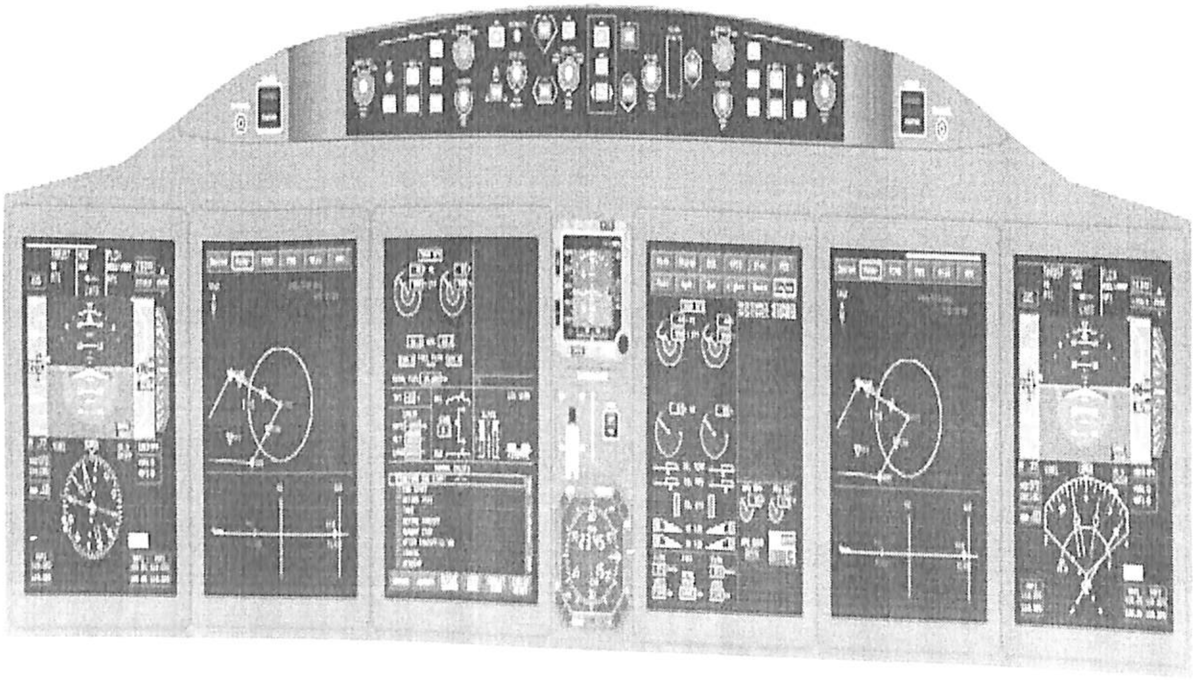


Figure 5 Typical electronic displays with multiple features (Honeywell International EPIC - Do 728)

❖ Warnings and risk communication

Risk evaluation and warning system principles are not unique to aircraft cockpits. The concept of warnings and the communication of risk are well established in many other fields. In the book *Warnings and Risk Communication* (Wogalter et al., 1999), many of the aspects of how to communicate warnings and risk information to be effective, and what factors influence the communication process are explored in detail. The book covers many fields with illustrated examples that relate mostly to traffic signs, medicine and food labels and other conventions. The general method is based on a model called *Communication-Human Information Processing* (CHIP) that includes: *Source, channel, attention, memory, attitudes, motivation* and *behaviour* as steps in a framework.

The authors describe the methods of assessing attention in the context of warnings. Attention can be measured more-or-less directly by tracking eye movements, measuring detection alternatively reaction times or by self-reporting of attention. These three most common methods for measuring attention have their benefits and drawbacks.

- *The eye movement* method is probably the most direct method of assessing visual attention. This method is a good measure especially for investigating the pre-attentive aspects of salience manipulators (border, icon, and color or signal word) and how they draw attention when they pop-out. While very attractive for use because of the exact results, the eye tracking experiments are very expensive and data collection can be time consuming.
- *Detection* or *Reaction Time* (D-RT) is another direct method of measuring attention. While it is much easier and cheaper to use, the drawback is that the researcher does not gain information about the visual path taken in order to locate the warning. In addition, participants can falsely report having detected the warning.
- *The Self Reports* method involves asking the participant questions whether they saw the warning or not. This method should be used only in context of memory studies, but not as a measure of pure attention due to possible bias.

Warnings and Risk Communication describes the different components of comprehension in regards to warning messages. Readability, coherence, explicitness and brevity are important issues when looking at verbal messages. If pictorial symbols are used it is important to know the target user population, their experience with the product, competence (ability to read) and hazard perception. Memory can be measured by open-ended recall, which is asking the participants to recount all they remember. It is usually more important that people remember the idea (lenient scoring) rather that the exact text (strict scoring) of the warning. Another method of checking memory is by recognition tests. These tests are more realistic than memory recall since safety warnings are supposed to cue people about potential hazards. Matching techniques may also be used but it does lend itself to guessing. What we as humans perceive as the truth is often only attitudes and beliefs. This is very important to remember in order to understand risk perception when evaluating a warning message. Beliefs are any cognitive content, which is held as being true. If people do not believe that they need to take precaution, they will ignore the warnings.

The authors of *Warnings and Risk Communication* also treat methods in which one can evaluate compliance with warning information and signs. One method used is called the *Incidental Exposure*, where the participants are not informed that the study deals with warnings. Instead a cover story is given and behaviour is expected to be more as in real life. The method might be including deception, which requires consent and approvals. In summary, the authors state that little research has been done regarding how warnings influence beliefs and attitudes. This is a very important issue in the cockpit where very determined and strong willed individuals communicate. Despite the relevance of many of the findings described above very little implementation of such methods has been seen in the aviation industry. The issues of language, belief, or even pure recall issues are not part of an approval process. Is it the lack of time or the lack of a requirement to do so? Could general rules of design be implemented to the aircraft world or is it too unique in its environment?

❖ Addressing human error

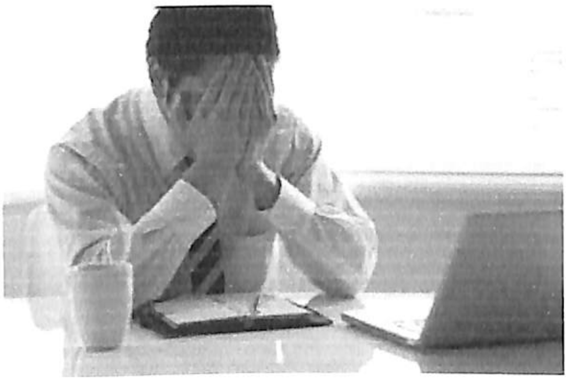
Human error has been deeply investigated for its causes by Reason (Reason, 1990) and several theories produced. The well known "Swiss Cheese" model illustrating the defences that prevent an accident from occurring is one relevant for cockpit design. The model divides errors into several subsets of behaviour but does not quantify or specify the means to determine the size of the holes in the cheese slices. In a recent paper addressing the classification of human behaviour, a team from the University of Illinois Aviation Research Lab (Shappell et al., 2001) explain a new *Human Factors Analysis and Classification* tool (HFACS). The tool uses data gathered during accident investigations and develops the human error classification proposed by Reason into more operational related errors. *Errors* are separated from *violations* and each group addressed in detail. This process helps to focus on areas that require training of skills and supervision programs. The weakness in this method is its reliance only on past accidents and its lack of reference to cockpit technology (especially novel features). In addition, the problem remains regarding what level of training is needed for safe operations and how to test training effectiveness in a reliable way (Rignèr & Dekker, 1999).

In the article *Coping with Complex Alarms* (Gibson, et al., 1996) the authors discuss sophisticated alarm systems in aircraft. They propose some recommendations for changing the training strategies. They state that the foundation of advanced training is that crews need to know more than merely how to work the system in order to diagnose problems. They must have sufficient knowledge about the system functional levels down to the level where they can have an effect on the outcome. This will help their mental model and reduce the risk of commission errors.

A new approach of addressing human error as part of the design safety analysis has recently been proposed by the CAA (JAA NPA, 2001). It goes the partial step of recommending the insertion of all human errors into system safety analysis. What is missing from the proposal is the identification of levels of risk introduced by these errors, whether in normal operations or errors following system guidance.

❖ Human performance using warning systems

Error tolerance and prediction capabilities are expected of future warning systems. The aim is to allow the operator to experiment with the control of variables and predict their outcome before committing to the action. The system will predict the results and the crew can determine whether to accept or take another action. The way an alarm is annunciate today, by very annoying alarms, guaranties detection but might be counterproductive to effective diagnosis. Diagnostic aids should be given more attention.



