SUITABLE UTILITY HELICOPTER COCKPIT DESIGN FOR TURKISH PILOTS

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ABSTRACT

SUITABLE UTILITY HELICOPTER COCKPIT DESIGN FOR TURKISH PILOTS

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Designing a suitable utility helicopter cockpit for Turkish pilots is the main theme of this thesis. Helicopter cockpit is one of the ultimate human machine interface application. Consequences of pilot errors during flight in any helicopter cockpit can be catastrophic. Human errors can only be prevented by user-friendly cockpit design. In this thesis, reach compatibilities to controls in the cockpit are evaluated and the suitable positions of analogue indicators at front display panel are examined in order to obtain a user-friendly utility helicopter cockpit design.

Human anthropometry is the most significant factor for evaluating cockpit reach compatibilities to controls; so all critical operational reach parameters of Turkish pilots are examined. The anthropometric study revealed vision problems and showed that the height of display panel is inappropriate for most pilots.

Suitable positions of the indicators on pedestal are determined by using qualitative and quantitative approaches. As a quantitative approach Multi Criteria Decision Making (MCDM) algorithms are employed. Card sorting methodology is used for the qualitative evaluation of the aforementioned display panel design.

Although there are some approaches in literature for designing of displays, a specific design methodology related with the arrangement of indicators on display panel is not offered so far. In this thesis, MCDM and Card sorting approaches are adapted and used in the design of a display panel for the first time. There are lots of similarities between the results of MCDM and Card sorting approaches. The main similarity is to provide separate locations on display panel for engine and flight system indicators. Finally the findings of these techniques are compared with the existing layout of the display panel of a utility helicopter.

Keywords: Cockpit Design, Anthropometric Evaluation, and Display Panel Design

ÖZ

TÜRK PİLOTLARINA UYGUN HELİKOPTER
KOKPİT TASARIMI

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Bu tezin temel konusu Türk pilotlarına uygun bir genel maksat helikopteri kokpitinin tasarımıdır. Helikopter kokpitleri en üst seviyedeki insan-makina ara yüzü uygulamalarından biridir. Uçuş süresince herhangi bir helikopter kokpitinde meydana gelebilecek pilot hatalarının sonuçları yıkıcı olabilir. İnsan hataları ancak kullanıcı-dostu bir kokpit tasarımıyla önlenebilir. Bu tezde kullanıcı-dostu bir kokpit tasarımının elde edilmesi amacıyla, kokpitin içerisindeki kontrollere uzanma mesafelerinin uygunluğu değerlendirilmiş ve ön paneldeki analog göstergelere ait uygun konumlar incelenmiştir.

Kontrollere uzanma mesafelerinin uygunluğunun değerlendirilmesinde antropometrik veriler en önemli faktördür, bu nedenle Türk pilotlarına ait bütün kritik uzanma mesafeleri incelenmiştir. Antropometrik çalışma görüş alanı ile ilgili bazı problemleri ortaya çıkarmış ve gösterge panelinin yüksekliğiyle ilgili bir uygunsuzluk tespit edilmiştir.

Pilotların zihinsel yüklerini azaltmak maksadıyla, ön paneldeki göstergelere ait uygun pozisyonlar nitel ve nicel yöntemleri uygulayarak tespit edilmiştir. Çok Kriterli(Amaçlı) Karar Verme (MCDM) teknikleri nicel bir yöntem olarak kullanılmıştır. Kart sınıflandırması metodu is anılan gösterge paneli tasarımın nitel olarak incelemesinde kullanılmıştır.

Literatürde göstergelerin tasarımıyla ilgili bir çok yaklaşım olmasına rağmen, göstergelerin bir panel üzerine yerleştirilmesiyle ilgili spesifik bir tasarım metodolojisi şu ana kadar önerilmemiştir. Bu tezde bir gösterge panelinin tasarımında ilk kez Çok Kriterli(Amaçlı) Karar Verme ve Kart sınıflandırması metotları adapte edilmiş ve kullanılmıştır. Çok Kriterli(Amaçlı) Karar Verme ve Kart sınıflandırması metotlarının sonuçları arasında bir çok benzerlik bulunmuştur. Temel benzerlik ise gösterge panelinde motor ve uçuş göstergeleri için ayrı alanların tahsis edilmesidir. Bu sonuçlar halen kullanılmakta olan bir genel maksat helikopterinin gösterge panelinin yerleşimi ile karşılaştırılmıştır.

Anahtar sözcükler: Kokpit tasarımı, Antropometrik Değerlendirme ve Gösterge Paneli Tasarımı

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CHAPTER-I

INTRODUCTION

Flight deck is the ultimate human machine interface application. It uses human senses of touch and sight in a safety critical situation. Aviation systems, present at flight deck, are complex environments causing excessive mental workload and the consequences of errors can be catastrophic. In order to prevent any human error a user-friendly cockpit must be designed. Utility helicopter cockpit design, that is pilot- flight deck interaction, is the main concern of this thesis. Thus reach compatibilities of the cockpit due to aviator anthropometry and positions of analogue indicators at front display panel to provide right and easy perception of information must be determined.

The reasons of excessive mental workload for the pilot are related with the number of stimuli in the cockpit, like the output produced by warning indicators, status displays, flight path displays, ATC data links, weather information, navigation information communications and a constant need of situation awareness. (Stokes & Wickens, 1988). For example, the pilots of an American Airlines Boeing 757 bound for Cali, Colombia, altered their landing approach from one that required them to pass over the airport and reverse course to one that involved a shorter, straight-on approach in December 1995, The pilots became so distracted by display interfaces and functions while interacting with automated systems used to navigate the aircraft's flight path. They failed to notice that they were heading directly toward El Deluvio mountain peak and at 9:38 p.m. they struck the mountain at an elevation of 8,900 ft, killing all of the 163 passengers except 4 on board (Aeronautica Civil, 1996; Strauch, 1997). The reduction of pilot workload with the new technology is generally exploited by the addition of another new system (Billings, 1997; Smith, 1999). Effects of new systems and the expansion of automation in the cockpit on pilot performance are not considered. On April 14, 1990, an Indian Airlines Airbus A320 aircraft crashed just short of the runway at the Bangalore, India airport. The aircraft was destroyed and 90 people were killed. The probable cause of the accident was the failure of the pilots to realize the gravity of the situation and immediately apply thrust. Pilots tried to understand why the auto flight system was in idle/open descent mode in the final seconds of the flight. (Funk, Suroteguh, Wilson, and Lyall 1998)

Despite the aforementioned accidents there is still relatively little research on human and cockpit interface interactions. The inadequate feedback on status of the system, lack of visibility and designs, that do not reduce cognitive load are the fundamental reasons of interactions problems. Another matter is that the operators do not fully apprehend what their automated aviation systems are doing. These problems may lead to situational awareness errors and overall system failures. (Sarter, Woods, & Billings, 1997). For instance the Flight Management System (FMS) was designed to optimize flight paths. The features of the FMS have changed. (Billings, 1997). However the interface itself has remained relatively static. Thus it requires about 1,200 hr of experience for a pilot to achieve a real understanding (Riley, 2001). All of the required features are available, but they are difficult to execute. The FMS is a good example of a system that has features defined from an engineering perspective. User perspective is not considered. The Federal Aviation Administration (FAA) Human Factors Study Team Report showed that about 70% of the fatal accidents on the interaction between flight crews and modern cockpits are due to human error potentially induced by the design of cockpit interfaces (Singer, 1999).

Lack of standardization of aviation system interfaces also increases the number of errors (Singer, 1999). Interfaces can vary from one environment to another. Adapting to different interfaces is difficult for pilots and air traffic controllers in terms of transferring their abilities and experience to different cockpits or ATC stations. Furthermore the needs of the novice operator may not be considered, because of the fact that experts generally evaluate systems. It is vital that new systems and new components for existing systems must be evaluated both for their functions and comparative usability.

This thesis is presented in four chapters, trying to solve the usability problems of cockpits in terms of reach compatibilities and locations of analogue indicators to prevent aforementioned human errors. In Chapter II, an overview of display design literature is reported. Review of the theories and existing approaches, dealing with the problem of useful display design, will be discussed. Methodology of thesis is explained in Chapter III. The literature review and the theory related with the research methodology are also given in Chapter III. In order to show the appropriateness and sufficiency of AS-532 Cougar helicopters for Turkish pilots an anthropometric evaluation is made. Some problems related with eye levels are found. Then, front display panel of a general utility helicopter is designed via quantitative and qualitative approaches. Multi Criteria Decision Making (MCDM) algorithms are used as a quantitative approach. For the qualitative analysis of the same problem Card Sorting methodology is employed. Chapter IV and Chapter V are devoted to interpret and discuss the results of methodologies stated in Chapter III. The results of experimental study are compared with an existing display design.

CHAPTER-II

OVERVIEW OF THE LITERATURE

In this chapter a general review of display design literature is presented. The question of “How a useful display can be?” is explained. Then, characteristics of effective techniques for evaluating usability in aviation systems are defined. The literature review and the theory related with the research methodology are given in Chapter III.

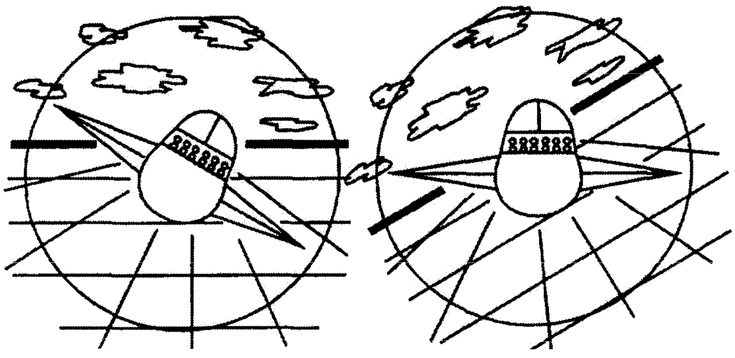
2.1 Properties of a Useful Display

There are lots of different parameters making an aviation display more useful. Information presentation characteristics of aviation displays, like graphically vs. textually formats and reference frames, is one of them. Simultaneous presentation of different displays is another point that must be considered and this may be more useful also by helping situational awareness in spatial tasks. In addition requirements of navigational tasks (WRF/ERF) have a great effect on information presentation characteristics and determine the properties of displays.

First of all, general idea supports the superiority of graphically presented information, but not all of the empirical data show a clear advantage of graphically presented information. (Desanctis, 1984; Tullis, 1981). Nawrocki (1972) found no significant advantage remembering previously presented information between graphics or text. In addition pictures alone often lead to quicker completion times on procedural tasks, but words lead to greater accuracy (Booher, 1975, Rigney, Lutz, 1976; Stern, 1984). Wickens and Scott (1983) determined two factors that might influence the effectiveness of graphically versus textually presented information. The compatibility between the stimulus, the cognitive processing and the response required for the task (or S–C–R compatibility) is the first factor. It is proposed that tasks requiring spatial–analog processes will be best served by visual spatial displays and poorly served by textual displays. (Wickens et al., 1983) The second factor suggested by Wickens and Scott (1983) is the degree of integration while presenting several pieces of information simultaneously.

Williams (1999) shoved the superiority of graphical over textual information display. In his flight simulator study, pilots were faster using the map display than using either of 2 text displays. For instance, global positioning system (GPS) units are used in most navigational displays of general aviation (GA) aircraft today and have a function for shoving the nearest waypoints. Williams (1999) states, *"In most current GPS units, nearest airport information is displayed in a text-based format".* Results of his study showed that the use of the tabular, text-only format normally found on such displays was significantly slower and less accurate than either a map display of nearest airport information or the text display that included the orientation symbol. Participants were faster and more accurate with the track-up map display than with the north-up map. Pilots instead focused solely on the GPS display to perform the task. Although some of the pilots expressed a preference for the text-based formats, most preferred the map-based display. The results regarding the superiority of graphical over textual information display of nearest airport information shoved that the graphical display had not only advantage of S–C–R compatibility but also an advantage due to the integration into a single presentation of current aircraft heading and bearing to the nearest airport. Text display eliminates this advantage.

The reference frame used to present attitude information to pilots has to be considered as an important information presentation parameter. The two main attitude display types are the moving-horizon/fixed aircraft reference and the moving-aircraft/fixed horizon reference. Former display type has been referred to as “inside-out” and the latter ”outside-in". (Previc, Ercoline, 2000) The "outside-in" attitude display type includes a moving-aircraft attitude reference instead of a moving-horizon. It has been found to be superior at preventing roll-reversal errors during normal flying and in recovering from unusual attitudes. Although its usefulness, the majority of military and civilian aircraft have failed to adopt this format. This type of display has a general superiority in maintaining spatial orientation. An illustration of the main differences between two types of attitude display (the "outside-in," or moving-aircraft, format at left and the "inside-out," or moving-horizon, at right) is shown at Figure 2.1. (Johnson and Roscoe, 1972)



Moving Aircraft Moving Outside World

Figure 2.1 Outside-In and Inside-Out (Johnson and Roscoe, 1972)

For instance, pilots encountered difficulty in maintaining their spatial orientation during instrument flight conditions with an inside-out type attitude display. It is not easy to perceive aircraft bank. Fitts and Jones (1947) showed an instance of that. Pilots in reading and interpreting their instruments made 270 errors. 19 (7%) of them involved a perceived reversal of the actual bank of the aircraft. "Roll-reversal" errors were documented during unusual-attitude recoveries at subsequent studies. However the outside-in format is quicker to learn and it is not easy to transfer. This format may be linked to the way of brain processing orientation information in 3-D space. Control-display compatibility, which is direction of the manual movement relative to the display that it controls, and figure ground relation are other explanations for outside-in display's advantages. Research conducted during the past years has demonstrated the superiority of the outside-in format in unusual-attitude recovery among novices or pilots trained on both formats. (Previc & Ercoline, 2000) The outside-in display provides superior attitude awareness relates to the figure-ground issue. Johnson and Roscoe (1972) determined that the moving–horizon symbol is far less likely than the actual earth itself. The artificial horizon violates several significant properties related with background. Johnson and Roscoe stated that "ground surfaces should ideally be relatively formless, lie behind the figure, and yet appear to be uninterrupted by it." However the moving horizon in an inside-out display has a clearly distinguished form. It lies in the same optical plane as the aircraft symbol. Thus it does not appear to extend continuously behind the aircraft symbol.

Next, simultaneous presentation of different displays is sometimes more useful. The joint presentation of multiple maps may result in response competition. Gatti and Egeth (1978) have shown that distracters can interfere with the processing of targets (attentional selectivity). A visual angle of 5 degree between distracter and target cannot stop interference. (Gatti and Egeth 1978, see also Duncan 1984, Eriksen and Yeh 1985, LaBerge *et al.* 1997). Thus, dual displays will be beneficial in both WRF tasks (track-up) and ERF tasks (north-up), if the simultaneous presentation of those maps does not interfere.

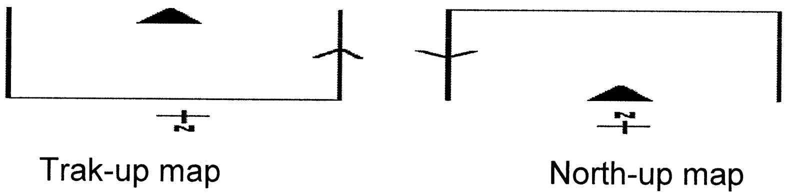


Figure 2.2 Dual Condition (Tlauka et al., 2000)

Figure 2.3 shows the WRF task given at as in the dual condition. Mountain (triangular symbol) is the target and located in the `South'. Aircraft symbol is pointer which indicates the aircraft's current heading. A summary of the Tlauka et al.,(2000)'s research results is presented in Table 2.1. It was found north-up maps have faster reaction times than track-up and dual maps ($p < 0.05$) in the WRF task. The dual map condition was superior to all other conditions for response errors in the ERF task and resulted in faster reaction time in the WRF task (relative to track-up maps). Reaction times in ERF task do not significantly differ. In conclusion, dual displays facilitated responses.