Sequencing is suggested as a method of for example replaying the event at pilot's choice. Prioritizing and grouping are techniques used already on existing systems, but in a way of spatially organizing the display as to show systems that are closely related as a single global variable that is easier to monitor. The author describes display integration where emergent features, which are the size and shape of an object, will show early trend changes of the status of a system. The meaning of colour should not only to be status related but also be dependent on the operational phase. Prioritization logic has been implemented in most aircraft system designs but grouping and error tolerant designs have not been systematically implemented yet, partly due to other constraints (commonality with older models, space, and cost). One reason might be that pre-design activities are very limited, the subsystems are designed by independent vendors and the philosophy of a system usually takes form too late for significant changes.

❖ Validating simulators for Human Factors use

Mission Oriented Simulators (MOS) are often used in Human Factors research. The level of fidelity needed for such research is evaluated in a *National Aeronautics and Space Administration* (NASA) paper (Orlady et al., 1988), guidelines for conducting such research determined and recommendations for alternative methods given to improve research productivity. The paper gives very valuable inputs to researchers using simulators and provides checklist and tips for test teams.

The *Mission Oriented Simulation* method gives the opportunity to determine which level of simulation is sufficient and for what purposes and scenarios. The idea is to validate data of several devices (from full simulator to part-task PC). In this approach flight-testing is required to gather actual flight data of the scenarios. It is then necessary to validate the behaviour of the simulations in each required test condition. If the expected characteristic does not appear in the simulation, the fidelity is probably insufficient. Since some deficiencies will not be seen by objective tests, subjective evaluations of *Subject Matter Experts* (SME), such as pilots, are needed for a complete validation.

Another aspect of MOS is the pilots' acceptance of the scenarios and representations. It was found that while accepting deficiencies in simulation fidelity, pilots did not tolerate unrealistic tasks and scenarios. NASA therefore recommends that the overall conditions leading to tactical and strategic decisions must be realistic in order to test failure conditions. One last comment regarding simulations is the need to avoid exposing the crew to experiences that might be psychologically damaging, such as a crash of a fully loaded large transport aircraft.

Limited simulation tools have been used in most recent aircraft projects. The main aim has been to look at flight controls interface and handling characteristics prior to flight (Singer & Person, 1996). The use of simulation for display and logic verification has been limited to *Bench Testing* of local interfaces rather than a full aircraft layout. The reason being the difficulties in validation, of the simulators in order to get credit for test results based on those tools only. It was often found that the complexity of the system and its integration with other aircraft sensors made the investment unreasonable and therefore the actual aircraft was used as a simulator for limited testing prior to flight.

❖ Decision aids for the complex cockpit

In modern complex cockpits, the crew is required to absorb many pieces of information often in time critical conditions. In several papers on *Model Based Reasoning* (MBR) applied to cockpit warning systems (Ovenden et al., 1993; Noyes et al., 1995; Ovenden, 1993), the authors describe the advantages of using MBR techniques as a method of making warning systems more "Intelligent". The cases when multiple failures occur simultaneously are discussed and the potential of conflicting procedures highlighted. It emphasizes the importance of ensuring that appropriate warning system information is presented in a form that the individuals can readily understand. MBR provides a novel approach to warning system design and is in general based on a system model representing the correct function of each condition. By comparing actual behavior to the modeled one, early trends of failures or abnormalities can be detected and the crew informed. Unlike conventional systems that are fault oriented, the Model-Based system can take into account broader goals such as strategic inputs, navigation, fuel left etc. A detected discrepancy can be identified and categorized (convergent, divergent, stable, oscillating) and the relation to the predicted model displayed.

The main advantages of this method are claimed to be the early detection and reaction to slow and non-linear parameter changes that would usually have gone undetected until developed into a more serious condition.

Finally, the method allows a more flexible and goal driven prioritization to be programmed that will reduce pilot workload and improve decision support in cases of complex failures. This method has been partly used in the integration of a warning system into a helicopter project. The reluctance of industry to have a more widespread use of predictive systems is the long development and testing time needed and the risk for large number of nuisance warnings when entering service. As long as no specific requirements are set by the user or the authorities the manufacturer will probably take the low risk approach to design. In many cases the added value of an early predictive warning is questioned by the operators. It might cause larger number of diversions or flight cancellations that are not directly flight safety related (Nibbelke, et al., 2000).

❖ User involvement

The research method based on *User involvement* (Noyes, Starr & Rankin, 1996; Noyes, Starr & Frankish, 1996), shows advantages of using pilots in the design process. Unlike the ICIS experimental method (ICIS, 1997) described above, this method uses the pilots for knowledge elicitation in the early stages of a project. More than 1300 questionnaires were evaluated and analyzed. The pilots represented were the typical end user population using modern systems, and flying different types of aircraft. By defining criteria and addressing the different functions of warning systems for example, designers can improve the features of future warning systems to take into account present deficiencies. By getting a large sample of pilots, the risks of bias and other validity risks (Cook & Campbell, 1989) are minimized and external validity of the results is secured. In order to ensure the robustness of the widely spread questionnaire, a semi-structured pre-study interview process using smaller numbers of participants was performed. This allowed the team to evaluate the comprehension, semantics, style and content of the questionnaires. After completing the analysis of the questionnaire results, the team returned to a small sub-sample of flight deck crew to check the validity of the results.

This method is sensitive to interpretation of terms and scenarios but the use of the three-stage interview method (Noyes et al., 1995) assures that the *user-interface* will also be *user-oriented* in the design. Unfortunately, such broad subjective methods require unacceptable time and resources from a competitive industry and unless a simpler and much more limited method can be provided, this will remain a method used for research. It would be helpful if generic recommendation could be implemented in certification guidance material as an aid in a design process.

❖ Implementation by industry

When reviewing all the research done regarding Human Factors aspects of cockpit design issues, it is surprising to notice that very few of these methods and results have been implemented in the aircraft industry. Although the large manufacturers do engage in research projects with several known institutes, the final design products show very little traceability to such research (FAA, 1996; AIA/AECMA, 1998).

A positive example though is the cooperation between industry and researchers (Boeing &

Massachusetts Institute of Technology (MIT)) in the study which focuses on the display features of the new terrain displays (TAWS) (Kuchar & Hansman, 1993) introduced in the last few years into all large aircraft. The research gives concrete results to industry on the best method to display terrain by providing pilot ratings and pilot response based on part-task simulation. The general conclusion was that the plan view (map like) display was best perceived by the pilots and also showed best avoidance response. Even though some of the issues were not fully covered, it seems like most of industry selected to pursue this track and present terrain (TAWS) in the map mode.

Despite all these research examples, very little has been used by industry when approaching the design of a new cockpit. Some large manufacturers might have used structured methods but many smaller ones have not. The author's personal involvement in the development and certification process at SAAB Aircraft and Fairchild-Dornier shows very little has been done in the way of a structured Human Factors cockpit evaluation process or implementation of external research results.

❖ What information does the pilot need?

Information overload in the cockpit of a commercial aircraft during malfunctions or emergencies is a serious concern, which originates from several aircraft accidents (FAA, 1996; Billings, 1997). In one accident case (SAS accident, Sweden, 1991), an MD80 lost thrust from both engines shortly after takeoff. The crew was presented with an unusual amount of critical information. Visual and aural warnings were given as well as alert messages on the overhead enunciator panel, all at the same time (Mårtensson, 1995). The pilots were overloaded with information, and in interviews performed several years later (Mårtensson & Singer 1998), many pilots suggested that information in the warning system should be prioritized in a way that the pilots could perceive it properly and act accordingly (Woods, 1995; Ulfvengren et al., 2001). The crew alerting systems of the modern transport aircraft can handle almost any malfunction that the pilot is expected to deal with. These features are tested, certified and taught to crews in simulator training sessions. There are variations in the philosophy of display of the alerting information between the manufacturers but many methods implemented in today's aircraft show satisfactory results and good human integration for the task defined (Pritchett, 2001). However, in case of multiple faults in a high workload situation, the warning system of the modern cockpit is not always easy to use and understand. The tendency is to overload the display with *warnings*, *cautions* and inoperative system information accompanied by various aural warnings and cues. The pilot becomes overloaded with information and cannot handle all at one time. The result is that the pilot may disregard the information, return to basic flying, and rely on his own perception of the situation, a strategy which turned out to be the correct one in the accident mentioned above, but might have catastrophic effects in other emergencies. This issue is addressed in detail in Paper A of this thesis and empirical results are presented and discussed. The present regulations define only few individual warnings in detail (red and amber colour use, landing gear warning, etc) (CFR14, FAR 25.1322). Several design standards have been developed, some giving the pilot the entire information available (figure 9), some implementing a certain level of prioritization and others providing high levels of automation followed by system guidance. All of these methods have been approved but none was scrutinized by objective criteria of *fail* or *pass* based on operator response. Test pilots faced with these systems often revert to a subjective evaluation that tries to look at the consistency, readability and lack of ambiguity of the displays. Despite many simulator sessions for evaluating failures, these are done by a prepared crew and in a sterile environment. The minimum qualified pilot is usually not requested to participate in the certification of failure cases of a new design.

❖ Integration of FMS

In commercial flight, on most modern aircraft today, navigation and flight path are being controlled by a system generally called the *Flight Management System* (FMS). The interface with the crew in the cockpit is achieved by an active display called the *Control Display Unit* (CDU) and is the input/output channel. In addition, the system displays its planned/executed route on a *Navigation Display* (ND) and flight path guidance by means of a *Flight Director* (FD) on the *Primary Flight Displays* (PFD).

The technical requirements and methods for testing system performance, accuracy and fault analysis are well established and are defined in the certification material (AC 25-15) for such systems and aircraft (FAA, 1998). The methods for technical validation of such systems have been used successfully in many types of aircraft avionics and have shown a very high level of reliability. However, validation of the way the system interfaces with the crew, displays information or reacts to crew inputs is not well defined and each manufacturer or vendor is free to adapt its own philosophy and methods of showing compliance (Singer, 1999). This issue is addressed in detail in Paper B of this thesis and the specific design features are presented and discussed.

In the late nineties, new *Air Traffic Control* (ATC) regulations were published that mandate the installation of FMS into all aircraft that use medium and upper airspace in Europe (part of JAR OPS 1). This produced growing demand for cheap *off-the-shelf* systems for integration into older aircraft of all sizes. Many of the transport category aircraft flying today have not been designed with an FMS as part of the cockpit. Many aircraft are still featuring the so-called *classic-cockpit* and are lacking the modern avionics bus communication technique used on the integrated cockpits. When such designs are evaluated, it is for the correct function of the system during normal operation but not for possible error modes and crew mismanagement. In order to explain the problem in more detail, examples from present modern FMS designs are described and deficiencies highlighted. The risk involved in these features will be shown and possible effects of making an error will be discussed.

The CDU is the main interactive interface between the crew and the FMS for programming and checking performance. The standard interface includes a screen, line select keys, alphanumeric keys, specific function keys and warning lights. This design is typical to all manufacturers, but unlike the typewriter (or PC), there is no standard position for the letter keys. In addition, several function keys have a different use in each design (figure 10). The *Navigation* (NAV) key for example; on one design is used for *navigating* while on another design it is used for *planning* only. The *Flight Plan* (FPLN) keys; on one design are used for *planning* while on the other they are used for *navigating*. These features increase the risk of *negative transfer* when transitioning between systems. The CDU has a limited display area and in order to integrate all the functions required for navigation and performance, several menu layers are needed. The limited display area, when interfacing with large size navigation and performance data required for today's airspace, emphasizes the Keyhole Effect (Sarter & Woods, 1997). This effect is the property of having small view port relative to the large size data it is used to interface with. Since layers are unavoidable, the design aim should be to minimize the number of layers and more importantly, to keep the operator oriented at all times as to his position and his possible hidden options. The fact that the positioning of these functions is not logical to the operator means that the pilot needs to search by means of trial and error through up to 10-15 menus until finding the right function.

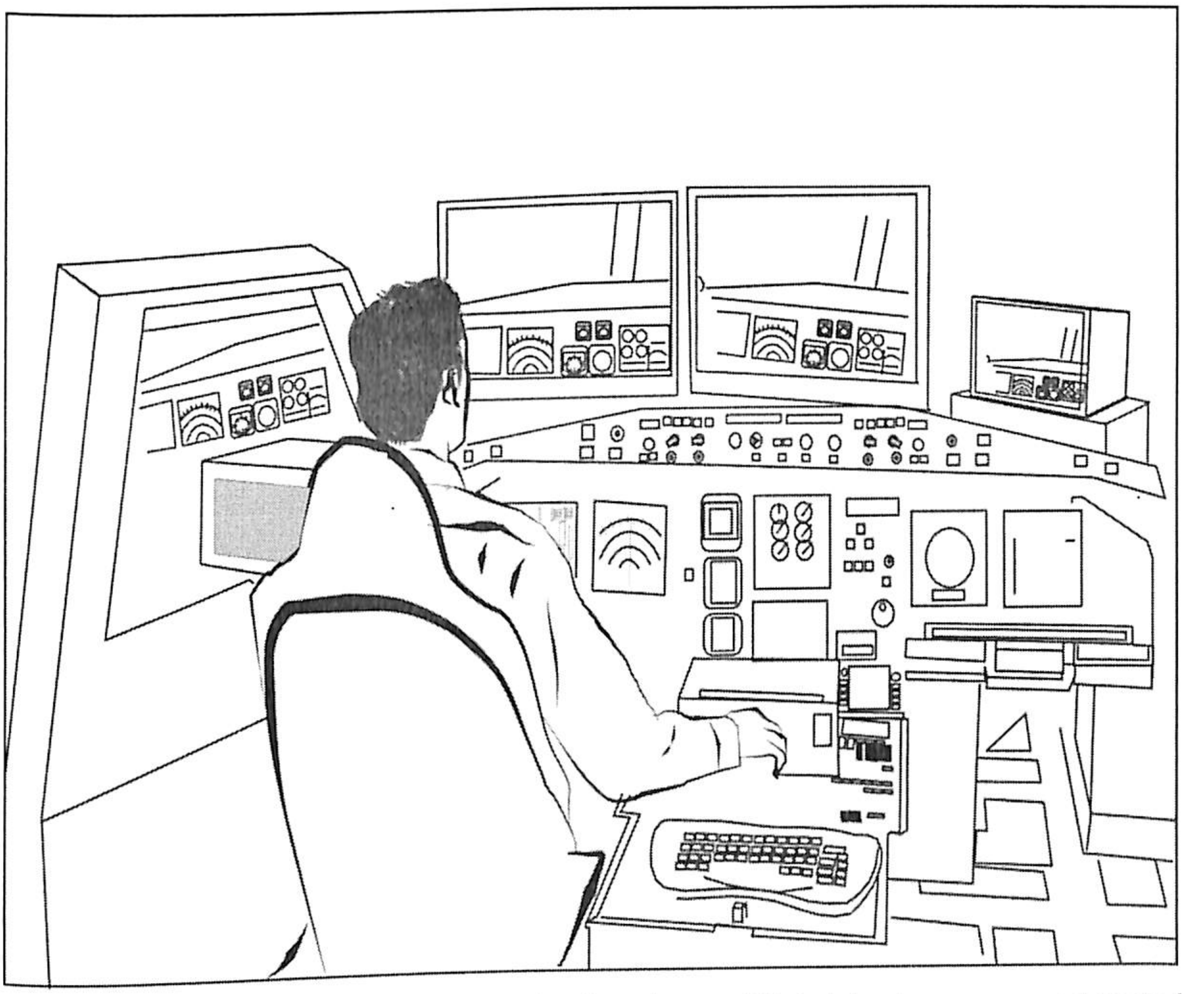
Since no cues are available for this search the pilot has to rely on memory or perform the time consuming search. This is a characteristic that increases workload and frustration and should not be a feature in a modern interactive display.

For flight critical actions, like changing flight plan or selecting a direct route to a new waypoint, some designs allow the pilot to review the navigational change and then accept or cancel it before the change is implemented. Other designs are much less tolerant and once a change is initially prompted it is immediately implemented. Direct-to and delete functions are the normal methods for the pilot to modify a flight plan in flight. These modifications affect the aircraft flight path when implemented and therefore must include cues for crew verification. Since slips and errors are quite common in the cockpit environment due to turbulence, parallax errors or procedural errors, it is essential to have a review function for critical changes. The system in this case must be fault tolerant and include clear review functions.

The CDU, being an alphanumeric display, is not the most optimal display for building pilot situation awareness of aircraft position, trend and navigational forecast. When making a navigation track change some designs depicts both the active track and suggested change for the pilot to review prior to activation. This display on the ND gives the pilot a graphical depiction of the CDU change in form of a temporary route change overlaying the active route. This feature allows all crewmembers to review the change before activation and has been found to increase system fault tolerance. Other designs display the change in aircraft track only after it has been activated and executed. Such changes to active flight path without crew confirmation have been known to cause confusion and reduce safety margins if error made in congested airspace, as might have been the case in a Saab340 accident (FOCA, 2001).