Table 2.1 Mean RT scores (ms) and error scores (%) (Tlauka et al., 2000)

	Map conditions		
	Track-up	North-up	Dual
WRF task			
Mean reaction time score (ms)	1346	957	1139
Error score (%)	4.17	3.33	3.82
ERF task			
Mean reaction time score (ms)	1080	1161	1099
Error score (%)	1.39	2.50	1.25

Tlauka et al., (2000) is determined how the simultaneous presentation of different map displays can help situational awareness in spatial tasks. In his study, some of the participants relied on an ego-centered reference frame (ERF: left/right judgments with respect to the aircraft's current heading) and the other on a world-centered reference frame (WRF: identifying the compass heading associated with a landmark). Track-up and north-up maps were compared with a dual aircraft display consisting of both track-up and north-up maps. Displays and environment have to be aligned. If they are not, to provide situational awareness in spatial tasks mental rotation is required. (Evans and Pezdek, 1980). It is known that north-up (compass heading `North') and track-up (aircraft's current heading which is aligned with the top of the display) maps are mostly used to provide spatial information. (Wickens and Long 1995, Wickens and Prevett 1995, Williams *et al.* 1996

Last, properties of displays depend on the requirements of navigational tasks. Ego-centered reference frames (ERFs) are good for track-up maps. Because they correspond to the traveller's forward field of view and facilitate the maintenance of the current navigational path. Hovewer world-centered reference frames (WRFs) are better at north-up maps. Those types of maps, including the four cardinal points of the compass, support situational awareness. Wickens and Prevett (1995) states that "Navigational tasks that require the use of WRF information are typically best performed with north-up maps while track-up maps appear to enhance performance in ERF tasks" This suggests that performance in navigational tasks is dependent on both the display type and the task.

2.2 Choice of Display Type

Real flight navigation is often cognitively more demanding. Pilots have to look at numerous indicators and dials. Both the speed and accuracy of decisions can be affected by the choice of display formats. North-up display was easier to use and most effective for the task that was performed. Pilots were significantly faster using the map display than using either the text-only display or the enhanced-text display. The inclusion of an orientation symbol in the text display did not eliminate the advantage of graphical display. North-up mode was more effective than the track-up mode if the task was a world-referenced judgment instead of an ego-referenced judgment. Far fewer errors were committed under the north-up condition than under any of the other conditions. Track-up display is more effective for lateral tracking than a north-up display. Wickens et al. (1996) advocate the use of a track-up map. His recommendation supposes that the primary use of displays is to maintain lateral and vertical position. The design of earlier systems affects the design of GPS units. Current GPS manufacturers selected to show nearest airport information in a text-only format.

2.3 Design Process

Early usability evaluation of human interfaces can reduce operator errors. The aim of an interface is to provide a dialog between the operator and the device. In a usable system, the dialog is intuitive and natural. It allows the user to work in harmony with the system. (Clamann & Kaber, 2004) However, making a usability evaluation for any system has unique challenges.

Controls and displays are updated gradually for individual systems up to the last 30 years. New displays are introduced to cockpits without redesigning the control array. They are fit where there is still available space. This has resulted in a complex array of knobs, switches, and displays. They do not integrate intuitively. Flight deck design process did not change effectively from that of the 1930s to 1970s. (Sexton, 1988) With the capabilities of new electronic technologies to integrate these displays and controls into "glass" cockpit technologies, significant changes began in the late 1970s. The design and implementation methodologies used for introducing new components and retrofitting systems were similar to those employed in the 1960s despite the technological advances, (Sexton, 1988). For instance complex integrated displays were developed applying methodologies designed for analog ones. Cockpit designs found in the Boeing 757 and 767 that use six, integrated, cathode ray tube displays instead of the clusters of single instruments of older models produced by these methods. Sexton (1988) states that, they did not demonstrate any substantial reduction in pilot workload. One vital factor, generally excluded from the design process in traditional approaches, is the early participation of the end user or a usability expert (Stein, 2000).

As the development of the system proceeds, the cost of making revisions increases dramatically. If usability problems with the system are found after functional prototypes have been completed, it is very difficult to correct them. (Sarter et al., 1997; Stein, 2000). Several aviation system designers have proposed participatory design methodologies. Several methodologies have already existed, however they are not applied consistently. (Benel, 1998; Sexton, 1988; Williges, Williges, & Fainter, 1988) The participatory design process of Lockheed-Georgia Company for new systems, and simulators of aircraft, are described below (Sexton,1988):

- ✓ Design team selection: Include a pilot familiar with the proposed system; human factors engineers, mechanical design engineers, and avionics engineers. Team members must be involved full time with the project.
- ✓ Mission analysis: Get, forecast, and determine information on the project due to user needs, operating environment, procedures, and new technologies. Forecasts for technology levels are used in

preparation of documented mission scenarios, which detail the environments and situations.

- ✓ Design: By using the mission scenarios, team conceptualizes the aircraft design. The forecasts are also used as design considerations. A full-scale model (mock-up) is developed. Technological trade-offs can be agreed on
- ✓ Test: The configuration is tested with real pilots using scenarios. After the test, design is integrated in a flight simulator.

Rapid prototyping of user interfaces; walk-through evaluations with pilots; and more formal user evaluations, including human factors experiments on control configuration, panel layout, and menu design is applied by some other manufacturers (e.g., Honeywell; Riley, 2001). However companies, conducting usability testing, see this process as one of the causes for slow acceptance of novel technologies in the cockpit because of the time needed.

2.4 Usability Evaluation Techniques

Confirming the behaviors (making sense to the user) of an interactive system is what we expected from usability evaluation techniques. These techniques can be grouped into two main classes, usability testing and usability inspection (Virzi, 1997). Usability testing includes formal experimental evaluation of an interface. It involves a controlled experiment, a working hypothesis, test participants, formal procedures and analysis of statistics, can be performed on system use in either a lab or the practice setting. Subjective data, such as user satisfaction, can also be collected and evaluated, but its main purpose is to answer a specific question (the number of errors encountered) about the interface. Prior to beginning, all goals are assigned quantitative levels and matched to usability metrics. An experiment is designed to evaluate whether the interface meets the criteria established in the form of a usability goal.

(Wixon & Wilson, 1997). On the other hand, inspection (walkthrough and nonwalkthrough) covers a variety of informal methods. (Newman & Lamming, 1995). Sequences of events, determined by user goals, are analyzed in walkthrough techniques like the cognitive walkthrough and model-based evaluation. Nonwalkthrough techniques do not need an evaluation sequence based on the task. Review-based evaluation and heuristic analysis are included in nonwalkthrough category. Both walkthrough and nonwalkthrough techniques can be used depending on the experiment. Each method has specific strengths and weaknesses and no single technique is superior for all usability evaluation tasks. The ideal combination is to use a usability test combined with another technique. However, there has been only limited application of usability evaluation in aviation systems (Kaber et al., 2002).

2.5 Usability in Aviation

Effective techniques for evaluating usability in aviation systems must have the following characteristics: (Clamann & Kaber, 2004)

- Cost-effective: The usability evaluation should not pose an excessive additional financial burden on vendors.
- Rapid execution: Any usability evaluation technique should not slow the process of adding state of the art technology to new aircrafts. Because technology is advancing faster than the capability to add it to a new aircraft.
- Integrated in the full development life cycle: It is necessary to build usability into the development process (Singer, 1999; Smith, 1999; Stager, 2000; Stein, 2000; Williges et al., 1988).
- Input from a variety of domain experts: Aviation systems must be designed for the intended user population. Operators or the pilots should be involved early and continually in the design process (Stein, 2000; Virzi, 1997).

- Transferability and scalability to cockpit design: Any usability evaluation technique must be adaptable to the context of cockpit interface design.

2.5.1 Applicability of the Evaluation Techniques

Although usability testing is more expensive than most of the inspection methods, the advantage of accurate, quantifiable results often outweigh the costs. In order to perform rapid usability inspections, heuristic evaluation has been used effectively for over 10 years. Heuristic evaluation can be performed faster and with less expense than the other inspection techniques at any phase of the development process, either with or without an interface. In order to identify usability issues, Kaber et al. (2002) performed a warm heuristic analysis of the Multi-Control Display Unit (MCDU). Seven experts took part in a group evaluation of the MCDU. They based on principles of learnability, flexibility, and robustness. It was concluded that the MCDU violated several of the principles. It seems that current design heuristics for usability may not be directly transferable to an aviation context. There may be a need to adapt existing heuristics and develop new ones for evaluations of aviation systems. It may be possible to use these contemporary human factors principles as a basis for heuristic evaluation. Research has already been performed to identify new guidelines for modern aviation systems. (Williges et al., 1988).

2.5.2 Combining Techniques

Because of the high level of expert involvement, combining a formal usability test with a cognitive walkthrough, would be fairly expensive and should only be considered if the results are far superior to less costly combinations. The cognitive walkthrough evaluates learnability and the Goals, Operators, Methods and Selection Rules (GOMS) model examines performance. Performance and learnability can also be evaluated through empirical testing. Thus, usability tests can be adapted to include the benefits of the cognitive walkthrough and GOMS model without any additional cost or time. Walkthrough technique may not be necessary when usability tests have already being conducted. (Nielsen & Phillips, 1993).

2.5.3 Usability Techniques in Aviation

It is necessary to improve displays, which is using natural dialog; speaking the user's language; minimizing the user's memory load; being consistent; providing appropriate feedback, shortcuts, clear exits to processes, and understandable error messages; and preventing errors. (Singer, 1999) Clamann et al., states, (2004) "Usability testing, heuristic evaluation, and cooperative evaluation may be most applicable to the aviation context." These three techniques may greatly reduce the number of usability flaws.

Heuristic Evaluation: Before any prototypes are developed, a usability expert should perform a cold heuristic, exposing flaws in the design, evaluation at the task-function analysis step. This will result in less time lost due to revisions. The quality of the evaluation can be increased by the use of a usability expert. After a prototype is developed, another additional heuristic evaluation could be conducted. The results of all the evaluations should be shared within the design team. (Clamann & Kaber, 2004)

Cooperative Evaluation: Clamann et al., (2004) proposes making cooperative usability evaluations. Representatives from various system development areas (computer programmer, graphic artist, human factors expert, etc.) must attend to cooperative evaluation during the development process after the results of the heuristic evaluations have been applied to the design. By this the amount of time needed by the larger group to spend in evaluation meetings can be limited.

Usability Testing: A usability test, involving a sample of the user population, should be conducted after the application of heuristic and cooperative evaluation. In order to assess the design principles, it is significant to define usability metrics before performing any tests. Usability measures are most useful when combined with a quantitative frame of reference. (Singer, 1999) Pilot performance data and errors should be recorded. Thus, not only the component that is changing but also its affect on the system should be examined. Thus any aviation systems usability testing methodology should be designed to perform aforementioned criteria. (Billings, 1997; Stein, 2000; Woods & Sarter, 1993). Furthermore, overall system performance should be compared with and without the new component in the same environment. There should also be a test that gathers quantitative data for that comparison. Results should be preserved to provide benchmark data, after the completion of evaluations. (Clamann & Kaber, 2004) For initial testing, several databases could be benchmarked (Singer, 1999).

CHAPTER-III

METHODOLOGY

Layout of the cockpit, related with aviator anthropometry (reach compatibilities) and front display panel design to provide right perception of information are the two main issues that were considered while making cockpit design research. An anthropometric evaluation of AS-532 Cougar helicopters is performed to show the appropriateness and sufficiency of it for Turkish pilots. After that display panel is designed. As the technology develops, integrated displays will provide weather and terrain information simultaneously. This presentation for specific display properties would improve the decision-making process, but real flight navigation is often more cognitively demanding. Pilots have to look at numerous indicators at the same time, so not only the displays, but also the display panel including them must be useful. Both the speed and accuracy of decisions can be affected by the display panel formats. Although some approaches are proposed for designing or usability evaluation of displays in Chapter II, a specific design methodology concerned with the arrangement of indicators on display panel is not proposed so far. For the first time, we offer, adapt and employ MCDM and Card Sorting approaches as a specific design methodology for the display panel design. In this design study the best natural dialog between the crew and interface is considered while reflecting user perspective to design by applying quantitative and qualitative approaches; with this way proper positions of analogue indicators on the front display panel are determined. Results of two different approaches are compared.

3.1 An Anthropometric Evaluation of Cougar Cockpit

In terms of pilot's performance, human size is the most significant factor for evaluating cockpit accommodation. In order to assess physical aviator-cockpit reach compatibilities, 20 subjects are placed in the cockpits (10 pilots at the left seat and 10 pilots at the right seat) of AS-532 Cougar helicopters. They are dressed in the warm weather training uniform of Turkish Army pilots and requested to operate VHF/UHF radio systems and NADIR. In this study all critical operational reaches are measured and evaluated to present good cockpit solutions. Considering both the Anthropometric Measures of Turkish Pilots and dimensions of cockpit and pedestal, except eye level and sitting eye height, L/UCL of all measurements are found acceptable in terms accessibility of all controls. Some visual problems related with eye levels are identified.

3.1.1 Recent Studies

3.1.1.1 Anthropometric Researches

Commodities, made in accordance with standards of other nations, do not fit our limits very well. It is known that anthropometric measures of Turkish people are different from that of other nations. To design a new ergonomic cockpit or to assess other frequently used cockpits in terms of usefulness and safety, anthropometric measures of Turkish people have to be used and the minimum dimensions should account for the 1st - 99th percentile of the Normal Distribution.

Substantial variation was encountered in the reach-related demands for different aircraft in a recent study to determine Anthropometric Cockpit Compatibility Assessment of US Army Aircraft Pilots. (Schopper & Cote, 1984) In order to assess physical aviator-cockpit reach compatibilities, 16 subjects were placed in the cockpits of all current US Army helicopters (except AAH-64) and fixed-wing aircrafts and were requested to operate all primary controls, critical switches, knobs, etc. Minimum total arm-reach requirements throughout the fleet are ranged from 147 to 168 cm; minimum crotch-height requirements are ranged from 69 to 78 cm. Three aircrafts could not accommodate a sitting height above 102 cm. Very large personnel experienced difficulty in achieving full lateral cyclic and stick movement in several aircraft. Among several candidate measures of upper and lower body reach capabilities, total arm reach (span) and crotch height, which are also investigated in this thesis, were found to be the most efficient discriminators between those who could and those who could not perform all critical operational reaches. (Schopper & Cote, 1984)

Another anthropometric research was conducted considering seat accommodation against expected population's body dimensions in order to ensure that seat standards are such that passengers would be able to quickly evacuate an aircraft in the event of an emergency. The health implications of aircraft seat were also considered, specifically the occurrence and prevention of Deep Vein Thrombosis (DVT).(ICE Ergonomics, 2001) Dimensions investigated are given in Table 3.1

Table 3.1 Descriptions of Seat Dimensions (ICE Ergonomics, 2001)

Dimension	Description	Minimum
A	The minimum distance between the back support cushion of a seat and the back of the seat or other fixed structure in front	26 inches (660mm)
B	The minimum distance between a seat and the seat or other fixed structure in front.	7 inches (178mm)
C	The minimum vertically projected distance between seat rows or between a seat and any fixed structure forward of the seat.	3 inches (76mm)

Space between seats is the most important thing on long-haul flights. Major problems for these dimensions are knocked knees, insufficient legroom; knee aches and pains. To meet the report's recommended standards, which are presented at Table 3.2 entire rows of seats on current aircraft would have to be removed and depending on the aircraft, at least one seat per row would have to be removed to provide adequate seat width. 100 seats would have to be removed from the economy sections of airplanes now in service. Ticket prices might increase upwards by 25 percent (ICE Ergonomics, 2001). Seats are taken into account in accordance with the recommended dimensions, which is given at Table 3.2, in this thesis.