Any user of PC software expects an *Undo* function in order to recall incorrect inputs, whether they are due to errors or slips. This function is not a standard feature in CDU software and each design has its own criteria for providing an *Undo* feature. This feature is lacking even in the flight critical parameters such as *Direct-to* and *Delete* of some FMS models. In order to retrofit existing aircraft, interfaces between *Electronic Flight Instruments* (EFIS) and FMS of different vendors are becoming more common. This may highlight differences in communication standards with the effect that the different displays show different colours for the same waypoint (not fully regulated by *Advisory Circular* AC 25-11) (FAA, 1987). Combining this with aircraft manufacturers who have different colour standards and the resulting display might be confusing and misleading. The lack of industry standards for colour-coding makes the task of integrating avionics difficult and usually with unexpected results.

❖ PC static simulation for measuring pilot response



The next level of simulation used was also based on a PC but having a more automated recording feature and combining more flexibility to change the layout and order of the test points. In addition, the participant replied by making inputs on the keyboard (or joystick). Even here the test was run without any interference from the test conductor. In this experiment the data was collected automatically, and treated also using statistical methods.

Paper D (Singer & Dekker, 2002 – Paper D) describes in detail the empirical research performed to determine the effects of the roll index of the ADI on pilot recovery errors from a banked flight condition. The PC part-task simulation method was found optimal for understanding of the contribution of the sky pointer in roll reversal errors, since the evaluated conditions were static and well defined. The experiments were conducted so that the position of the roll index was varied according to the three different conventions, while keeping the inside-out configuration. The bank angle was varied randomly along the normal operational range across trials, but in order to be sure about the source of performance variance, pitch angles were kept unchanged (at 0°). 13 pilots participated in the test; all flew commercially and had backgrounds in either military or general aviation. The purpose of this selection was to guarantee some familiarity with all ADI formats, while drawing from the population currently most exposed to the commercial ADI.

Using a PC set-up, the three ADI conventions were presented one after the other, in a representation resembling the newer Liquid Crystal Display (LCD) ADIs, with 10 trials for each set-up. Each pilot thus conducted 30 trials, with the typical experiment lasting about 20 minutes. The order of format presentation was randomized across the pilot sample in order to offset any learning effects. In each trial set, bank angles were varied randomly across an operational range of up to 50° in both directions. ADIs with a static bank angle were presented for 1 second, after which the pilot had 10 seconds to recover from the bank angle using a computer joy stick or keyboard. The time of presentation (1 second) and static bank angle were used to mimic the kinds of situations that were the interest of this study (FOCA, 2001). The experiment relied on automatic test sequences and recordings, with no experimenter intrusions. The direction of the initial recovery was recorded, as well as Reaction Time (RT), that is, the time to start the initial recovery. Following the recovery attempt, the pilot was asked to indicate the perceived bank angle within a range of 10°. This secondary task was given in order to ensure that pilots were using the ADI for precision bank angle determination, focusing them on the roll index. Directions of recovery, RT and pilots' estimates of bank angle were all recorded automatically for later analysis. At the end of each test the subject was asked to his preferred ADI prior to disclosure of the results.

❖ Error rates when reading text

Three methods of message syntax were designed into typical warning messages representing five different failure cases normally encountered. The data collected from 11 subjects, each exposed to 15 cases was analyzed for errors using electronic multiple choice questions.

The following results were attained after 165 runs:

Display method:		**Error rate:**
Speech oriented	(Do728/S2000 inspired)	**4%** errors (2 of 55 runs)
System oriented	(A320 inspired)	**8%** errors (4 of 55 runs)
Index oriented	(B777 inspired)	**17%** errors (9 of 55 runs)

These results show a clear decrease in error rates when using the speech-oriented method (Do- 728, S-2000) of writing a warning message. The message grammar is based on normal spoken English grammar rather than a system or maintenance oriented syntax. The results are based on a limited number of subjects and do not take into account the total design philosophy of each aircraft type. Nevertheless, based on equal conditions and using a limited simulation, the results do show a significant difference in pilot error rates.

When comparing several methods of text syntax to display warning messages, the results showed that the solution using a natural speech word hierarchy (write as you speak), produced the least errors in recall. In this case the goal was to determine the best of three more or less equivalent technical solutions and to aid management in accepting a Human Factors subjective recommendation by using empirical results. Based on this experiment the guidelines for a new aircraft cockpit display philosophy was modified and implemented (Fairchild Dornier, 2001)

❖ Measuring end-to-end performance and workload

In the certification process of the HUD as the means of pilot-in-the-loop approach aid (Singer & Dekker, 2001 - Paper B) a detailed description of using a full flight simulator for certification was shown. The total performance of the aircraft, including pilot precision, errors and variation were all measured and analyzed statistically in all predicted environmental and operational conditions. The participants were the typical end-users with minimal training on the new HUD system and the testing was done in high workload and fatigue conditions. Since this specific certification of the SAAB 2000 HUD in 1995 (Singer, 1999), many other HUD systems have been approved in a similar way with impressive airline safety record (FSF, 1997; HF-HWG, 2001). When evaluating the future certification of integrated systems like the FMS, the method used in the HUD certifications is proposed as an effective tool for validating other complex systems with pilot performance issues. Navigation systems can be measured as to their ability to follow the intended path, including system performance and crew interface. It is important to keep in mind that when measuring performance parameters not to be tempted to just measure the easy ones.

❖ The DIVA project

The author of this thesis participated as a test pilot and designer in a recent project that addressed several of the deficiencies and solutions found in Human Factors research and attempted to find practical solutions based on a structured methodology. This project can be used as a good example of a new structure for a *Human Centred* and *Performance Based* approach to cockpit design. The DIVA (Design of Human/Machine and their validation in Aeronautics) project (Nibbelke, et al., 2000) used the experience of the aviation industry and research institutes and addressed the issues of *Controlled Flight Into Terrain* (CFIT) displays and system failure presentation (including early predictions).

The project utilized a step-by-step approach making use of accepted management and cognitive tools. The method consisted of three phases:

- The first phase was gathering the user requirements with the help of a management tool called *Quality Function Deployment* (QFD). This tool was developed to fit the cockpit environment, and included a large matrix that converted customer requirements into lower level engineering requirements. The tool also allowed for subjective ratings of importance and relative importance of the parameters (Nibbelke et al., 1998).
- The second phase included the review of relevant accident data in order to construct realistic scenarios in which the new design feature could be validated. The scenarios were determined based on expert inputs including test pilots. The scenarios were built around simulation tools that allowed exposure of a non-expert crew to time and flight phase limited scenarios. Objective measuring equipment, such as eye tracking devices and data recording equipment were combined with subjective evaluations. Uninvolved experts including test pilots and test engineers performed a structured design review. This was in order to get a second opinion of the experiment layout and correlation with the initial customer requirements. The review also considered whether known human factor guidelines were implemented in the design.
- The last phase was the actual evaluation performed by airline pilots of varying experience and recording objective and subjective data. The simulations were performed with and without the new design features or with different levels of automation of the features. This data was then compared with the initial management tool and correlation was evaluated.

The DIVA project implemented the new approach of systematically using customer requirement criteria, accident data, to base modern technical solutions. The design was determined by experts such as test pilots and validated in simulators using line pilots. Despite the improved approach used by this project, the time scale and simulation complexity encountered requires a simplification of the process in order to become usable for the process of design and validation of a real aircraft project. In addition, the method has not been shown to be superior to the classic method of *good engineering practice* since no parallel conventional approach was tested for comparison.

❖ New Human Factors rules and guidance material

In order to ensure common compliance documentation for all applicants and minimize the competitive issues, detailed certification rules and guidance material must be provided by the relevant regulatory agencies. The requirements for detail do not indicate a need for prescriptive paragraphs. The requirements should be based on freedom of innovation but set strict requirement to provide compliance with predefined performance levels. Several means of compliance should be provided including analysis, simulation or experiments with appropriate fail/pass criteria. Such material should include guidance on error risk quantification, objective performance criteria, the use of simulation and the participating evaluators. In addition, guidance on what credit can be expected for actual service experience without further testing must also be specified.

One effective method of improving future designs is undoubtedly the improvement of the design certification requirements and associated advisory material. For the *Transport Category* aircraft this is mainly regulated by the FAR/JAR 25 (FAA, 1998) and several *Advisory Circulars* (AC/ACJ). As explained in the introduction, the Human Factors contribution to incidents and accidents has become a major concern in recent year. In order to address the Human Factors issues in the cockpit design phase, the *Human Factors Harmonization Working Group* (HFHWG) was formed. The HF HWG was created in August 1999 per the tasking published in the Federal Register, July 22, 1999 (FAA, 1999). The members chosen to build the team were chosen for their expertise in the fields of design, certification, research or operation of modern large aircraft. The author of this thesis was selected for the team as an industry representative contributing with experience as a test pilot involved in design evaluation and certification. The tasking that was accepted by the group can be summarized as follows:

- Review the relevant existing FAA/JAA 25 rules and regulatory material applicable to flight deck design, to determine their adequacy to consistently address design-related flight crew performance vulnerabilities and the prevention and management of flight crew errors.
- Based on this review, recommend the updating of existing rules and advisory material or development of new rules, new advisory materials and the associated implementation plan.

  As work progresses, identify implications for qualifications and operations to be communicated to and addressed by other appropriate groups. The following can describe the methods used by the working group to achieve the tasks (HFHWG, 2001):
- The first approach consisted of a direct review of the regulatory material by using a carefully constructed list of Human Factors topics to examine each component of the rules and associated advisory documents to determine if the topics were consistently addressed or not, and why.
- The second approach was experience based. It started from a collection of data describing either human performance problems (e.g., accidents or incident reports, experience of airline pilots or test pilots) or actual instances in which certification experts could not find regulatory material with which to address an obvious Human Factors design issue. This approach enabled the group to find data driven evidence of deficiencies in the present regulations.

  Starting from an integrated list of the deficiencies identified by both approaches, the group used predefined criteria to derive recommendations for developing or updating relevant FAR/JAR 25 rules and advisory material. These criteria will evaluate the safety benefit as well as the expected acceptance and efficiency of these recommendations and will indicate priority of implementation. If needed, the group will also issue recommendations for additional work that should be carried out on non-FAR/JAR 25 rules (operations, licensing, maintenance, etc.).

The review process performed 1999-2001 (HF-HWG, 2001) showed clearly the weakness of the structure and philosophy of the present regulation framework. The regulations are based on old design solutions, are either very generic or difficult to show objective compliance with or specify outdated solutions. The index system is system based and does not fit the modern integrated cockpit where many systems are cross woven in function, logic and failure modes. The role of crew resource management has not been addressed in the design and the usability issues are mentioned only in general. The main dilemma of the working group is how to turn the rules and regulations into a flexible but consistent tool that will also address future designs and fit with the operational rules that address the cockpit and crew.

The method used to define the best criteria was based on the review of the literature and expertise of the group members. The evaluation criteria are based on the expected safety improvement which will result from the modifications introduced by the HF-HWG, as well as the feasibility of the recommendations, based on technical issues, cost-effectiveness, and the expected level of acceptance by both the regulatory authorities and industry. The prioritization of the recommendations was based on a weighed voting methodology used on previous programs addressing safety initiatives by regulation. This process, which was modified as needed to fit the HF- HWG task, used expert judgment to evaluate recommendations against a set of rating scales, which were then combined partly through the use of a mathematical algorithm. The final report of the group will consist of recommendations for changes in the design regulations and advisory material that will enable to set better criteria for the approval of the human machine interface in commercial aircraft cockpits (final report expected - June 2002). Since not all deficiencies have the same weight regarding potential causation of accidents, the emphasis will be set on such issues that the group has defined as most critical and where a change will have the largest effect.

❖ PILOT IS RESPONSIBLE FOR SAFETY OF FLIGHT

It is understood that the pilot has the primary responsibility for the safety of a flight. It must be appreciated that a system can confuse the pilot or limit his or her ability to control the aircraft safely. This condition may not be immediately obvious to the pilot. If the pilot cannot effectively understand, oversee and retain management authority over the system functions, then the pilot has lost the ability to safely operate the aircraft.

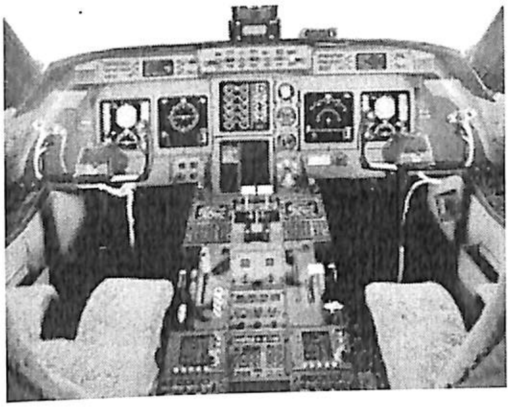
A safety pilot is a rated pilot who helps maintain visual separation from other aircraft, clouds, and terrain while another pilot is wearing view limiting devices for the purposes of simulating instrument conditions. The pilot in command (PIC) of an aircraft is the person aboard the aircraft who is ultimately responsible for its operation and safety during flight.

2.2 REVIEW AREA NARROW

A narrow description about the project is that A cockpit or flight deck is the area, usually near the front of an aircraft, from which a pilot controls the aircraft. Most modern cockpits are enclosed, except on some small aircraft.

- **Human Factors influence on cockpit design and Layouts**

The complexity in instruments displaying aircraft systems and performance resulted in high stress levels and error rates. Examples of this were missed signals, misinterpreted information and limited detection and recognition of a number of instruments by the flight crew (Weiner and Nagel, 1988).



Data shows that there was an increasing trend in the number of displays (Instruments & gauges) up until the 1980's where there was a sharp decrease (Wiener & Nagel, 1988). The reduction of the number of instruments in cockpit designs coincided with the perception and human information processing focus that dominated the HF era in aviation around that same time (Salas and Maurino, 2010). It also coincided with the introduction of next generation aircraft such as the Boeing 757/767 and A310. In modern next generation cockpits the studies of these HF topics are reflected in design. There is not only a significant reduction in the number of instruments but the display of information in the form of glass cockpits reflects the improved understanding of the human cognitive process and the application to this in design of the systems (the objective of HF). Although the aircraft checklist has long been regarded as a foundation of pilot standardization and cockpit safety, it has escaped the scrutiny of the human factors profession. The improper use, or the non-use, of the normal checklist by flight crews is often cited as a major contributing factor to aircraft accidents. This paper reports the results of a field study of flight deck checklists, and examines this seemingly mundane, yet critical device, from several perspectives: its functions, format, design, length, usage, and the limitations of the humans who must interact with it. Certain socio technical factors, such as the airline "culture," cockpit resource management, and production pressures that influence the design and usage of this device are also discussed. Finally, a list of design guidelines for normal checklists is provided. While the focus of this paper is on the air transport industry, most of the principles discussed apply equally well to other high-risk industries such as maritime transportation, power production, weapons systems, space flight, and medical care.

The direction of controls and levers should operate in the natural sense and also flow with the checks and procedures. It is natural for example, to turn a dial clockwise to increase something and anticlockwise to decrease. In an emergency situation where the pilot is overloaded with information, switches and controls will be operated in an instinctive manner which may be opposite to what the pilot intends to do if it is not designed to operate in the normal sense. Boeing's philosophy on switch direction is the 'sweep on' concept, where all switches on the cockpit sweep/switch on with the arm rising up no matter where the switch is located. Although this is very different compared to the Airbus single push ON/OFF button operation, the commonality between the two design philosophies is that it is put in place to reduce the chance of inadvertent operation. The Diamond DA42, a modern light twin training aircraft, has three identical levers for the park brake, cabin heat and cabin defroster situated together forward of the main throttle quadrant. The aft position of lever is to turn the cabin heat and cabin defroster unit OFF but park brakes ON. There has been cases where aircraft have landed with park brakes on (in some cases resulting to a forward flip), the natural tendency for the pilot to line up all the levers would have contributed to the cause of the accidents.

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Modern aircraft systems are integrals of many separate systems which may again be part of another subsystem (Pallett, 1992). Although any part of the system has the potential to fail, the workspace constraints make it impractical to situate all the different warnings in prominent view to the pilot. Typically, a master warning and a master caution light is positioned somewhere directly in front of the pilot. Should the master warning or master caution light up, the pilot will have to determine the source of the problem by referring to enunciator panel located elsewhere or on a more modern aircraft opening the relevant pages in the EFIS system.

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2.3 FACTORS CRITICAL TO SUCCESS OF STUDY

- Various idea about the books
- Proper idea about the topic
- Proper idea about the industry
- User Involvement
- Executive Management Support
- Clear Statement of Requirements
- Proper Planning
- Realistic Expectations
- Small Project Milestones
- Competent Staff
- Ownership
- Clear Vision and Objectives
- Hard working Focused Staff.

While some remained the same, some are no longer in the top ten (clear statement of requirements, realistic expectations, ownership, and hard-working focused staff). At the same time new factors have moved into the top ten (emotional maturity, optimization, Agile process, project management expertise, execution, tools and infrastructure).

The identification of Project Management Expertise as a Critical Success Factor responsible for influencing the final outcome of a project is definitely positive news for project management discipline to continue receiving attention and executive sponsorship.