Table 3.2 Recommended Seat Dimensions (ICE Ergonomics, 2001)

Dimension	Minimum	Minimum (New)
A	660mm (%77)	711mm (% 95) or 747mm (% 99)
B	178mm	Armrest level 230-255mm Cushion level 210mm
C	76mm	305 mm (% 95)
Foot Rest	-	355 mm
Armrest	-	497 mm (% 95) or 583 mm (%99)

Next, a new training aircraft is being designed to accommodate 97% of the potential pilot population. This will allow entrance to pilots with statures ranging from 4’10” to 6’5”. Given body sizes of these extremes, determining their accommodation in subsequent aircraft assignment is essential. While the entire Air Force inventory is slated to be evaluated (and is in progress) the accommodation analysis for the first aircraft, T-38, has been completed. Subjects were placed in both fore and aft cockpits to evaluate the ability to reach and operate controls, vision over the nose, shin-panel, thigh-stick, and head-canopy clearance distances. The results were used to generate regression models, using anthropometric measures, to predict the ability of cases in a potential pilot population to simultaneously assure adequate vision and reach to controls. A regression model using Span and Sitting Acromion Height proved to have the best combination of simplicity and predictive accuracy. In order to determine accommodation for a case, an algorithm was designed that finds the lowest seat position possible that still allows adequate vision. From this position the ability to operate rudders and reach other critical controls is determined. Originally, the accommodation results were startling low for females (5%) and for males only about one half were accommodated (55.3%). The draft requirements of

- Stick Positions - Full Forward and Left, - Full Forward, and
- The reach to the Canopy Jettison T-handle

were primarily responsible for this disaccommodation. AETC, however, has since evaluated and removed them from the requirement list. Without the extreme stick positions and reach to canopy jettison the accommodation increases to 69.4% for females and to 94.1% for males in the front cockpit. (Hudson, 1997)

3.1.1.2 Vision

Visual flight rules affect the flight safety more than anthropometric problems. General Aviation (GA) accident statistics indicate that visual flight rules (VFR) and instrument meteorological conditions (IMC) are major safety hazards (Goh & Wiegmann, 2002). Impaired vision aroused from the weather conditions or an unacceptable design with an insufficient visibility, increase the possibility of accidents. One of the objectives of this thesis is to improve display zone to eliminate impaired vision. Furthermore, the visual demands of a task and the location of visual displays are important not only in themselves but also because they largely determine the posture of the head and neck. (Look carefully at the printed text on this page – fix your eyes on one particular word near the centre of the page. You will find that other words become less distinct with increasing distance from the central point of fixation and the margins of the page are not more than an indistinct blur.) Only the central part of the visual field is sufficiently sensitive for demanding visual tasks such as reading text or recognizing a face. The area of foveal vision is limited to a solid angle of some 5^0 about the line of central fixation. Visual work demands that the foveal regions of both eyes be directed convergent upon the task. If we sit or stand with our head up, and look ahead, our eyes will naturally assume a slight downward gaze of some 10^0 or 15^0 vertical – this is called relaxed line of sight. The direction of gaze is altered, firstly, by movements of the eyeballs in their sockets (orbits) by means of the orbital muscle and, secondly, by movements of the head and neck. Taylor (1973) states that the eyes may be raised by 48^0 and lowered by 66^0 without head movements. In practice, only a part of this range of movement is used. Weston (1953) in his classic study of visual fatigue suggests that, in practice downward eye movements were limited to $24\text{-}27^0$; beyond that point the head and neck are inclined forwards and the neck muscles come under tension to support the weight of the head. (See Fig. 3.1.)

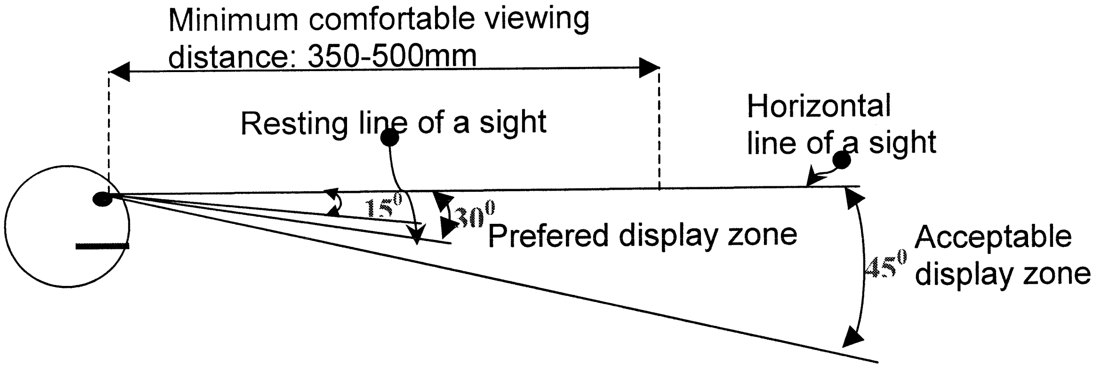


Figure 3.1 Visual Areas (Pheasant, 1986)

Grandjean et al., (1984) described an experiment in which a group of VDU operators were given an adjustable workstation and encouraged to set it to their own satisfaction over a period of one week – the preferred visual angle was 9^0 downwards from the horizontal. Brown and Schaum (1980) have also conducted fitting trials on VDU workstations. Their results are reported in co-ordinate form but it is possible to calculate that the average preferred visual angle, which was 18^0 down-wards. (Pheasant, 1986) On the basis of the above findings it is concluded that the preferred zone for vision extends from the horizontal line of sight downwards to an angle of 30^0 and the optimal line of sight is somewhere in the middle of this zone. Given that some modest degree of neck flexion is acceptable this could be extended a further 15^0. (See Fig. 3.1)

Visual comfort and satisfactory posture also depends upon displays being located of a suitable distance from the eyes. When focused on infinity, or any object more than around 6m distant, the lens of the eye is completely relaxed. To look at closer objects than this, requires effort both of the orbital muscles for convergence and of muscle within the eye itself for accommodation. Visual work performed excessively close to the eyes is fatiguing and leads to "eyestrain" – a poorly defined condition involving blurring of vision, headache and "gravelly" sensations around the eyes. For most practical purposes an absolute minimum viewing distance is considered as 350 mm, but 500mm is safer and as much as 700mm may be desirable.

The VDU operators studied by Grandjean et al. (1984) adjusted their workstations to an average visual distance of 760 mm (settings ranged from 610 to 930mm). The data of Brown and Schaum (1980) give an average preferred figure of 624mm. It is interesting to note that pain and spasm in the neck muscles (trapezius, sternomastoid, splenius, etc.) can lead to "mechanical headache" – experienced in various parts of the head and face and not uncommonly around or behind the eyes (Travell 1967, Dalassio 1980, Travell and Simons 1983). The symptoms of mechanical headache and eyestrain are exceedingly similar (Pheasant, 1986). In this thesis, eye distances are examined to prevent eyestrain.

Last, a research was made to investigate the accuracy of pilots' copying air traffic control clearances, twenty-four airline pilots listened to 28 taped clearances and copied them down on an answer sheet using shorthand, longhand, or some combination of these according to their preferences. The copied clearances were analyzed by the number of correctly copied elements, the number of omitted elements, and the number of extraneous elements that were not present in the original clearance. Preliminary results indicate a strong influence of habit and familiar operating environment and procedures on the accuracy of copying unfamiliar information. (Rantanen & Kokayeff, 2002) Main communication and cruising systems in Cougar are VHF/UHF/FM radio systems and NADIR 10/1000 INS/GPS cruising systems. Accuracy of pilots' while using these devices is not a concern of this thesis. This thesis is concerned with acceptableness of hand displacements to reach to aforementioned communication and cruising systems.

3.1.2 Method

3.1.2.1 The Helicopter Used; ASL 532 UL Cougar

ASL 532 UL Cougar is a medium weight Helicopter with a large cabin, particularly suited for passenger transport. Fitted with the appropriate equipment, Cougar is capable of a wide range of missions, which are troop carrying, load carrying, search and rescue, casualty evacuation and ferry flight. The twin-engine concept, combined with an expansive power reserve, makes Cougar an aircraft particularly suited to various missions, and means safety and retention of operational capabilities over a wide altitude and temperature envelope. Its cockpit has been designed for a crew with two pilots and eventually a 3rd man. The pilot seat is located on the right, the copilot's one at the left hand place. The ergonomy has been thoroughly studied in order to optimize the exterior visibility, the flight instrument lisibility and the accessibility of all controls from the crew stations. The floor can withstand the crash loads exerted by the pilot and copilot seats. The cockpit has been designed to accommodate all the flight instruments as well as the optional radio-communication or radio-navigation equipment enabling the aircraft to be flown in IFR conditions. Some features of the cockpit are

- 2 pilot and copilot seats adjustable in height and fore-and-aft, complete with safety belts and extensible shoulder harness
- Engine controls
- Master cut-off switches
- Rotor brake control
- Landing gear control
- Differential wheel brakes at pilot and copilot stations
- 2 adjustable heating and ventilation outlets (Cougar Technical Specification, 1998)

However, some reach and vision problems of Turkish Pilots are observed. Seats and pedals are adjustable, but sometimes adjustments of them to a standard position for a certain part of the flight causes some problems of vision and reach, especially while landing or at hover position. For instance, an adjustment of seat height for a flight over 200 feet will not well suit to the requirements of landing approach. Because of the lift force need pilot raises the collective, and pitch angle of the blades is increased, while increasing the torque of the main rotor system. Due to torque increase, to control heading of the helicopter and prevent spinning around, the pilot has to press foot pedals more than during normal flight in order to change the blade angels of tail rotor and create anti-torque. To reach pedals pilot has to slip his body, and the eye height decreases.

3.1.2.2 Subjects and Body Part Selection

Turkish Army Aviation pilots, who are trained and capable to fly Cougar helicopters, are selected to participate this study. They have at least 1000 hours of flight experience with this helicopter. Their dress is the warm weather training uniform of the Turkish Army. Their age changes 26 to 40. All of them are male pilots.

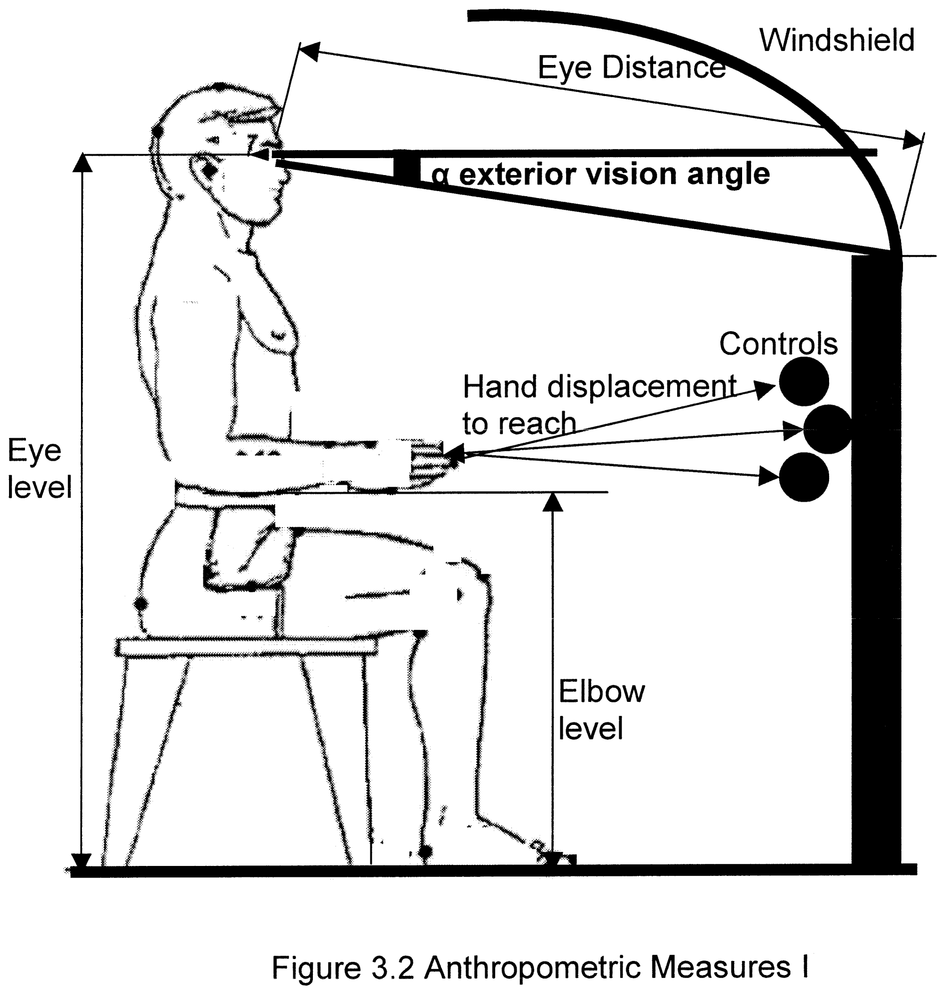


Figure 3.2 Anthropometric Measures I

The control of a helicopter consists of movement of the aircraft along the three principal axes and rotation about the axes. These rotation movements are called pitch, yaw and roll. Cyclic stick controls the forward, reverse and sideward flight. Pitch and roll is controlled by cyclic. Collective stick controls vertical flight. Foot pedals control yaw. Cyclic, collective and pedal inputs must be combined to control the horizontal and vertical flight of helicopter. Due to the mentioned cockpit accommodation studies explained in section 3.1.1 and control mechanism of a helicopter flight stature, total arm span, elbow level, hand displacement to reach to some controls like VHF/UHF/FM radio systems and NADIR, eye distance, eye level (for determining visual zone) constitute the main research points of this study. All of the measures are shown at Figure 3.2 and Figure 3.3. The reasons for selection each measure is explained below

- Elbow level: The probability of hitting the arms of pilots to pedestal and obstructiveness of it in the event of any emergency is considered.
- Eye level: This distance is taken to determine field of exterior vision (α).

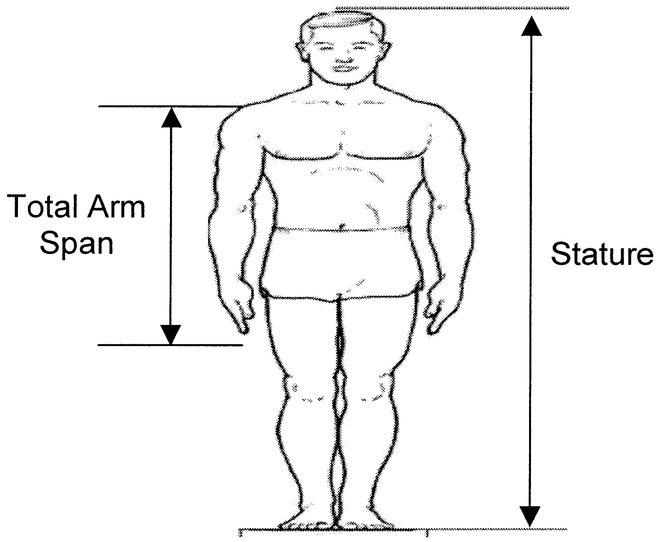


Figure 3.3 Anthropometric Measures II

- Eye distance: It is the distance from eye of pilot to the top point of display panel (See Figure 3.2). This distance is taken to determine exterior vision (α) angle and prevent eyestrain.
- Stature: This measure is taken to check the space for pilots while getting in the cockpit of Cougar.
- Total Arm Span: Total arm reach (span) is the most efficient discriminator to perform all critical operational reaches.
- Hand displacement to reach to VHF/UHF/FM radio systems, NADIR 10/1000 INS/GPS: It is the distance from hands of the pilot to these controls. If pilot sits at left seat this distance is taken from right hand of pilot to these controls. On the other hand, if pilot sits at right seat this distance is taken from left hand of pilot to these controls

3.1.2.3 Data Collection Procedure

Before Flight: 20 subjects were dressed in the warm weather training uniform of Turkish Army pilots. 10 of the pilots sit at right seats and 10 of them sit on the opposite. Seat is adjusted by each pilot to the best position to the preferences of pilot at the beginning of the flight. Readjustment of the seat during the flight is not allowed.