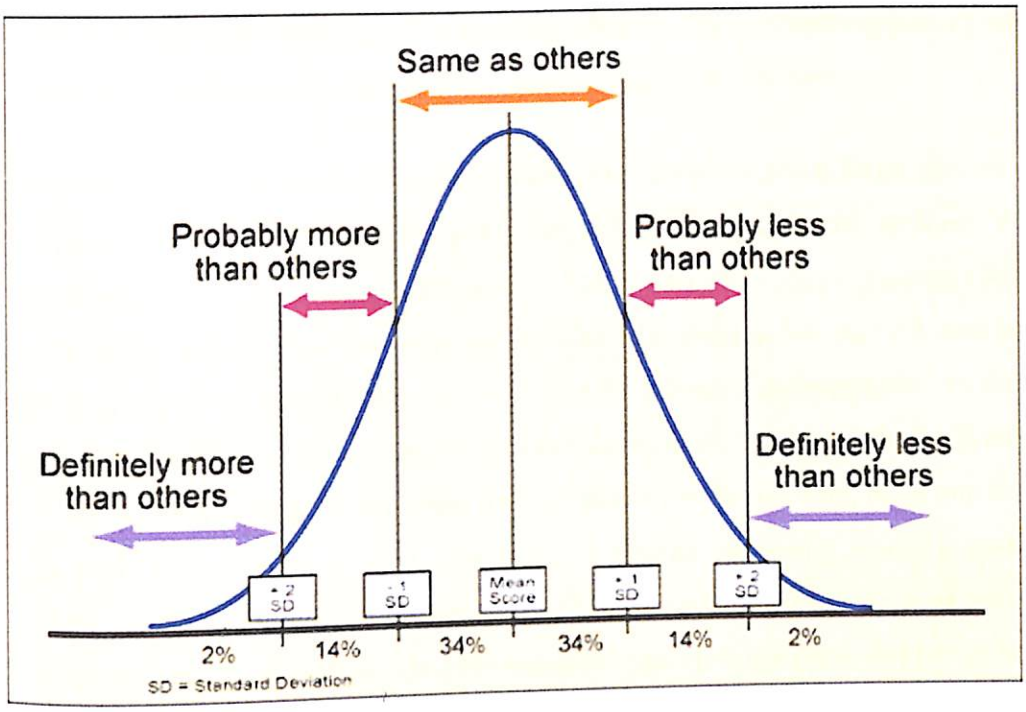
Also the mention of "Execution" is important since time and again it has been shown that well laid plans are of no use if they cannot be executed well. So the focus on Execution is of utmost importance. Project Managers need to keep this list in mind during the various phases of the project and translate it into specific and actionable items for their own projects based on the relevance and importance of each of the success factor.

2.4 SUMMARY

I have written brief about the industry. And also I have used various notes, pictures and graphs for this project. And use the correct way for the success of the project. A cockpit or flight deck is the area, usually near the front of an aircraft, from which a pilot controls the aircraft. Most modern cockpits are enclosed, except on some small aircraft. The cockpit of an aircraft contains flight instruments on an instrument panel, and the controls that enable the pilot to fly the aircraft. In most airliners, a door separates the cockpit from the aircraft cabin. After the September 11, 2001 attacks, all major airlines fortified their cockpits against access by hijackers.

The evolution of cockpit design is credited to the advancement of Human Factors as a formal discipline. The definition of HF by Koonce (1979) reads "The study of the human's capabilities, limitations, and behaviors and the integration of that knowledge into the systems we design for them with the goals of enhancing safety, performance, and the general well-being of the operators of the system". The very early generation of flying was based solely on see (visual) and feel and was a relatively physical task. Control of the aircraft was solely 'stick' and 'rudder' and was a manual operation. Therefore Cockpit design was very basic with very few instruments to provide the pilot with information on aircraft and engine performance, cockpits normally consisted of three or four major instruments and there were only controls for basic flight.

Anthropometry is an integral part of ergonomic design, for aircraft designer's anthropometry is not limited to the measurements alone but also who the targeted users and operators are. It is not feasible to design a cockpit for every individual in the world; rather a normal distribution is used where an aircraft is designed for the 5th to 95th percentile of the intended population (NASA, 1978). (Note that this is not the same as the middle 90% of the population)



The design eye position, also known as eye datum or design eye reference point (DERP) is one of the key aspects of cockpit design. A pilot should be able to view all the main cockpit instruments while maintaining a reasonable view of the outside world with minimal head movement (FAA, 1993). The instruments should be located high enough for easy viewing but low enough so that it does not obstruct the view of the runway ahead during takeoff and landing. The aircraft designer will first allocate a design eye position and from there build the cockpit around it, factoring in the reach envelope the designer can then position the controls, switches and dials to cater for the 5th to 95th percentile of pilots (Coombs, 1999).

In order to operate the aircraft as intended it can be seen that all pilots must use the same reference datum. This is normally achieved by adjusting the seating position in both vertical and fore/aft axis. Some aircraft will also have adjustable rudder pedals and/or control yoke/joy stick to ensure the pilot's view is in alignment with the design eye position. To highlight the significance of the design eye position, sitting just 1 inch below the reference point on a Boeing 767 will result in losing 40 meters of ground vision during final approach.

Airline pilots remain seated for an extended period of time, long haul routes are often in excess of sixteen hours. While the importance of seat comfort itself is explanatory, there is also big emphasis on designing a seat that offers sufficient back support (Roskam, 2002[15]). More information on aircraft seat ergonomics can be found here.

Humidity and illumination can also affect pilot comfort. Most large aircraft cockpits have a separate environmental control panel for pilots to regulate the ambient temperature. The difference in insolation due to the large windscreens often means that the cockpit will require a different setting than the rear cabin. The illumination on the left and right side of the instrument panel should have the ability to be adjusted independently to suit the individual pilot. The display is the presentation of information and can come in the form of visual, aural or tactile. While visual is the main form of display in the cockpit, aural and tactile has its uses as well. Aural warnings from the likes of ground proximity warning system (GPWS) or traffic collision avoidance system (TCAS) and tactile warnings such as the stick shaker are powerful aids for the aircraft to communicate and alert the crew. Warnings will be discussed in more detail later. As mentioned previously the display in the modern cockpit is designed around the design eye position. Ideally all displays should be large, legible, well lit and easy to operate. Due to workspace constraints however more prominent and frequent displays will have priority over ones that are less essential.

Illumination and colour plays a vital role in instrument displays. Instruments and controls can be lit internally, externally or both. Aircraft designers need to ensure lighting does not create glare or shadows and produce the correct brilliance for day and night operations. There should then be a way for pilots to fine tune the luminosity to accommodate each individual's light sensitivity. Modern day LCD screens on glass cockpits have a narrower field of vision; however, as long as the pilot is seated aligned with the design eye position the display should not interfere with everyday operations (Nagabhushana & Sudha, 2011).

The correct use of color schemes can aid in alerting the crew if something needs to be bought to attention. Using too many different colors however may clutter the screen and cause confusion. The main colors used for system monitoring are green (normal), amber (caution) and red (alert or emergency). On the horizontal situational indicator (HSI), the following colors are typically used.

CHAPTER 3

RESEARCH DESIGN, METHODOLOGY AND PLAN

3.1 DATA SOURCE

The two types of data; they are primary data and secondary data. The data in this project is the **secondary data.** The whole of the project is constituted by the secondary data.

Secondary data are statistics that already exist. They have been gathered not for immediate use. This may be described as "those data that have been compiled by some agency other than the user or researcher in question".

There are two distinctive sources of secondary data, they are

- Internal sources
- External source

Some of the external sources are

- Internet
- Published marketing research
- Books and journals
- News sources
- Directories
- Magazines and articles
- Research reports

3.2 RESEARCH DESIGN

In this research I use descriptive research.

Research design is simply a plan for a study. This is used as a guide in collecting and analyzing the data. It can be called a blue print to carry out the study. It is like a plan made by the architect to build a house, if a research is conducted without a blue print, the result is like to be different from what is expected at the start.

Descriptive research is used to describe characteristics of a population or phenomenon being studied. It does not answer questions about how/when/why the characteristics occurred. Rather it addresses the "what" question (What are the characteristics of the population or situation being studied?) The characteristics used to describe the situation or populations are usually some kind of categorical scheme also known as descriptive categories. For example, the periodic table categorizes the elements. Scientists use knowledge about the nature of electrons, protons and neutrons to devise this categorical scheme. We now take for granted the periodic table, yet it took descriptive research to devise it. Descriptive research generally precedes explanatory research. For example, over time the periodic table's description of the elements allowed scientists to explain chemical reaction and make sound prediction when elements were combined.

Hence, research cannot describe what caused a situation. Thus, Descriptive research cannot be used to as the basis of a causal relationship, where one variable affects another. In other words, descriptive research can be said to have a low requirement for internal validity.