During the Flight: Pilots were requested to operate VHF/UHF radio systems and NADIR 10/1000 INS/GPS cruising system. Flight was performed at different altitudes (max. 200 feet.) High voltage lines (100 feet) were present at flight area. Weather was calm and ground was plain. Flight velocity was in the range 0-120 knots. Flight safety is considered. VHF/UHF radio systems, NADIR and landing gear switches are operated during flight.

After the Flight: Each hand displacement to reach to VHF/UHF/FM radio systems, NADIR 10/1000 is taken without spoiling the flight positions of the seats. Two people are charged for measurement, while one of them procures the sensitivity of the measurement (always same position), the other measures the body parts. In addition eye distances are measured on the helicopter. Other standard anthropometric (stature, total arm span, elbow level, sitting eye height see Figure 3.2 and Figure 3.3) measurements are performed on the ground.

3.1.2.4 Statistical Analysis

After conducting measurement process the data obtained is evaluated. Average, Lower Control Limits **(LCL)** and Upper Control Limits **(UCL)** of all dimensions are calculated to cover distribution of the **1st - 99th** percentile of population. Thus ***z*** value is taken as 2.59. L/UCLs are compared with the relevant dimensions in cockpit considering acceptableness in terms of accessibility of all controls. Unacceptable measures are determined. Regression analysis between eye distances & eye-levels and eye levels & exterior vision angles are determined.

3.2 Display Panel Design with a Quantitative Approach

Determining the positions of indicators on display (Borda) panel constitutes one of the most significant parts of cockpit design. Importance of data represented by the indicators and frequency of use of all indicators and other cruising systems impact the flight safety, crew performance and display panel design. Proper positions of the indicators on display panel must be determined with regard to aforementioned characteristics. Indicators are considered as a set of alternatives (decision variables) each defined by two criteria and assumed that decision maker's (DM) preferences are consistent with some underlying utility function. Thus components of the most influential front display panel indicators list for a safe flight is graded with respect to these criteria which are **effects of misapprehending information on the indicator on flight safety and frequency of use during flight.**

3.2.1 Method

3.2.1.1 Multi Criteria Decision Making (MCDM) Approach; Overview

The exact form of the utility function is unknown; therefore the type of the DM's utility function is identified by means of applying a combined algorithm. The algorithm for classification of indicators must be determined according to the form of u(x). (Köksalan & Sagala, 1995) Then an interactive approach for discrete alternative multiple criteria decision-making compatible with the identified utility function type is employed, after adapting the algorithm suggested by Köksalan and Ulu (2003). Best decision variable (indicator) deserves to be located firstly on display panel. Next, in accordance with the grades of pilots each location is ranked accordingly revealing suitable places best to worst. Last indicators are positioned to suitable locations.

3.2.2.2 MCDM Applied to Display Panel Design

Utilities of each indicator during the flight have to be considered, while locating them on display panel. This utility is related to the mission (function) of indicator. Frequency of use of any indicator and the importance of data represented by that indicator determine its utility. According to class of utilities, indicators can be located on display panel. In order to arrange indicators to some classes, these multi utility characteristics of any indicator can be transferred into a decision support algorithm. An MCDM approach is implemented to reflect the aforementioned multi utility characteristics into an optimization model. The aim of this approach is to find an order to locate each indicator and obtain a good perceptional environment to provide needs of pilots during flight.

3.2.2.3 Indicator Types Used

Mostly used general utility helicopters in Turkish Land Forces, their analog display panels and pilot checklists are examined. (UH-1H *Pilot Check-List,*

1998) Aforementioned survey helped mould the following list of the most influential front display panel indicators for a safe flight and 24 alternative equally separated locations on display panel (See Table 3.3 & Figure 3.2).

Table 3.3 Display Panel Indicators

Airspeed indicator	**X_1**
Attitude indicator	**X_2**
Altimeter indicator	**X_3**
Fuel pressure indicator	**X_4**
Fuel quantity indicator	**X_5**
Dual tachometer	**X_6**
Radio compass indicator	**X_7**
Variometer	**X_8**
Torquemeter Indicator	**X_9**
Magnetic Compass	**X_{10}**
Main generator loadmeter	**X_{11}**
Voltmeter	**X_{12}**
Clock-chronometer	**X_{13}**
N1 indicator	**X_{14}**
EGT indicator	**X_{15}**
Engine oil pressure indicator	**X_{16}**
Engine oil temperature indicator	**X_{17}**
Transmission oil pressure indicator	**X_{18}**
Transmission oil temperature indicator	**X_{19}**

3.2.2.4 Subjects Selection

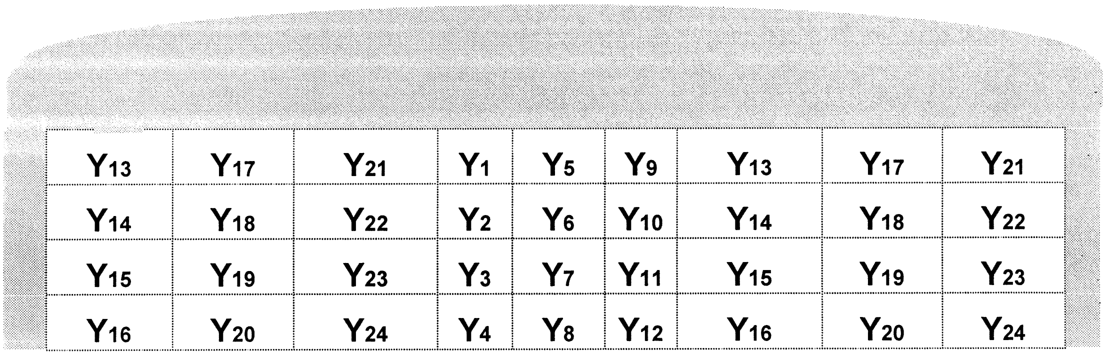
A design engineer and three pilots participated in this study. DM is a design engineer and has been working in the aviation sector in Ankara. The attendees at this study are the actual end-users of the new display panel. Three Turkish Army Aviation pilots, who have trained and capability to fly at least one type of utility helicopter such as UH-1H, S-70 or Cougar, are selected to participate in this study. They have at least 1500 hours of flight experience with a utility helicopter. Their age changes 26 to 40 years. They are male pilots.

3.2.2.5 Data Collection Procedure

On a 100 scale three pilots graded indicators on this list in terms of two criteria; **effects of misapprehending information on the indicator on flight safety and frequency of use during flight**. First criterion grade increases proportionally as the importance of flight information represented by this display increases. That is to say if pilot wants to see an indicator at first sight, this item will get a higher point. For instance, let's consider attitude indicator and clock-chronometer. Misapprehending information on attitude indicator has a greater effect on flight safety than clock chronometer, so attitude indicator gets a higher point in terms of this criterion. On the other hand second criterion grade increases according to how often the pilots look at these indicators during one hour of flight.

Pilots get in a general utility helicopter (UH-1) one by one and adjust the seat by changing adjustment limits in height and fore aft to best flight condition. Each pilot graded 24 alternative locations on display panel in terms of visibility on a 100 scale, while looking at forward flight horizon. As in the case of a real flight each tried to see the locations from Y_1 to Y_{24} with a very small move of their eyeballs.

Pilots are ordered not to incline their heads or necks. At this position eye movements of pilots are limited to 24^0-27^0. Since we know that the location of visual displays extends from the horizontal line of sight downwards to an angle of 30^0, the places that are out of optimal line of sight may get lower points. Because of that, best locations are determined in terms of not only visibility but also human neck health. Each location will be ranked according to that criterion and listed from highest point to lowest one. These 24 locations are demonstrated at Figure 3.4.



Y_{13}	Y_{17}	Y_{21}	Y_1	Y_5	Y_9	Y_{13}	Y_{17}	Y_{21}
Y_{14}	Y_{18}	Y_{22}	Y_2	Y_6	Y_{10}	Y_{14}	Y_{18}	Y_{22}
Y_{15}	Y_{19}	Y_{23}	Y_3	Y_7	Y_{11}	Y_{15}	Y_{19}	Y_{23}
Y_{16}	Y_{20}	Y_{24}	Y_4	Y_8	Y_{12}	Y_{16}	Y_{20}	Y_{24}

Figure 3.4 24 Alternative Locations of Display Panel

3.2.2.6 Algorithm for Testing the Form of Utility Function

DM is expected to be consistent with some underlying function while expressing his preferences and it's also quite unlikely for the DM to have a quasi-convex utility function, but quasi-convexity test is necessary in order to detect linearity. The DM's utility function is consistent with a linear function if it is consistent with both a quasi-concave and a quasi-convex function. To test whether or not the DM's preferences are consistent with a quasi-concave, a quasi-convex and a linear or a general monotonic utility function a combined approach given below suggested by Köksalan and Sagala (1995) is applied. Suggested number of iterations is 4 even for relatively larger problems. Thus, iteration number is taken as 3.

1. $i \leftarrow i + 1$, Select two alternatives . Ask the DM the preferred one and denote it by X_1 and the inferior by X_2. (Initial i=0)

2. Let **$E_2 = 0,1X_1 + 0,9X_2$** Ask the DM E_2 vs. X_2.

(a) If X_2 is preferred go to Step 3.

(b) If E_2 is preferred go to Step 4.

3. STOP; the DM's preference is not consistent with a quasi-concave function. Conclude that DM has a general monotonic function.

4. Let **E_1= 0,9X_1 + 0,1X_2** Ask the DM to compare E_1 with X_1.

- **(a)** If E_1 is preferred and i=N go to Step 5 to conclude quasi-concave u(X).
- **(b)** If X_1 is preferred and i=N go to Step 6 to conclude linear u(X).
- **(c)** If E_1 is preferred and i<N go to Step 7 to keep checking non-quasiconcavity.
- **(d)** If X_1 is preferred and i<N go to Step 1.

5. STOP; the DM's utility function is not consistent with a quasi-convex function (hence with a linear function) but is consistent with a **quasi-concave** function.

6. STOP; the DM's utility function is consistent with both a quasi-concave and a quasi-convex function. Therefore conclude DM has a **linear** utility function.

7. Set **$i \leftarrow i + 1$,** choose a new pair of alternatives, ask the DM to compare the alternatives, and denote the preferred alternative as X_1 and the inferior alternative as X_2.

8. Let **E_2= 0,1X_1 + 0,9X_2** Ask the DM to compare E_2 with X_2.

- **(a)** If X_2 is preferred go to Step 9.
- **(b)** If E_2 is preferred and i=N go to Step 10.
- **(c)** If E_2 is preferred and i<N go to Step 7.

9. STOP; the DM's preference is not consistent with a quasi-concave function. Conclude that DM has a **general monotonic** function.

10. STOP; the DM's utility function is consistent with a quasi-concave function.

3.2.2.7 Algorithm for Arranging Indicators

In accordance with the form of utility function; u(X) a suitable algorithm that finds the most preferred alternative of DM is used. (Köksalan & Ulu, 2003) Indicators are accepted as the decision variables, best decision variable deserved to be positioned firstly on Figure 3.2. Then, it is removed from the alternative decision variable list and the second best one is determined and so forth. The aim of this approach is to find an order to locate each indicator to suitable classes in terms of aforementioned criteria. The algorithm suggested by Köksalan and Ulu (2003) is adapted as follows:

Alternatives are ranked one by one starting from the most preferred. Once an alternative is ranked, it is removed from the candidate stack due to the fact that there are 19 classes (ranks) and each class must have exactly one alternative. So, remaining candidates compete for the next class, which is the best available class. Since iteration number is taken as 3 in Section 3.2.2.6, which means DM makes 3 comparisons while determining the form of his utility function; those results are used to reduce the weight space of DM's utility function initially. Thus, alternatives are ranked with as few questions as possible.

Step 0. Define C_i as the set of alternative that is placed in class *i* (i= 1...19 where i=1 corresponds to the best class and i=19 corresponds to the worst class).

Let T be the set of alternatives whose classes are not yet identified and let it contain all alternatives initially.

Let S be the set of non convex-dominated alternatives in T.

Note that S shall be updated as T changes.

Let b be the index of best class among empty classes and set b=1 initially.

Let each set be initially empty.

Step 1. If |T|=0 go to step 2.

Otherwise, select an alternative, X_m from set S.

If |S|=1, it means X_m dominates all other alternatives in T.

Put X_m in C_b.

Let T ← T – {X_m} and b ← b+1 and repeat step 1.

Otherwise, select two alternatives X_m and X_n from set S and solve the following LP:

$$\begin{array}{ll} \textbf{Max} & \varepsilon \\ \textbf{s.t.} & \beta(X_n - X_m) \geq \varepsilon \\ & \beta(X_p - X_s) \geq \varepsilon \textbf{ for all } X_p \gg X_s \\ & \beta \geq 0,\ \varepsilon \textbf{ URS} \end{array}$$

If ε is found as 0, meaning $X_m \gg X_n$, let S ← S – {X_n} repeat step 1 until all pairs in S are compared according to the above LP.

If |S| ≥ 2 and all pairs are compared according to the LP, **ask DM to compare remaining alternatives in S**. Let X_m be the most preferred alternative in S. Put X_m in C_b. Then, let T← T – {X_m} and b ← b+1 and repeat step 1.

Step 2. STOP, all alternatives are placed.

3.3 Display Panel Design with a Qualitative Approach

In a design study, it is necessary to discover the latent side of user's ideas to understand user on a personnel level. Determining display panel design with a quantitative approach may not reflect the latent side of the actual end user needs, which is user perspective. Comfort is the added value of design study and it is very subjective. Qualitative research adds value to design by revealing the conceptual model, which is the first impression get from any object in the mind of end user. A designer has to know the reasons between the links of users' mind and interpret their results in order to reflect them to product.

3.3.1 Method

At the beginning of any information design exercise, it is normal to be confronted by a very long list of potential subjects to include. The challenge is to organize this information in a way that is useful and meaningful for the users of the system. While careful investigation and analysis of the information may reveal some clues, it can be virtually impossible to determine which topics should be grouped together. The difficulty related with organizing the content stems from lack of knowledge about how real users make use of this information. Without this, any exercise in information design is a purely theoretical one. A card sorting session can go a long way towards resolving this problem.

3.3.1.1 Card Sorting

This is a method for discovering the latent structure in an unsorted list of statements or ideas. The investigator writes each statement on a small index card and requests six or more informants to sort these cards into groups or clusters, working on their own. It is a very simple, and often very effective, method of working with users to come up with a usable design. Card Sorting is appropriate when you have identified items that you need to categorize. An "open card sort" exercise lets the users create and name their own piles, while a “closed card sort” presents to the users a set of predefined (but empty) piles, and the user then sorts the cards into these pre-determined groups. (Robertson, 2001). The card sorting will inform about how real users think. It should be noted, however, that a card sorting exercise does not produce a finished information design.

Much of the value from card sorting comes from listening to the comments of users as they sort the cards: knowing why people place certain cards together gives deeper insight into their mental models than the pure fact that they sorted cards into the same pile. (Tullis & Wood, 2004) User testing and cart sorting differ in two key ways. User testing is an evaluation method. There is already a design, and it is tried to find out whether or not it's a good match with human nature and user needs. Although people differ substantially in their capabilities (domain knowledge, intelligence, and computer skills), if a certain design element causes difficulties, it can be seen so after testing a few users. Card sorting is a generative method. There is not yet a design, and the goal is to find out how people think about certain issues.

3.3.1.2 Card Sorting Applied to Display Panel Design

The quantitative approach is solely based on the preferences of DM and results of some analytical techniques. However designing a display panel by only depending on them may not efficiently reflect user perspective to end product. Before any design, mental models of users for a new product have to be understood well by the designer, so we applied card-sorting methodology. Card sorting sessions are an important opportunity to involve the actual users in the design process. This makes them feel involved in the project, and emphasizes that the end product will be built to meet their needs. This increases user enthusiasm and reduces any resistance to change when the system is implemented. It also allows realistic and accurate information to be conveyed regarding the timetable and scope of the project.

3.3.1.3 Preparing the Topic List

The first step to conducting card sorting method is to determine the list of topics. It is actually quite tricky to come up with a workable topic list. There are a number of issues that must be considered. The length of the list needs to be manageable. Too few items, and there is little scope for the users to come up with a structure. Too many items and the task become confusing.

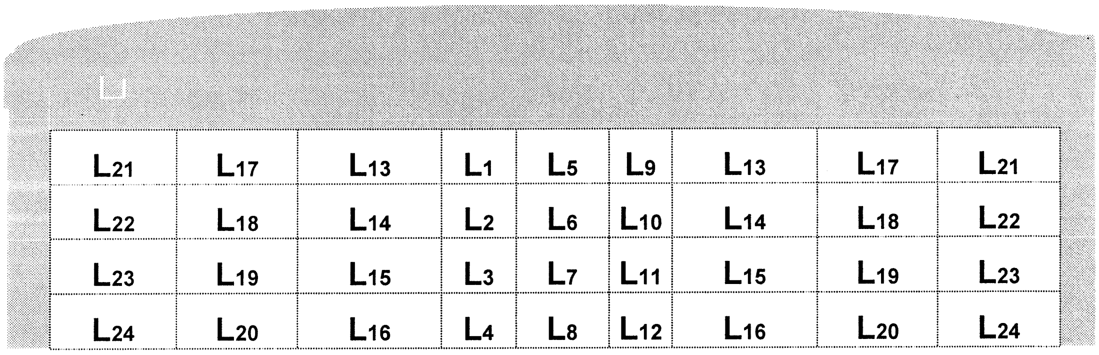
The hardest challenge is to find the right level of detail, which is how much information encompassed by each item on the list. A topic such as "human resources" is perhaps too broad, while "rate of leave accrual" is probably too specific. The terms used in the list must be meaningful to the participants in the session. The general rule when selecting topics for inclusion is to ensure that they are "neutral".

Pilots can involve the design process and find the suitable locations of indicators just by attaching them on display panel. Preferences of pilots for the location of each indicator have to be considered. Because of that, topic list is the list of the most influential front display panel indicators for a safe flight. After examining the analog display panels of mostly used general utility helicopters in TLFs, we have prepared this list. (Table 3.3 and Figure 3.5).

3.3.1.4 Subjects Selection

All participants must be representative of the eventual users of the structure, which is designed. At least six participants must attend. More participants means, the more data to be analyzed. Tullis and Wood (2004) recommend testing twenty to thirty users for card sorting. Based on their data fifteen users must be tested. Correlations of 0.90 (for fifteen users) or maybe 0.93 (for twenty) are good enough for most practical purposes.

The attendees at the card sorting session will be the actual end-users of new display panel. They can adequately reflect their needs and expectations to panel design since they are selected from experienced pilots. These pilots may have faced with more flight safety conditions than inexperienced ones. The sample was composed of eight male pilots, having 1500 hours of flight experience and can fly at least one type of utility helicopter. Flight experiences of the pilots are also selected as the same as the ones of MCDM approach since we compare the results of two methods. Their age varied between 29 to 40 years old.



L_{21}	L_{17}	L_{13}	L_1	L_5	L_9	L_{13}	L_{17}	L_{21}
L_{22}	L_{18}	L_{14}	L_2	L_6	L_{10}	L_{14}	L_{18}	L_{22}
L_{23}	L_{19}	L_{15}	L_3	L_7	L_{11}	L_{15}	L_{19}	L_{23}
L_{24}	L_{20}	L_{16}	L_4	L_8	L_{12}	L_{16}	L_{20}	L_{24}

Figure 3.5 Alternative Locations for the Cards (Indicators)

3.3.1.5 Material

Names of indicators to be located are printed on individual cards. Cards are large enough to accommodate the names in a font that participants can read easily when spread out on a desk or table-at least 14 point. The following materials are used;

- The cards and a cloth (where Figure 3.5 is drawn on it)
- A photograph machine to take photos of display panel (cloth)
- A notepad and pen (for recording the participant's verbal feedback.)
- A utility helicopter of UH-1 (while sorting locations of display panel)

3.3.1.6 Conducting Cart Sorting Session

Steps of conduction cart sorting session are explained below.

1. Display panel of a general utility helicopter (UH-1) is covered with a cloth where the 24 alternative locations are drawn on it.
2. Pilots get in a helicopter (UH-1) one by one and adjust the seat by changing adjustment limits in height and fore aft to best flight condition according to themselves.
3. Cards are shuffled or randomized prior to each participant session. It is ensured that all participants have the same understanding of the process.
4. Pilot is asked to locate indicators on the cloth by attaching them to suitable locations in a way that makes sense to them.
5. Using the frequency of selections for a particular location a new display panel design is formed
6. Comments of pilot are listened and noted as they sort the cards. It is very significant to know why pilots place certain indicators together. In order to perceive their mental models, pilots are required to think aloud.
7. Key words are comprised from the comments of pilots. They select the most five important key words out off all the key words that he mentioned and ranks them.
8. Pilot makes a comparison among five key words and gives points from 1 to 5 from most preferred to least preferred one. n the end a photograph of the panel is taken, or if it is not possible, written on Figure 3.5.
9. The results of experiments are analyzed to investigate the reasons of similarities and differences. The best design, comprising of the mental models of pilots, is tried to be achieved.

CHAPTER-IV

RESULTS

In this chapter data presented in, quantitative and qualitative techniques that were discussed in chapter 3 are analyzed.

4.1 Results of Anthropometric Study and Interpretation

4.1.1 Results of Anthropometric Study

The results of anthropometric measures defined at Section 3.1.2.2 are given at Table 4.1. First of all, dimension of stature is analyzed. Measurement data of stature is given in Appendix A. Minimum and maximum measurement values for the stature are 167 cm with a frequency of 2 and 180cm with a frequency of 2 within a sample size of 20. Z value is taken from the Tables of Normal Probability Functions as 2.58, which covers the 99th percentile of the normal distribution. Mean is 174.65 cm. UCL is 185.67cm and LCL is 163.63cm. There is enough space for pilots (height: of cougar from foot step to the upper point of cabin door is 164cm) to get accommodated in the cockpit of Cougar. Pilots get on the helicopter by bending their heads. On the other hand this does create a discomfort neither during entrance nor during flight.

Anthropometric data for the total arm span measure can be found in Appendix A. Minimum and maximum measurement values for the total arm span are 67 cm with a frequency of 2 and 73cm with a frequency of 2 within a sample size of 20. Mean is 70.75 cm with a 2.7cm of standard deviation, thus UCL and LCL are calculated in order to cover the 99th percentile of the normal distribution. UCL & LCL interval is acceptable for the cougar helicopter considering all the controls on pedestal like VHF/UHF/FM radio system and NADIR 10/1000 INS/GPS cruising system reaches. Maximum displacement to reach to landing gear and radio systems is 25 cm, which is less than LCL of arm span. In addition fore and aft interval of the seat is 8.7 cm, which is greater than 6,966 (2.58*2.7) 3-sigma value of total arm span. Therefore if the pilot is uncomfortable, there is enough room both for pushing and pulling the seat.

Table 4.1 Results of Anthropometric Measures

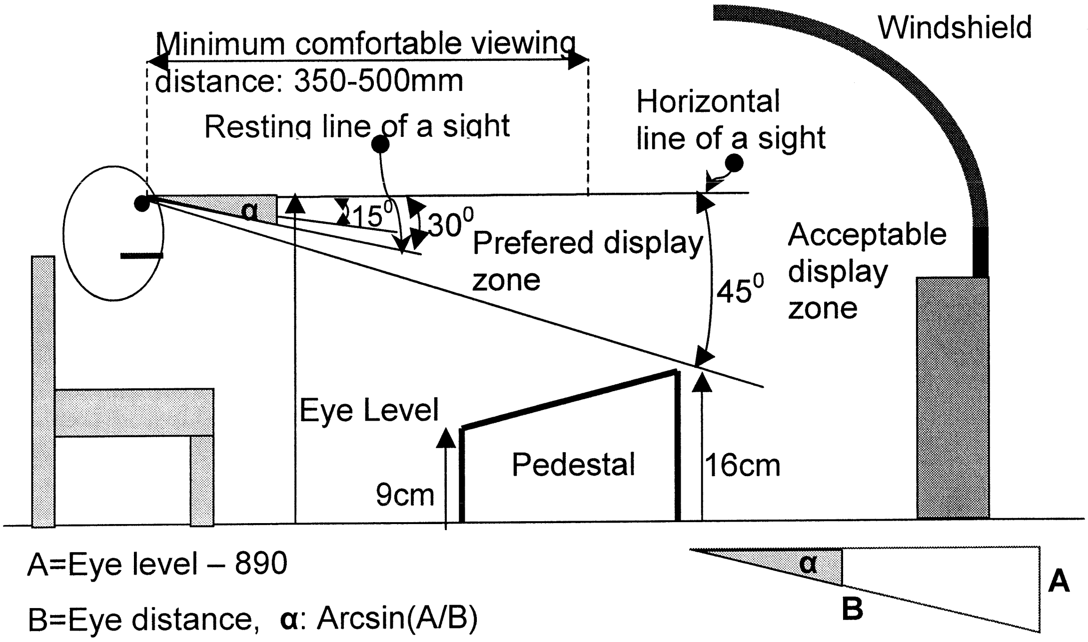
Measure	**Mean**	**Std.Dev.**	**LCL**	**UCL**
Stature	174.65	4.27	163.63	185.67
Arm Span	70.75	1.74	66.25	75.25
Elbow level	41.65	3.67	32.17	51.13
Eye level	96.65	2.68	89.73	103.57

Elbow level is analyzed to reveal the probability of hitting with the elbow to pedestal. The heights of intersection points at pedestal with the elbow of pilot are between 9-16cm. (see Figure 4.1) LCL and UCL for this measure are 32.17 - 51.13cm. These limits are higher than height of 9-16 cm. Thus the pilot will be able to use his arms without hitting the pedestal. The relevant statistical data is presented in Appendix A. A detailed statistical analysis for each hand displacement to reach to VHF/UHF radio and NADIR systems can be found in Table 4.2. All the hand displacements for these controls are less than the LCL of total arm span. Thus, layout of these controls is acceptable in terms of pilot reach compatibilities.

Table 4.2 Distances Reached By the Pilot within the Cockpit

Measure	**Mean**	**Std. Dev.**	**LCL**	**UCL**
Hand displacement to reach to UHF/VHF Radio	21.6	2.76	14.49	28.71
Hand displacement to reach to NADIR From Left Seat	8.1	2.47	1.73	14.47
Hand displacement to reach to NADIR From Right Seat	14.5	2.46	8.15	20,85
Eye distance	40.6	2.60	33.38	47.32

Preferred display zone (15^0-30^0) and minimum comfortable viewing distances are shown in Figure 4.1 (Pheasant, 1986). Field of vision of pilots is found in order to determine its appropriateness to preferred display zone. Statistical details are given in Appendix-B. Eye levels (A+890) of 20 pilots and eye distances (B) are measured in order to calculate α angle. This angle is equal to arcsine (B/A).



A=Eye level – 890

B=Eye distance, α: Arcsin(A/B)

Figure 4.1 Proposed System Draft

LCL and UCL for eye level are 89.73 -103.57cm. LCL and UCL for eye distance are 33.88-47.32cm. Exterior angle of vision (α angle) is calculated according to these measurements. The minimum and maximum calculation results for exterior angle of vision are 6.20^0 -18.12^0. The average is $10,71^0$ and it is less than preferred display zone of 15^0-30^0. Eye distance interval for the sample, 33.88-47.32cm is narrower than 350-500mm minimum comfortable viewing distances. Statistical details for calculation of angles can be found in Appendix-B. LCL of 89.73 cm for eye level is very close to 89 cm, which is the highest point of the front display panel. During some part of the flight (e.g. while landing pilot moves down in his seat in order to press foot pedals more) pilots stated some vision problems that may be a cause of lowering eye level less than 89cm. In order to provide a better exterior vision eye distances and α angle should be improved.

4.1.2 Enhancing Vision

Visual sufficiency of cockpit is a major factor affecting flight efficiency and safety. Aforementioned vision problem can be improved by lowering the height of display panel. However redesigning the display panel and rearranging the places of other avionics (displays, radios, altitude meters, gyroscopes etc.) is costly. Instead of lowering the height of display panel the location of seat and its height can be changed in a less costly way.

In order to find the optimal location and height of the seat, regression analysis is used. Best results for the regression analysis between eye-level (y: dependent variables) and eye distances (x: independent variables) are given by the equation $y = 0.4143x+92.3$ (Equation 1) and correlation is 0.898 in Appendix C. Another regression analysis is made to find out the relationship between exterior angle of vision (y: dependent variables) and eye levels (x: independent variables). The best regression equation is $y = 0.005x^3 - 0.1281x^2 + 1.2248x + 5.2868$ (Equation 2) and correlation is 0,997 Appendix **D.** The regression equations, estimates of eye levels, estimates of angles and deviation correction indices are presented in Appendix C, D.

It is needed to find, acceptable eye levels, which will provide sufficient exterior vision. For this purpose, randomly assigned eye distance values (x values), taken within minimum comfortable viewing distance limits of 35-50cm, are placed in the regression equation (Equation1) to estimate eye level (y) values. Eye level values are calculated as shown at Table 1 in Appendix E. Eye level values are found as 93.05 - 102.09cm. These new eye level values are independent variables (x) for the eye level-angle (y) regression (Equation 2). After aforementioned computation method exterior vision angle interval is found as 7.54^0-14.81^0 in Table 2 in Appendix E. Although minimum comfortable viewing distances are used, preferred display zone could not be achieved, since the display panel is very high. In order to improve vision of pilot eye distances must be greater than minimum comfortable viewing distances.

Therefore a reverse trial and error method is used to calculate the eye level values (x) that will satisfy recommended exterior angle of vision (**α = 15^0 - 30^0)**. Until exterior angle of vision interval (y: dependent variables) reaches to 15^0-30^0, some new values are given to eye levels (x: independent variables) in the equation $y = 0.005x^3 - 0.1281x^2 + 1.2248x + 5.2868$ in a trial and error manner. After a few iterations at Table 3 in Appendix E, it is found out that if the eye level interval is 118-127 cm, than exterior angle of vision interval is 16.34^0-30.00^0.

The eye levels calculated in this way will demand a change in the eye distances. Until eye level interval (y: dependent variables) reaches to 118-127 cm, we randomly give new values to eye distances (x: independent variables) in the equation in the equation $y = 0.4143x+92.3$. The new eye distance interval is found as 104-118cm at Table 4 in Appendix E.

If the eye distance is 104 cm, eye level is 117.95 cm then angle is 16.34^0. If the eye distance 118cm, eye level is 127.55 cm then angle is 30.00^0. These are the best computational results given in Appendix-E; however there is not enough space at the cockpit to cover the calculated eye distance (104-118cm) interval. Results;

I. The location of seat and its height cannot be changed according to these results
  - ➢ Due to lack of space at cockpit of Cougar,
  - ➢ Even there was enough space at cockpit of Cougar, there may occur reach problems to some controls (like pedals, collectives etc.,) because the new eye level and eye distance interval is very wide.

II. Display panel cannot be lowered, since redesigning the display panel is very costly.

III. Designers must take into account user needs from the beginning till the end of a design process. Once more it is proved that changing design after completing the product is more costly.

IV. Eurocopter manufactures (Cougar) helicopters especially for European market. Turkish people's anthropometric measures are different than most of the Europeans. Stature height (taller pilots) should be an important decision parameter in selection of Turkish Cougar Pilots.

V. If any type of helicopter will be procured from any other country or manufactured in Turkey it is necessary to evaluate this new cockpit in terms of Turkish Pilots' anthropometric measures.

4.2 Results of Quantitative Approach and Interpretation

4.2.1 Form of Utility Function

Display panel indicators, which are given at Table 3.3, are graded by three pilots with respect to two criteria.