The description is used for frequencies, averages and other statistical calculations. Often the best approach, prior to writing descriptive research, is to conduct a survey investigation. Qualitative research often has the aim of description and researchers may follow-up with examinations of why the observations exist and what the implications of the findings are.

3.3 DATA ANALYSIS PROCEDURE

The direction of controls and levers should operate in the natural sense and also flow with the checks and procedures. It is natural for example, to turn a dial clockwise to increase something and anticlockwise to decrease. In an emergency situation where the pilot is overloaded with information, switches and controls will be operated in an instinctive manner which may be opposite to what the pilot intends to do if it is not designed to operate in the normal sense. Boeing's philosophy on switch direction is the 'sweep on' concept, where all switches on the cockpit sweep/switch on with the arm rising up no matter where the switch is located. Although this is very different compared to the Airbus single push ON/OFF button operation, the commonality between the two design philosophies is that it is put in place to reduce the chance of inadvertent operation. The Diamond DA42, a modern light twin training aircraft, has three identical levers for the park brake, cabin heat and cabin defroster situated together forward of the main throttle quadrant. The aft position of lever is to turn the cabin heat and cabin defroster unit OFF but park brakes ON. There has been cases where aircraft have landed with park brakes on (in some cases resulting to a forward flip), the natural tendency for the pilot to line up all the levers would have contributed to the cause of the accidents.

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Modern aircraft systems are integrals of many separate systems which may again be part of another subsystem (Pallett, 1992). Although any part of the system has the potential to fail, the workspace constraints make it impractical to situate all the different warnings in prominent view to the pilot. Typically, a master warning and a master caution light is positioned somewhere directly in front of the pilot. Should the master warning or master caution light up, the pilot will have to determine the source of the problem by referring to enunciator panel located elsewhere or on a more modern aircraft opening the relevant pages in the EFIS system. The most important aspect of any warning system is that it needs to be reliable and only report genuine problems or malfunctions. The crew must be able to trust the information presented to them, even in situations where it may appear to be contradictory to what is perceived to be happening. False warnings can be detrimental to flight safety; a false engine fire warning may result to an unnecessary in flight engine shut down, creating additional workload in an one engine inoperative environment. This is why with some systems such as the GPWS, it is mandatory by law to report any false alerts (known as nuisance warnings). The idea of compiling this information is to enhance the reliability of such crucial equipment. Aircraft controls supplement aircraft displays in communicating to the pilot. It provides a two way interaction between the aircraft and the crew. Controls should be easy to reach and be positioned appropriately in accordance to their usage. Controls which are used frequently should be positioned in a more prominent position. Controls should move in the natural sense and controls that complement each other or frequently used in conjunction of each other should be grouped together if possible. Standardisation is important to avoid unnecessary confusion (Roskam, 2002). Although different aircraft manufacturers have their subtle differences, generally the layout of controls and gauges are set in the natural sense. Good aircraft type knowledge may not always prevent inadvertent actions. The Beech Bonanza, a popular light twin, initially had the gear lever positioned on the right side of the throttle quadrant, a position commonly used for flap settings. This resulted in numerous gear up landings where pilots raised the gear during short finals when the intention was to lower flaps. The manufacturer soon repositioned the gear lever as well as adding a squat switch to prevent the gear rising below a certain power setting. The accident records for gear up landings on the Bonanza is about 40% higher on the earlier non-standard cockpit layout aircraft than the later revised models (Landsberg, 1994). Other notable non-standard control layout aircraft include the Douglas DC-3, where the throttle quadrant levers are arranged as pitch, throttle then mixture as opposed to the standard throttle, pitch, mixture arrangement. Other layouts, such as the standard 'T' instrument arrangement have remained the same since it was first derived.

Direction

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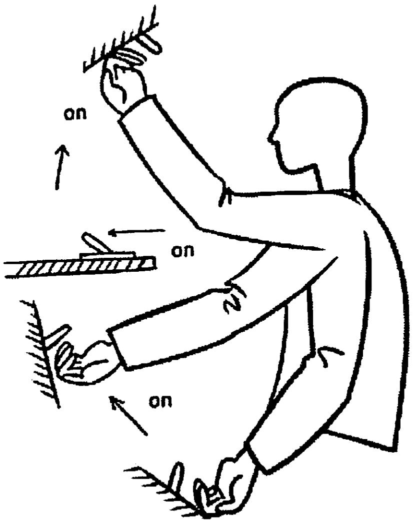

Boeing's 'sweep on' concept means all switches are turned on when switched upwards, irrespective to their location.

Control Loading

Control loading is the amount of forced feedback the pilot receives when manipulating the primary flight control. The force feedback must not be too strong that an average strength pilot will have difficulty in moving the controls, nor too light which will create over controlling problems. The force should be linear and equal between different axis (ie: the sensitivity of pitch and roll are not vastly different). The force should be strong but sensitive enough for the pilot to appreciate what is happening and provide control responses matching to what is required (Enol, 2012). On large aircraft with hydraulic systems this can be achieved by manipulating the control feedback motor torque, on aircraft with direct linkage between control and control surfaces, this is achieved by the use of aerodynamic devices such as trim tabs, anti trim tabs and horn balance which manipulate the aerodynamic force exerted on the control surface..

Warning System

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The idea of compiling this information is to enhance the reliability of such a crucial equipment (Spitzer, 2006).

☐ Checklists

In the modern airline environment, the checklists are as essential as the instruments and controls themselves (Harris, 2004). Checklists and the cockpit layout should be coherent of each other and aircraft manufacturer would have had this in mind before arranging the cockpit layout. The actions should follow a practical flow pattern that is not only easy to remember but can also be conducted swiftly if required.

Cockpit design and layout started from very basic which advanced to an overcrowded cockpit. The introduction of many instruments and gauges was for the purpose of providing information to the pilot regarding the performance of his/her aircraft. This however also resulted in high stress levels and a high error rate due to the lack of the human capability to process all this information. HF advanced in studies relating to the human cognitive process and attention and memory limitations in the 1980's. As a result of the research carried out, cockpits were designed to better suit the human operator. Reduced number of instruments, the use of the Glass Cockpit and the display of information on these screens amongst many other things have all been introduced over recent years. It is inevitable that cockpit layout and design will change, but it is important that this change be in line with HF research which best suits the human operator and their limitations and capabilities.

CHAPTER 4

FINDINGS AND ANALYSIS

4.1FINDINGS

From all the information describes in the project tells that Cockpit design and layout started from very basic which advanced to an overcrowded cockpit. The introduction of many instruments and gauges was for the purpose of providing information to the pilot regarding the performance of his/her aircraft. This however also resulted in high stress levels and a high error rate due to the lack of the human capability to process all this information. HF advanced in studies relating to the human cognitive process and attention and memory limitations in the 1980's. As a result of the research carried out, cockpits were designed to better suit the human operator. Reduced number of instruments, the use of the Glass Cockpit and the display of information on these screens amongst many other things have all been introduced over recent years. It is inevitable that cockpit layout and design will change, but it is important that this change be in line with HF research which best suits the human operator and their limitations and capabilities. Modern aircraft systems are integrals of many separate systems which may again be part of another subsystem (Pallett, 1992[14]). Although any part of the system has the potential to fail, the workspace constraints makes it impractical to situate all the different warnings in prominent view to the pilot. Typically, a master warning and a master caution light is positioned somewhere directly in front of the pilot. Should the master warning or master caution light up, the pilot will have to determine the source of the problem by referring to annunciator panel located elsewhere or on a more modern aircraft opening the relevant pages in the EFIS system. Cockpit design and layout started from very basic which advanced to an overcrowded cockpit. The introduction of many instruments and gauges was for the purpose of providing information to the pilot regarding the performance of his/her aircraft. This however also resulted in high stress levels and a high error rate due to the lack of the human capability to process all this information. HF advanced in studies relating to the human cognitive process and attention and memory limitations in the 1980's. As a result of the research carried out, cockpits were designed to better suit the human operator. Reduced number of instruments, the use of the Glass Cockpit and the display of information on these screens amongst many other things have all been introduced over recent years. It is inevitable that cockpit layout and design will change, but it is important that this change be in line with HF research which best suits the human operator and their limitations and capabilities.