Table 4.3 Display Panel Indicators and Criteria Grades

Display Panel Indicators	**Decision Variable (Xi)**	**Grade of Criterion 1**			**Mean (Z1i)**	**Std**	**Grade of Criterion 2**			**Mean (Z2i)**	**Std**
Airspeed indicator	X_1	80	60	79	73.0	11	90	80	88	86.0	5.3
Attitude indicator	X_2	85	90	83	86.0	3.6	85	95	87	89.0	5.3
Altimeter indicator	X_3	75	90	81	82.0	7.5	70	90	65	75.0	13
Fuel pressure	X_4	65	50	65	60.0	8.7	75	80	76	77.0	2.6
Fuel quantity	X_5	50	30	30	36.7	12	60	40	40	46.7	12
Dual tachometer	X_6	65	30	65	53.3	20	70	70	72	70.7	1.2
Radio compass	X_7	100	90	100	96.7	5.8	100	100	100	100.0	0
Variometer	X_8	95	90	91	92.0	2.6	90	90	80	86.7	5.8
Torquemeter	X_9	90	90	91	90.3	0.6	95	100	98	97.7	2.5
Magnetic Compass	X_{10}	75	65	65	68.3	5.8	90	90	84	88.0	3.5
Main generator load.	X_{11}	80	60	75	71.7	10	85	80	81	82.0	2.6
DC Voltmeter	X_{12}	50	30	40	40.0	10	50	40	45	45.0	5
Clock-chronometer	X_{13}	80	60	70	70.0	10	85	80	85	83.3	2.9
N1 indicator	X_{14}	70	65	60	65.0	5	60	90	72	74.0	15
EGT indicator	X_{15}	75	60	65	66.7	7.6	80	80	80	80.0	0
Engine oil pressure	X_{16}	60	60	50	56.7	5.8	60	50	50	53.3	5.8
Engine oil temperature	X_{17}	75	60	70	68.3	7.6	80	80	75	78.3	2.9
Transmis. oil pressure	X_{18}	60	30	54	48.0	16	40	50	44	44.7	5
Transmis. oil temper.	X_{19}	60	70	65	65.0	5	50	75	70	65.0	13

Mean and standard deviations of the grades for each criterion are given on the Table 4.3. Z1i values are the means of grades for each indicator with respect to first criterion. Z2i values are the means of grades for each indicator with respect to second criterion. These values are used to plot the relationship between indicators ($Z1_8=92$ and $Z2_8=86,7$ for X8 at Figure 2). Since this is a ranking problem, the graph can be thought as combination of several efficient frontiers. The graph corresponds to the Table 4.3 is Figure 4.2.

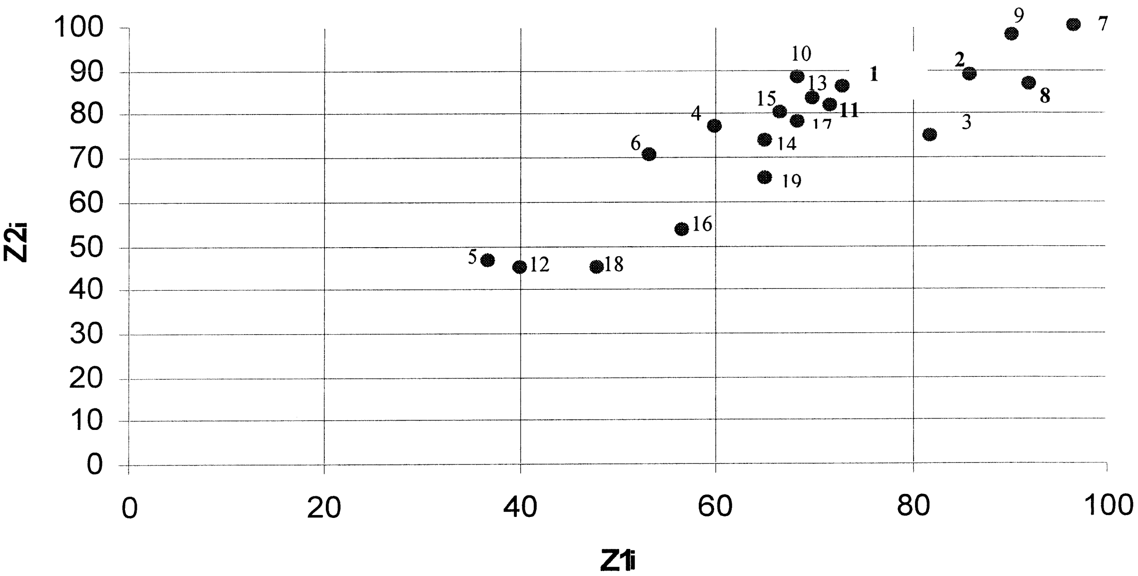


Figure 4.2 Graph of Alternative Indicators

According to these grades, aforementioned algorithm is applied. (Köksalan & Sagala, 1995) However, the number of alternatives that are candidates to be X1 and X2 with respect to the algorithm is small because few alternatives are efficient to each other. Moreover, suggested number of iterations is 4 even for relatively larger problems. Thus, iteration number is taken as 3. The alternatives to be compared are selected as X3 vs. X10, X19 vs. X6 and X5 vs. X18, which are the most far away alternatives to each other. In the end it is concluded that the utility function of the decision maker is linear which seems reasonable because points in Figure 4.2 are relatively close to each other. The form of utility function is $f(X_i)=\sum \beta_j X_{ij}$. Steps of the applied algorithm are the followings:

Step 0 i=0, N=3

Step 1 i=1 Alternatives are X3, X10. The preferred alternative by DM is X3.
Step 2 E2 69.7 86.7 E2 vs. X10, E2 is preferred
Step 4-d E1 80.63 76.3 E1 vs. X3, X3 is preferred

Step 1 i=2 Alternatives are X19, X6. The preferred alternative by DM is X19.
Step 2 E2 54.5 70.1 E2 vs. X6, E2 is preferred
Step 4-d E1 63.83 65.567 E1 vs. X19, X19 is preferred

Step 1 i=3 Alternatives are X5, X18. The preferred alternative by DM is X18.
Step 2 E2 37.8 46.467 E2 vs. X5, E2 is preferred
Step 4-b E1 46.87 44.867 E1 vs. X18, X18 is preferred

Step 6 i=N=3 Conclude linear

4.2.2 Arranging the Indicators

Concluding the DM has a linear utility function; alternatives shall be ranked using an appropriate approach. (Köksalan & Ulu, 2003)

- T is set of all alternatives. S = {X7} b=1 initially,
- Since |S|=1, X7 is in C_1.

  T ← T - {X7} and b=2.
- Now, S = {X8, X9}. According to the LP solution ε>0 for both X_n=X8

and X_m=X9 and X_n=X9 and X_m=X8, **thus the DM is asked** and he preferred X9.[1] S={X9}, |S|=1, X9 is in C_2.

T ← T - {X9} and b=3.

- S={X2, X8}. According to the LP solution, for X_n=X2 and X_m=X8 ε is found as 0. Thus, X8 » X2. S={X8}, |S|=1, X8 is in C_3.

  T ←T - {X8} and b=4.

- S={X2}, |S|=1, X2 is in C_4.

  T ← T - {X2} and b=5.

- S={X1, X3}[2] According to the LP solution ε>0 for both cases. Thus **the DM is asked** and he preferred X1. S={X1}, |S|=1, X1 is in C_5.

  T ← T - {X1} and b=6.

- S={X3}, |S|=1, X3 is in C_6.

  T ← T - {X3} and b=7.

- S={X10}, |S|=1, X10 is in C_7.

  T ← T - {X10} and b=8.

- S={X11, X13} According to the LP solution, for X_n=X13 and X_m=X11 ε is found as 0. Thus, X11 » X13. S={X11}, |S|=1, X11 is in C_8.

  T ← T-{X11} and b=9.

- S={X13}, |S|=1, X13 is in C_9.

  T ← T - {X13} and b=10.

- S={X15, X17}, According to the LP solution ε>0 for both cases. Thus **the DM is asked** and he preferred X15. S={X15}, |S|=1, X15 is in C_{10}. T ← T - {X15} and b=11.

---

[1] Note, whenever the DM gave new information about his utility function, this new preference information was used in the LP from that point on.

[2] Note, although X10 is not convex dominated by alternatives in T, we already know DM prefers X3 to X10 from section 4.2.1 (Step 1: i=1 Alternatives are X3, X10. The preferred alternative by DM is X3), so we excluded it from S.

- S={X17}, |S|=1, X17 is in C_{11}.

  T ← T - {X17} and b=12.

- S={X4, X14} According to the LP solution, for X_n=X4 and X_m=X14 ε is found as 0. Thus, X14 » X4. S={X14}, |S|=1, X14 is in C_{12}.

  T ← T - {X14} and b=13.

- S={X4, X19} According to the LP solution, for X_n=X19 and X_m=X4 ε is found as 0. Thus, X4 » X19. S={X4}, |S|=1, X4 is in C_{13}.

  T ← T - {X4} and b=14.

- S={X19}[3], |S|=1, X19 is in C_{14}.

  T ← T - {X19} and b=15.

- S={X6, X16} According to the LP solution, for X_n=X16 and X_m=X6 ε is found as 0. Thus, X6 » X16. S={X6}, |S|=1, X6 is in C_{15}.

  T ← T - {X6} and b=16.

- S={X16}, |S|=1, X16 is in C_{15}.

  T ← T - {X16} and b=17.

- S={X12, X18}[4] According to the LP solution, for X_n=X12 and X_m=X18 ε is found as 0. Thus, X18 » X12. S={X18}, |S|=1, X18 is in C_{17}. T ← T - {X18} and b=18.

- S={X5, X12} According to the LP solution, for X_n=X5 and X_m=X12 ε is found as 0. Thus, X12 » X5. S={X12}, |S|=1, X12 is in C_{18}.

  T ← T - {X12} and b=19.

- S={X5}, |S|=1, X5 is in C_{19}.

  T ← T - {X5} and b=20

- |T|=|S|=0. STOP, all alternatives are placed.

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[3] Note, although X6 is not convex dominated by alternatives in T, we already know DM prefers X19 to X6 from section 4.2.1 (Step 1 i=2), so we excluded it from S.

[4] Note, although X5 is not convex dominated by alternatives in T, we already know DM prefers X18 to X5 from section 4.2.1 (Step 1: i=3), so we excluded it from S.

During the process, DM is asked to make the following 3 comparisons: X8 vs. X9, X1 vs. X3 and X15 vs. X17 since LP did not lead to a clear solution. By applying the adapted algorithm for reducing the weight space of the DM's utility function, only 3 questions are asked to DM instead of 13 questions. Therefore, this method is far more efficient. The preference information gathered from determining the form of utility function in section 4.2.1 is employed for initial reduction in weight space. The graph (Figure 4.2) can be used for bi-criteria problems (as in this case) to reveal non convex-dominated alternatives, but if there are more than 2 criteria other methods to find the efficient frontier should be used. Alternatives are ranked as in Table 4.4 according to the adapted method explained in Section 3.2.2.7.

Table 4.4 Order of Locating Indicators

Order	Variable	Indicator
1	X7	Radio compass indicator
2	X9	Torque-meter Indicator
3	X8	Variometer
4	X2	Attitude indicator
5	X1	Airspeed indicator
6	X3	Altimeter indicator
7	X10	Magnetic Compass
8	X11	Main generator loadmeter
9	X13	Clock-chronometer
10	X15	EGT indicator
11	X17	Engine oil temperature indicator
12	X14	N1 indicator
13	X4	Fuel pressure indicator
14	X19	Transmission oil temperature indicator
15	X6	Dual tachometer
16	X16	Engine oil pressure indicator
17	X18	Transmission oil pressure indicator
18	X12	DC Voltmeter
19	X5	Fuel quantity indicator

4.2.3 Ranking Alternative Locations

Three pilots graded 24 locations on display panel in terms of visibility, given at Figure 3.2 on a 100 scale, while looking at forward flight horizon. These 24 locations and their points are given in Table 4.5. In utility helicopters both pilot and copilot sitting at left and right seats have to observe indicators established in the middle of display panel during some parts of flight. For this reason these locations which are in between Y1 to Y12 graded twice by the same pilot while located at left and right seat. All these grading experiments are performed on land and took 35 minutes for each pilot on the average.

Table 4.5 Visibility Points of Locations

Locations	**Seats:Left/Right**						**Mean**
	L	**R**	**L**	**R**	**L**	**R**	
Y1	88	86	89	86	88	87	87.3
Y2	87	86	88	87	87	86	86.8
Y3	86	84	87	85	87	84	85.5
Y4	85	84	86	83	88	84	85.0
Y5	88	89	86	87	89	89	88.0
Y6	86	87	88	88	87	87	87.2
Y7	86	86	88	87	87	86	86.7
Y8	86	86	87	87	86	86	86.3
Y9	87	88	87	88	87	88	87.5
Y10	87	88	86	88	85	88	87.0
Y11	84	86	84	85	86	87	85.3
Y12	87	88	85	87	84	86	86.2
Y13	94	--	95	--	95	--	94.7
Y14	96	--	99	--	99	--	98.0
Y15	90	--	89	--	90	--	89.7
Y16	86	--	87	--	85	--	86.0
Y17	98	--	95	--	96	--	96.3
Y18	100	--	99	--	100	--	99.7
Y19	92	--	91	--	92	--	91.7
Y20	88	--	88	--	89	--	88.3
Y21	93	--	94	--	93	--	93.3
Y22	97	--	98	--	98	--	97.7
Y23	89	--	89	--	90	--	89.3
Y24	85	--	87	--	85	--	85.7

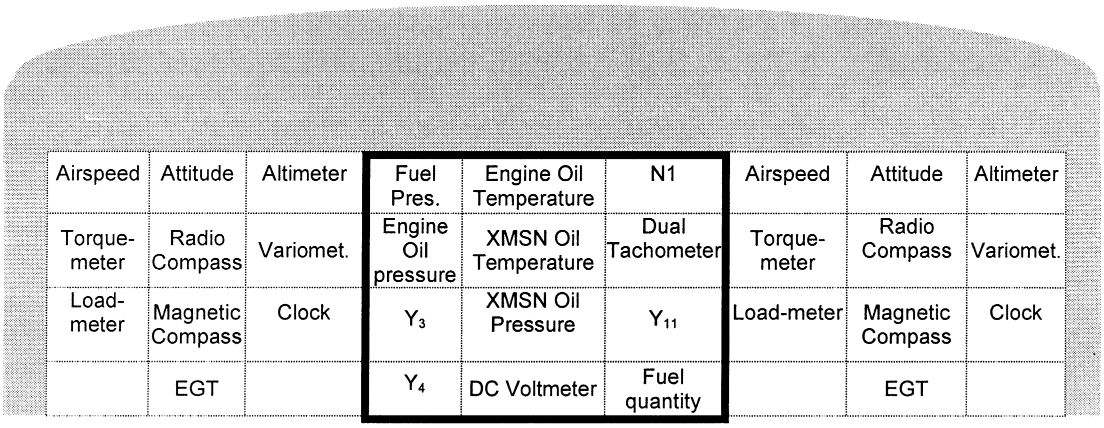
4.2.4 Locating Indicators to Suitable Places

Each location is ranked and listed from highest point to lowest one, revealing suitable places from best to worst. By combining the results of Table 4.4 and Table 4.5, following solution is presented in Table 4.6.

Table 4.6 Solution of MCDM Approach

Order	Location	Grade	Variable	Indicator
1	Y_{18}	99.7	X7	Radio compass indicator
2	Y_{14}	98.0	X9	Torque-meter Indicator
3	Y_{22}	97.7	X8	Variometer
4	Y_{17}	96.3	X2	Attitude indicator
5	Y_{13}	94.7	X1	Airspeed indicator
6	Y_{21}	93.3	X3	Altimeter indicator
7	Y_{19}	91.7	X10	Magnetic Compass
8	Y_{15}	89.7	X11	Main generator loadmeter
9	Y_{23}	89.3	X13	Clock-chronometer
10	Y_{20}	88.3	X15	EGT indicator
11	Y_5	88.0	X17	Engine oil temperature
12	Y_9	87.5	X14	N1 indicator
13	Y_1	87.3	X4	Fuel pressure indicator
14	Y_6	87.2	X19	Transmission oil temperature
15	Y_{10}	87.0	X6	Dual tachometer
16	Y_2	86.8	X16	Engine oil pressure indicator
17	Y_7	86.7	X18	Transmission oil pressure
18	Y_8	86.3	X12	DC Voltmeter
19	Y_{12}	86.2	X5	Fuel quantity indicator
20	Y_{16}	86.0	-	-
21	Y_{24}	85.7	-	-
22	Y_3	85.5	-	-
23	Y_{11}	85.3	-	-
24	Y_4	85.0	-	-

The solution in Table 4.4 is adapted on the display panel. If Figure 4.3 is examined, it can be clearly seen that engine and transmission system indicators form a group and other navigation and flight system indicators form another group. If some engine indicators are positioned to empty locations like Y3, Y4 a better design can be gained, since indicators of the same (engine) system must be close to each other in terms of cross-check. Card sorting methodology may give a better solution.



Airspeed	Attitude	Altimeter	Fuel Pres.	Engine Oil Temperature	N1	Airspeed	Attitude	Altimeter
Torque-meter	Radio Compass	Variomet.	Engine Oil pressure	XMSN Oil Temperature	Dual Tachometer	Torque-meter	Radio Compass	Variomet.
Load-meter	Magnetic Compass	Clock	Y_3	XMSN Oil Pressure	Y_{11}	Load-meter	Magnetic Compass	Clock
	EGT		Y_4	DC Voltmeter	Fuel quantity		EGT	

Figure 4.3 Display Panel Design with an MCDM Approach

4.3 Results of Qualitative Approach and Interpretation

Card sorting methodology was applied to 8 subjects. The experiments took 75 minutes on the average. Pilots have located indicators on the cloth described in Section 3.3.1.6 by attaching them to suitable locations. Comments of pilots are listened and noted as they sort the cards. Key words are prepared from the notes of think-aloud. Each individual pilot selects five most important key words out off all the key words, which he mentioned. Then he makes a comparison among five key words and gives points from 1 to 5 from most preferred to least preferred one. All 40 keywords of 8 pilots are grouped and 12 common different key words are identified. These are presented at Table 4.7

Table 4.7 Preferences of Key Words

Key Words	**Experiments & Preferences**								**Mean**	**Freq.**
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**		
Determining direction	**6**	**6**	**6**	**6**	5	**6**	**6**	**6**	5.88	1
Engine and flight indicators must be considered separately.	3	3	4	**6**	**6**	**6**	**6**	5	4.88	4
Engine and transmission systems must always be under control.	**6**	**6**	**6**	**6**	**6**	1	**6**	**6**	5.38	1
Frequency of use	**6**	**6**	**6**	4	**6**	**6**	**6**	**6**	5.75	1
Gages change control	**6**	**6**	**6**	**6**	3	**6**	**6**	**6**	5.63	1
Good vision	1	1	1	2	**6**	**6**	3	2	2.75	6
Indicator of the same system must be close to each other	4	4	2	3	1	3	4	3	3.00	8
Indicators must be positioned at the eye level	**6**	**6**	**6**	**6**	**6**	**6**	2	**6**	5.50	1
Cross-check affects the position of indicators	2	2	3	1	2	2	1	1	1.75	8
IFR &VFR effects the position of indicators.	5	5	5	**6**	4	5	**6**	4	5.00	6
Considering system pressures	**6**	**6**	**6**	**6**	**6**	**6**	5	**6**	5.88	1
Vestibular system affects the type & location of attitude indicator.	**6**	**6**	**6**	5	**6**	4	**6**	**6**	5.63	2

Six key words are stated and selected by more than one pilot and the other six key words are only stated and selected by one pilot. 2 key words, which are **"Cross-check affects the position of indicators"** and **"Indicator of same system must be close to each other"** are stated and selected by all of the 8 pilots. However key words like **"Indicators**

must be positioned at the eye level" or **"Determining direction"** are stated and selected by only one pilot. While grading key words, 6 points are assigned to the ones that are not stated and selected by the pilot in the relevant experiment. For instance **"Gages change control"** is selected in only experiment 5 and its point is 3. For other experiments it is given 6 points, since any pilot did not select it. In order to reveal the superiorities of key words to each other, preference means are calculated with respect to the points. Preference order, frequencies of each key word and their mean are given at Table 4.8.

Table 4.8 Order of Preferences

Order	User's Preferences	Mean	Freq.
1	Cross-check effects the position of indicators.	1.75	8
2	Good vision	2.75	6
3	Indicator of same system must be close to each other.	3	8
4	Engine and flight indicators must be considered separately.	4.88	4
5	IFR &VFR effects the position of indicators.	5	6
6	Engine and transmission systems must always be under control.	5.38	1
7	Indicators must be positioned at the eye level.	5.5	1
8	Gages change control	5.63	1
9	Vestibular system affects the type & location of attitude indicator	5.63	2
10	Frequency of use	5.75	1
11	Considering pressure of systems	5.88	1
12	Determining direction.	5.88	1

The most important key word is **"Cross-check affects the position of indicators"** with a preference mean of 1.75 and frequency of 8. Pilots have to cross-check N1, EGT, Torque-meter and Dual Tachometer to control the endurance of engine to different flight maneuvers at different altitudes since lift force of a helicopter is greatly affected by temperature and density of weather. These indicators are stated as the most important engine indicators in terms of flight safety. In addition a cross-check must be done by the pilots between Airspeed, Attitude, Altimeter and Vario - meter, which are the most effective navigation or flight indicators on airworthiness. Velocity of helicopter must be checked for different altitudes. Horizontal and vertical velocities are measured by Airspeed and Vario-meter. Position (attitude) of helicopter has to be under control to prevent Vertigo. Attitude information is necessary to show how the aircraft is moving, going downwards or upwards and lying left or right side.

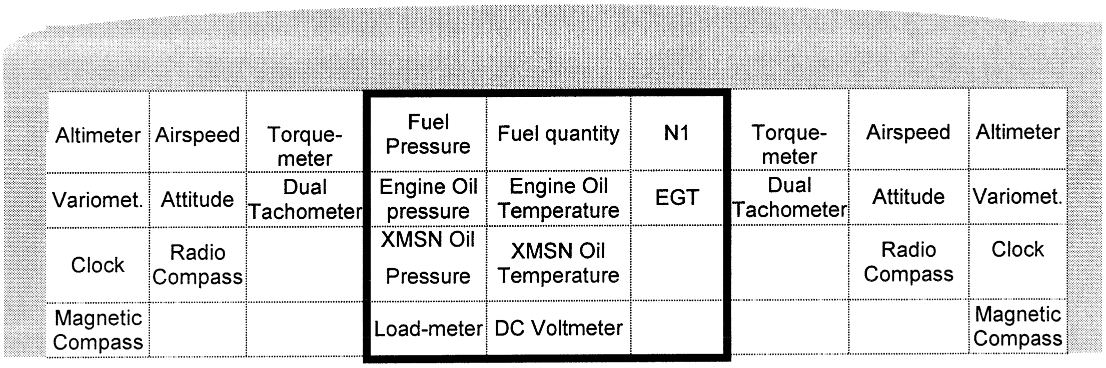
Providing "**Good vision**" is another significant necessity of interface design. Any interface or display lacking sufficient visibility will not meet the needs of users or pilots. 6 pilots selected "**Good vision**" and its mean is 2.75. Frequently used indicators must be positioned at the best visible locations. "**Indicator of the same system must be close to each other",** the basic rule of ergonomics and design is the third important key word with a mean of 3. 8 pilots consider it as important. For instance **"Fuel Quantity Indicator"** is located at L5 next to **"Fuel Pressure Indicator"** at L1 by 6 pilots.

Indicators of a helicopter display panel provide two different types of information. One is related with the status of engine, transmission systems, gears etc. But, navigational information like velocity, attitude, altitude, direction, route etc., can be monitored through the flight indicators. Main parts of a helicopter flight are engine start, departure, hover, flight and landing. During the flight, pilots generally check navigation system indicators. Engine and transmission system indicators are taken into consideration more during engine start, but they are less considerable during flight except hover or landing due to increased torque need. Four pilots select key word of **"Engine and flight indicators must**

be considered separately" and its preference mean is 4.88. This key word is the fourth important one.

"IFR &VFR effects the position of indicators" is the fifth important key word with a frequency of 5 and preference mean of 5. Instrument flight (IFR) and visual flight (VFR) creates different flying needs. While flying VFR, land and other geographical symptoms guide the pilot. On the other hand an IFR flight, which may start by entering a cloudy area or by flying at night necessitate the use of different indicators like Airspeed, Attitude, Altimeter and Vario-meter or night vision systems. For the rest of key words from (6 to 12) frequencies are less than or equal to 2. Their preference mean is greater than 5. These key words are found unimportant in the front display panel design. The least important key word is "Determining direction" with a preference mean of 5.88.

Selections of 8 pilots for the location of each indicator are given in Appendix F. For the diagrams in Appendix F, different colors are used in order to identify type of each indicator and to determine the location of it. Using the frequency of selections for a particular location a new display panel design is formed. It is presented at Figure 4.4.



Altimeter	Airspeed	Torque-meter	Fuel Pressure	Fuel quantity	N1	Torque-meter	Airspeed	Altimeter
Variomet.	Attitude	Dual Tachometer	Engine Oil pressure	Engine Oil Temperature	EGT	Dual Tachometer	Attitude	Variomet.
Clock	Radio Compass		XMSN Oil Pressure	XMSN Oil Temperature			Radio Compass	Clock
Magnetic Compass			Load-meter	DC Voltmeter				Magnetic Compass

Figure 4.4 Display Panel Design (Card Sorting Approach)

Pilots generally prefer the same locations for the indicators. For instance 6 pilots selected the location L1 for the Fuel Pressure indicator and 2 pilots selected L5. On the other hand 3 pilots selected the location of Clock as L23. Locations of flight system indicators at left side (Figure 4.4.) are mirror images of right side, since the pilots found it more useful.

Except Torque-meter and Vario-meter, engine system indicators are placed in the middle of the display panel in Figure 4.4. Helicopter can be flown by the synchronized use of controls and indicators. For a simple climb, pilot raises the collective then; the pitch angle of the blades is increased while increasing the torque of the main rotor system the helicopter climbs vertically. Cyclic, collective and pedal inputs can be combined so that horizontal and vertical motions can be coupled, while following the attitude meter, altimeters, airspeed, vario-meter indicator etc. (Dole, 1994). Because of the complexity of the aforementioned flight maneuvers it is required for both pilot and copilot to same type of flight system indicator separately on display panel. Legibility of each indicator is very important in order to perceive flight information properly, therefore pilots should be provided with essential displays just next to them.

CHAPTER-V

DISCUSSION AND CONCLUSION

There are lots of similarities between the results of quantitative and qualitative approaches. The main similarity is to provide separate locations for engine and flight system indicators. Engine system indicators are generally located in the middle of the display panel in both results, while flight systems are located on the sides of the panel. The fourth important key word of "**Engine and flight indicators must be considered separately**" stated in Card Sorting approach supports this result.

Although Torque-meter is an engine system indicator, it is located at flight system indicators part (Figure 4.3), as a result of MCDM approach. This is because of very high frequency (Mean_C2=97.7) of use of Torque-meter during flight maneuvers requiring more lift force such as hover. Because of that, Torque-meter is found as the second important display by the MCDM approach (Table 4.4). Similarly 6 participants of Card Sorting approach located Torque-meter at flight system indicators part. (See Appendix A) This indicator can also be accepted as a navigation tool for utility helicopters. It's thought that there should be two torque-meters on display panel for both pilot and copilot. In Card Sorting, pilots wanted it to be near to Airspeed, Attitude, Altimeter and Vario-meter.

There are some small differences between the results of the two approaches. One of the differences is the location of Load-meter and EGT. Load-meter is located in the engine system indicators part of L4 and EGT at L10 respectively (Figure 4.4, Card Sorting Approach). On the other hand, Load-meter is found to be located at Y15 and EGT at Y20 in the results of MCDM approach given at Figure 4.3. There are also some empty locations such as Y3-Y4-Y11 at Figure 4.3 in the vicinity of other engine system indicators. Their visibility grades are 85.5, 85 and 85.3 respectively. These grades are close to grades of Y15 and Y20, which have visibility grades of 89.7 and 88.3 (See Table 4.5). Because of the closeness of visibility grades for these locations, MCDM approach found the suitable position of load-meter as Y15 and EGT as Y20 at flight system indicators part, instead of Y3, Y4 or Y11 at engine indicators part. But their most suitable locations are found by Card Sorting approach at engine indicators part in accordance with the fourth important key word of "**Engine and flight indicators must be considered separately**".

Another difference is the arrangement of engine indicators. Engine indicators are located in a mixed way in the results of quantitative approach at the middle part of Figure 4.3. A more user-friendly solution could be revealed after considering location of any engine system indicator with respect to its function and functions of others around it. In order to provide efficient synchronization while observing displays, it is necessary to locate pressure and temperature or quantity indicators belonging to the same system side by side. With this pilots will have a chance of perceiving two different aspects of the same mechanical system, such as engine oil pressure and temperature at a glance. Besides, all participants of qualitative approach prefer the key word of **"Indicator of the same system must be close to each other"**. Fuel Pressure and Fuel Quantity, Engine Oil Pressure and Engine Oil Quantity, XMSN Oil Pressure and XMSN Oil Temperature are located next to each other at Figure 4.4 and this is advocated by all of the participants as stated above.

Torque-meter and Dual Tachometer are next to the N1 and EGT in Figure 4.4. Similarly, locations of Torque-meter, Dual Tachometer and N1 are also very close, while EGT is separated in Figure 4.3. Pilots have to crosscheck these indicators as discussed in the results of qualitative approach. Preference mean of **"Cross-check affects the position of indicators"** is 1.75. This explains why these four indicators are located next to each other. Positions of Airspeed, Attitude, Altimeter and Vario-meter at Figure 4.4 can be reasoned in the same way.

The findings are also compared with the display panel of a utility helicopter, which is currently in use in Turkish Land Forces (TLF) (Figure 4.5) (Source: TM 55 –1520-210-10). Positions of indicators are very similar to the results of quantitative and qualitative approaches. If the three figures (Figure 4.3, Figure 4.4 and Figure 5.1) are examined, general locations of engine and flight system indicators are found to be the same. In all approaches, two different areas are allocated for engine and flight system indicators. However, there is no symmetry (not mirror image) between the flight indicators in the current display panel. Locations of flight indicators do not change, wherever the pilot sits. For instance, if pilot sits at left or right seat, airspeed indicator is always in his left.