4.2 ANALYSIS

In several cases described in this thesis, the test pilot's role has been different than the traditional one. Instead of being the evaluator, the validation process changed to using the test pilot for assisting in the designing of the experiments and evaluations. The test pilot helps determine realistic scenarios while the typical line pilot, with minimum system training, is used for the evaluation and validation process. The results of such evaluations have shown so far a smooth entry into service and a safe track record for the HUD low visibility landing system (HF-HWG, 2001). Recent acceptance of the new approach to test pilot tasking by test pilots, authorities and designers shows a positive trend in the aviation industry in the direction proposed in this thesis. Finally, the new cockpit design validation process has been shown to assist in achieving a more reliable and systematic means of predicting cockpit usability and safety. It is based on incremental improvements and not one magic solution. The empirical examples described in this thesis are only spot checks for several design issues and are only the first step of applying the new method. International acceptance is needed and time will tell its success. The implementation of systems to provide safe operational use of the whole aircraft requires that, as much as possible, the pilot intuitively understands the system operation and that no surprises occur under normal, abnormal or failure conditions that would induce the pilot to take the wrong action. The system should be designed in a manner that a minimally skilled pilot will be able to use it correctly. A Human Centred Design philosophy provides a method to ensure that pilot expectations are met in the avionics suite performance and operation when it is installed in an aircraft.

4.3 CORRELATION/ REGRESSION ANALYSES

In my project, I use the correlation analysis. It is a statistical technique used for measuring the relationship or interdependence of two or more variable. Cockpit and human factors include many points that can easy to understand. **Correlation**, a statistical measure of a relationship between two or more variables, gives an indication of how one variable may predict another. The descriptive techniques discussed above permit a statement, in the form of correlations, about that relationship. However, correlation does not imply causation; that is, simply because two events are in some way correlated (related) does not mean that one necessarily causes the other. For example, some test data indicate that boys receive higher math-aptitude scores on college entrance exams than girls, indicating a correlation of gender with mathematical ability. But before concluding that gender **determines** mathematics aptitude, one must demonstrate that both the boys and the girls in the study have had the same mathematics background. Some studies have shown that girls are discouraged from taking or at least not encouraged to take more than the minimum mathematics requirements.

CHAPTER 5

INTERPRETATION OF RESULT

5.1 INTERPRETATION OF RESULT

My **hypotheses are true.** My hypothesis is that by designing a cockpit the human safety and comfort is necessary. A hypothesis must be testable, taking into account current knowledge and techniques, and be realistic. If the researcher does not have a multi-million dollar budget then there is no point in generating complicated hypotheses. A hypothesis must be verifiable by statistical and analytical means, to allow a verification or falsification. In fact, a hypothesis is never proved, and it is better practice to use the terms 'supported' or 'verified'. This means that the research showed that the evidence supported the hypothesis and further research is built upon that.

5.2 COMPARISON OF RESULT WITH ASSUMPTIONS (HYPOTHESES)

RESULT: BY DESIGNING A COCKPIT THE HUMAN SAFETY AND COMFORT IS NECESSARY

HYPOTHESES: THERE IS A VITAL ROLE IN COCKPIT DESIGN WITH HUMAN FACTORS

A research hypothesis is the statement created by researchers when they speculate upon the outcome of a research or experiment. Every true experimental design must have this statement at the core of its structure, as the ultimate aim of any experiment. The hypothesis is generated via a number of means, but is usually the result of a process of inductive reasoning where observations lead to the formation of a theory. Scientists then use a large battery of deductive methods to arrive at a hypothesis that is testable, falsifiable and realistic. This is too broad as a statement and is not testable by any reasonable scientific means. It is merely a tentative question arising from literature reviews and intuition. Many people would think that instinct and intuition are unscientific, but many of the greatest scientific leaps were a result of 'hunches'. The research hypothesis is a paring down of the problem into something testable and falsifiable. In the aforementioned example, a researcher might speculate that the decline in the fish stocks is due to prolonged over fishing. Scientists must generate a realistic and testable hypothesis around which they can build the experiment. This might be a question, a statement or an 'If/or' statement. Some examples could be: Is over-fishing causing a decline in the stocks of Cod in the North Atlantic. Over-fishing affects the stocks of cod. If over-fishing is causing a decline in the numbers of Cod, reducing the amount of trawlers will increase cod stocks. These are all acceptable statements and they all give the researcher a focus for constructing a research experiment.

CHAPTER 6

CONCLUSION AND SCOPE FOR FUTURE WORK

CONCLUSION

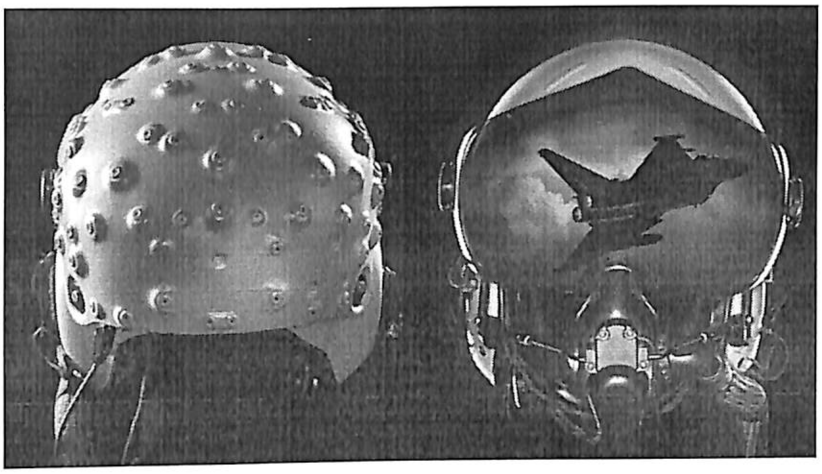
Cockpit design and layout started from very basic which advanced to an overcrowded cockpit. The introduction of many instruments and gauges was for the purpose of providing information to the pilot regarding the performance of his/her aircraft. This however also resulted in high stress levels and a high error rate due to the lack of the human capability to process all this information. HF advanced in studies relating to the human cognitive process and attention and memory limitations in the 1980's. As a result of the research carried out, cockpits were designed to better suit the human operator. Reduced number of instruments, the use of the Glass Cockpit and the display of information on these screens amongst many other things have all been introduced over recent years. It is inevitable that cockpit layout and design will change, but it is important that this change be in line with HF research which best suits the human operator and their limitations and capabilities.

FUTURE WORK

If you think your office needs a lick of paint and some new furniture, spare a thought for fighter pilots. Those who fly fighter aircraft like the F-16 or the Tornado are still, in effect, working in a 1970s office - because that's when those aircraft were originally designed. It takes a very long time to build a new fighter jet. Lockheed Martin's F-22 Raptor is currently the only supersonic stealth fighter in active service – but when the contract for the first prototype was signed in 1986, Apple's top-of-the-range Macintosh Plus computer had a mere 1Mb memory and no hard drive. The F-22 carried out its first combat mission on 22 September this year – three days after Apple released the iPhone 6. Technology has transformed in those intervening 28 years, and nothing dates faster than yesterday's vision of the future. Today's aircraft designers must guess what the world of 40 years' time might look like – a task that even the innovators in Silicon Valley might baulk at. "At the moment, I'm looking at stuff out to at least 2040," says Mark Bowman, chief test pilot for BAE Systems at Warton, Lancashire.The most modern jets – such as the RAF's Eurofighter Typhoon and the Lockheed F-35 Joint Strike Fighter that is yet to enter service – feature helmet-mounted displays, voice-activated controls and airliner-style control sticks. This is a big change from the cockpits cluttered with dials and buttons that fighter pilots flew in a few decades ago.

➢ Multi-tasking

Today's combat pilots may need to be simultaneously tracking an unidentified aircraft, watching live video footage of troops on the ground under fire from enemy forces, and talking to commanders back at base. They shouldn't have to also be scanning an array of dials and instruments to work out whether they're pointed in the right direction and how much fuel they've got left.



➢ Virtual cockpit

"Eye tracking; gesture control; neuro control; augmented reality - these sorts of things are being looked at," says Bowman. "If we go to an extreme, there might be something like an avatar with you in the cockpit, potentially helping you with decision-making."

The Typhoon and F-35 may offer the best clues as to what the fighter cockpits of the future will look like, but there is another aircraft which points an intriguing direction forward. The Reaper unmanned aircraft 'cockpit' isn't inside the aircraft: the crew – a pilot and a sensor operator – sit in front of an array of screens in a ground control station, which may well be thousands of miles away. In the future, that remote cockpit might not need to be on the ground: it could be inside a fighter jet, with one pilot controlling their own aircraft and a number of other unmanned ones at the same time. This wouldn't necessarily just be about gaining numerical advantage. "We fly people in Typhoons up to +9G and down to -3G, and you don't really want to go beyond that," Bowman says, referring to the multiples of the force of gravity that a pilot experiences during hard manoeuvres and which can cause pilots to black out. "But if you were linked to some sort of unmanned combat aircraft, that may give you higher levels of agility." With no human in the cockpit to lose consciousness from excess Gs, the sky really could be the limit.

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