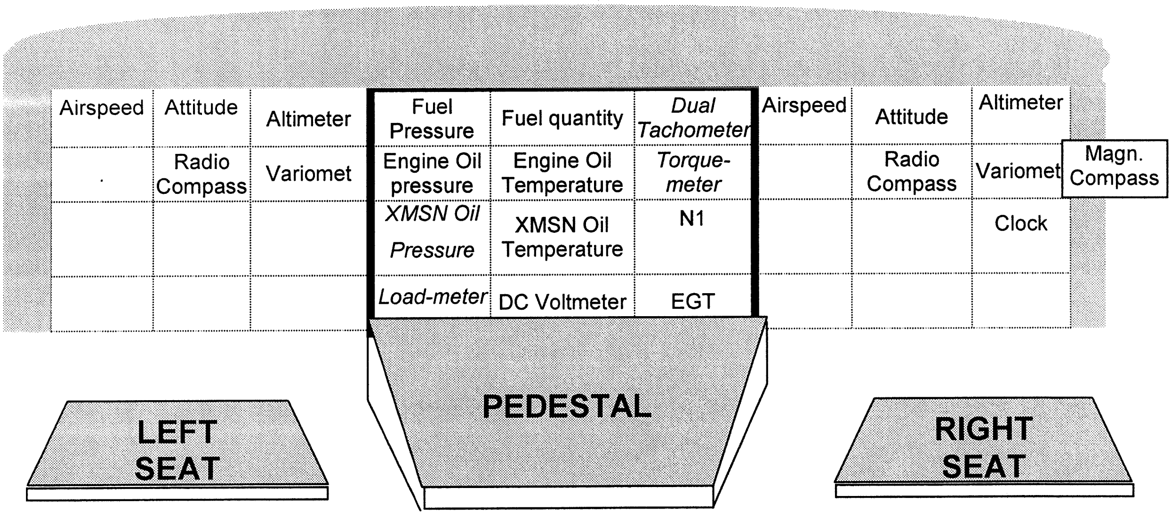


Figure 5.1 Display Panel of a Currently Used Utility Helicopter

MCDM methodology employed the grades for the following two criteria; **"effects of misapprehending information on the indicator on flight safety"** and **"frequency of use"** during flight as mentioned before. Locations of flight system indicators, which are at the right part of panel, like Airspeed, Attitude, Altimeter, Radio Compass, Vario-meter, Clock and engine indicators such as Fuel pressure, Engine oil pressure, Voltmeter indicators in Figure 5.1 are exactly the same with the results of MCDM approach. On the left panel, all aforementioned indicators, except clock, are at the same location. However, although engine system indicators are generally located in the middle of the display panel, their individual locations are found to be different. Indicators placed in the same locations in both displays are highlighted in Figure 5.2.

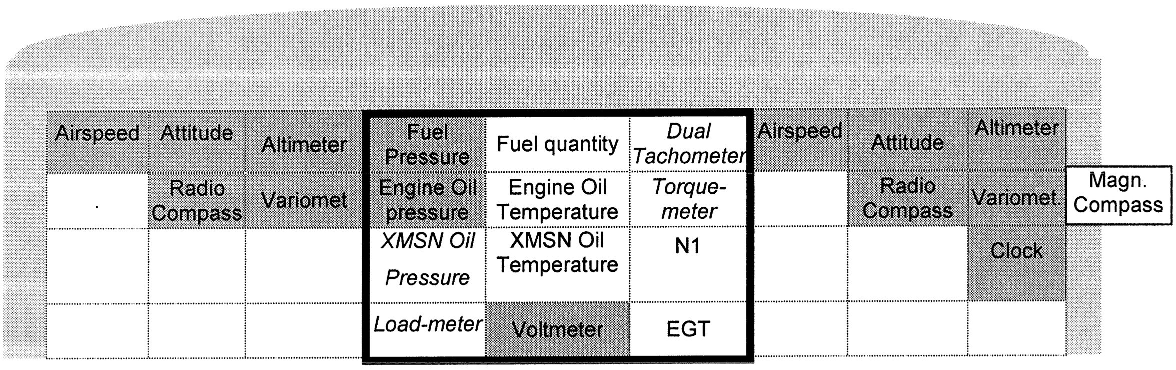


Figure 5.2 Similarities of Current Panel and MCDM Approach

On the other hand, as in the results of Card Sorting approach engine system indicators like Fuel Pressure and Fuel Quantity, Engine Oil Pressure and Engine Oil Temperature, XMSN Oil pressure and Temperature, Load-meter and Voltmeter are positioned at exactly the same locations at Figure 5.1. It is observed that, at the central panel Card

Sorting approach finds closer solutions to the current design. It may be suggested that, pilots might show preferences closer to central part of current display as a result of habit. Indicators placed in the same locations in both displays are highlighted at Figure 5.3.

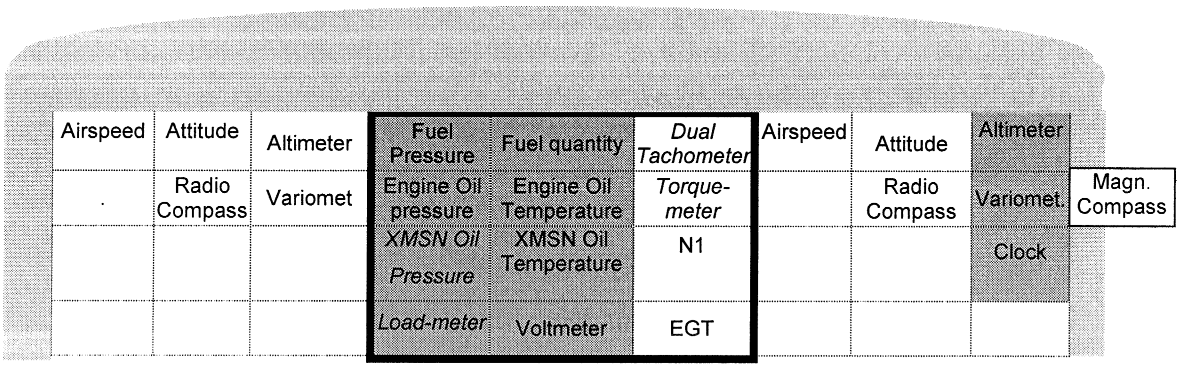


Figure 5.3 Similarities of Current Panel and Card Sorting Approach

Locations of six indicators, which are Fuel Pressure, Engine Oil Pressure, Voltmeter, Altimeter, Vario-meter and Clock are exactly same in the results of MCDM, Card Sorting designs and at current display panel. Locations of indicators (like N1), which are common in both methods but different in the original, must be given attention. The differences between the results of quantitative and qualitative approaches may arise due to the following reasons.

I. Closeness of the points assigned to locations by subjects, with respect to visibility (Table 4.6) in the MCDM approach.
II. Individual judgment of the DM in Quantitative approach might have affected the panel design. Classification algorithm could not find a solution in three cases. Therefore, DM is asked to compare two

alternative indicators for their respective importance. The choices of Decision Maker affect the results from this point onwards. Although Decision Maker is a design engineer, he may not be able to reflect needs of all users sufficiently.

III. Previous experience of pilots due to lengthy usage of the display panel in the current helicopter may influence their preferences during the Card Sorting experiments.

An efficient interface should provide a dialog between the operator and the device. In a usable system, the dialog is intuitive, natural and the user can work in harmony with the system. (Clamann & Kaber, 2004) Controls and displays in the air vehicles have been updated gradually for individual systems during the last 30 years. New displays are introduced to cockpits without redesigning the control array. They are placed wherever there is an available space and may not provide an intuitive dialog. This nonsystematic approach has resulted in a complex array of knobs, switches and displays. Flight navigation is complex and cognitively demanding. Pilots have to look at numerous indicators and make several decisions during a flight. Thus, it is very important that display panel must provide a natural dialog and minimize further complexities.

Although the ergonomics literature offers some approaches for the design of displays, no specific design methodology concerning the arrangement of indicators on display panel is offered so far. In this thesis, MCDM and Card sorting approaches are adapted and used in the design of a display panel for the first time. Proper positions of analogue indicators on front display panel are determined in order to provide right and easy perception of the flight information. Results obtained from MCDM and Card Sorting is compared with the current display design. Reasons of similarities and differences between the three panels are explained.

Results of this study must be considered before a new aircraft cockpit design or modernization in Turkey is made, or during aircraft procurements from another country. However future procurements would require digital displays rather than the analogue ones. Analogue displays would be still in use for the modernization of the existing vehicles.

For further work on this project prototypes of two display panels as given at Figure 4.3 and 4.4 should be prepared and a usability evaluation of three display panels (current, MCDM, Card Sorting) should be made to select the most usable one.

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APPENDIX A

LCL & UCL OF ALL CRITICAL OPERATIONAL MEASURES

STATURE	FREQUENCY
167	2
168	1
170	2
172	2
176	4
177	4
178	2
179	1
180	2

MEAN	174.65
STD.DEV.	4.27
z	2.58
AREA	0.99
UCL	185.67
LCL	163.63

ARM SPAN	FREQUENCY
67	2
69	2
70	4
71	3
72	7
73	2

MEAN	70.75
STD.DEV.	1.74
z	2.58
AREA	0.99
UCL	75.25
LCL	66.25

ELBOW LEVEL	FREQUENCY
38	1
39	7
40	1
41	4
43	2
44	2
45	2
54	1

MEAN	41.65
STD.DEV.	3.67
z	2.58
AREA	0.99
UCL	51.13
LCL	32.17

REACH (UHF/VHF RADIO)	FREQUENCY
18	2
19	1
20	1
21	1
23	2
24	1
25	2

MEAN	21.60
STD.DEV.	2.76
z	2.58
AREA	0.99
UCL	28.71
LCL	14.49

REACH (NADIR LEFT)	FREQUENCY
5	1
6	3
8	2
9	1
10	2
13	1
14	10

MEAN	8.10
STD.DEV.	2.47
z	2.58
AREA	0.99
UCL	14.47
LCL	1.73

REACH (NADIR RIGHT)	FREQUENCY
12	2
13	3
14	1
15	1
16	1
18	1
19	1

MEAN	14.5
STD.DEV.	2.461
z	2.58
AREA	0.992
UCL	20.85
LCL	8.151

APPENDIX B

CALCULATION OF CURRENT EXTERIOR VISION ANGLE

EYE LEVEL	FREQUENCY
93	2
94	0
95	7
96	2
97	5
98	0
99	0
100	1
101	2
102	0
103	1

MEAN	96.65
STD.DEV.	2.68
z	2.58
AREA	0.99
UCL	103.57
LCL	89.73

EYE DISTANCE	FREQUENCY
37	3
38	2
39	4
40	0
41	3
42	2
43	4
44	0
45	2

MEAN	40.60
STD.DEV.	2.60
z	2.58
AREA	0.99
UCL	47.32
LCL	33.88

EYE LEVEL-89	FREQUENCY	A	B	FREQ.
93-89	2	4	37	3
94-89	0	5	38	2
95-89	7	6	39	4
96-89	2	7	40	0
97-89	5	8	41	3
98-89	0	9	42	2
99-89	0	10	43	4
100-89	1	11	44	0
101-89	2	12	45	2
102-89	0	13		
103-89	1	14		

ANGLE	FREQUENCY
6.2062678	2
9.3324182	1
9.0847203	2
8.8498831	4
9.8303648	2
11.251848	1
10.980575	4
14.821821	1
15.46601	1
16.204693	1
18.126204	1

MEAN	10.71
STD.DEV.	3.15
z	2.58
AREA	0.99
UCL	18.83
LCL	2.59

A	B
4	37
4	37
6	37
6	38
6	38
6	39
6	39
6	39
6	39
7	41
7	41
8	41
8	42
8	42
8	43
8	43
11	43
12	43
12	45
14	45

A/B	Arksin(Rad)	Angle
0.1081	0.1083	6.2062678
0.1081	0.1083	6.2062678
0.1622	0.1629	9.3324182
0.1579	0.1586	9.0847203
0.1579	0.1586	9.0847203
0.1538	0.1545	8.8498831
0.1538	0.1545	8.8498831
0.1538	0.1545	8.8498831
0.1538	0.1545	8.8498831
0.1707	0.1716	9.8303648
0.1707	0.1716	9.8303648
0.1951	0.1964	11.251848
0.1905	0.1916	10.980575
0.1905	0.1916	10.980575
0.1860	0.1871	10.722152
0.1860	0.1871	10.722152
0.2558	0.2587	14.821821
0.2791	0.2828	16.204693
0.2667	0.2699	15.46601
0.3111	0.3164	18.126204

APPENDIX C

REGRESSION ANALYSIS OF EYE LEVELS & EYE DISTANCES

DEVIATON CORRECTION INDECES OF EYE LEVELS

E1	E2	E3	E4	E5
0.704503155	0.74181819	0.745105171	0.737385333	***0.871252596***
	0.74132371	0.741813993	0.744855106	***0.875827789***
		0.738531256	0.748080313	***0.883442879***
		0.740833426	0.739964604	***0.881750584***
			0.737569392	***0.880087137***
				0.878407776
				0.892029881
				0.896570623
				0.893145382
				0.903413594

Deviation	Deviation	Deviation	Deviation	***Deviation***
95	26.3	25.5	25.06	***22.85***

CORRELATION 0.89881947

REGRESSION EQUATIONS OF EYE LEVELS(y) & EYE DISTANCES(x)

E1	**$y = 0,0242x^2 - 0,0941x + 94,164$**	
E2	**$y = 0,0242x^2 - 0,0941x + 94,164$**	
E3	**$y = 0,0242x^2 - 0,0941x + 94,164$**	
E4	**$y = 0,0242x^2 - 0,0941x + 94,164$**	
E5	***$y = 0,4143x+92,3$***	**EQUATION 1**

ESTIMATES FOR THE EYE LEVELS(y)

Estimate 1	Estimate 2	Estimate 3	Estimate 4	***Estimate 5***	Eye Distance(**x**)	Eye Level(**y**)
87.22601505	91.84606788	92.253036	91.29722654	***93.77213282***	37	93
87.22601505	91.78484525	91.8455483	92.22207485	***94.26455672***	37	93
87.22601505	91.84606788	91.4391057	92.62139455	***95.08416194***	37	95
88.43839453	93.06058922	92.9990424	92.88997668	***95.26733101***	38	95
88.43839453	93.1226628	93.5352875	92.58929845	***95.0876066***	38	95
89.68487196	94.37221326	94.4346275	93.87084882	***95.27008709***	39	95
89.68487196	94.43516172	94.0167275	94.82176814	***96.74750928***	39	95
89.68487196	94.37221326	94.309799	95.23234446	***97.23998765***	39	95
89.68487196	94.43516172	94.853602	94.19919606	***96.86849394***	39	95
92.28012068	97.10310154	97.1673219	96.6113381	***98.73072903***	41	96
92.28012068	97.16787157	96.7373289	96.58722891	***95.21597262***	41	96
92.28012068	97.10310154	97.0388812	97.56566538	***95.71597853***	41	97
93.62889197	98.58808249	99.0249243	99.42032247	***96.91421386***	42	97
93.62889197	98.52236579	98.5875248	98.3417399	***96.72856808***	42	97
95.01176121	100.0441974	99.60091	99.47118966	***96.91070711***	43	97
95.01176121	99.97751009	99.9113887	99.4463668	***96.72578445***	43	97
95.01176121	100.0441974	100.487491	100.4537666	***98.2257812***	43	100
95.01176121	99.97751009	100.043632	100.8887293	***98.72578449***	43	101
97.87979355	103.0641393	102.607471	102.8066123	***99.08867473***	45	101
97.87979355	102.9954389	102.927322	102.4738347	***100.227866***	45	103

APPENDIX D

REGRESSION ANALYSIS OF ANGLES & EYE LEVELS

DEVIATON CORRECTION INDEXES OF ANGLES

E1	E2	E3	E4	E5
0.002839638	0.003004901	0.002913379	0.002691727	***0.00248336***
	0.003102276	0.002983812	0.002962894	***0.00263875***
		0.003096423	0.003205428	***0.00301138***
		0.003220741	0.003139916	***0.0029733***
			0.003267979	***0.00293619***
				0.00290009
				0.00328704
				0.00339948
				0.00330653
				0.00359976

Deviation	Deviation	Deviation	Deviation	***Deviation***
31	30.6	30.7	31.59	***29.31***

CORRELATION 0.996453107

REGRESSION EQUATIONS OF ANGLES(y) & EYE LEVELS(x)

E1	$y = 0,005x^3 - 0,1281x^2 + 1,2248x + 5,2868$
E2	$y = 0,005x^3 - 0,1281x^2 + 1,2248x + 5,2868$
E3	$y = 0,005x^3 - 0,1281x^2 + 1,2248x + 5,2868$
E4	$y = 0,005x^3 - 0,1281x^2 + 1,2248x + 5,2868$
E5	$y = 0,005x^3 - 0,1281x^2 + 1,2248x + 5,2868$

EQUATION 2

ESTIMATES FOR THE ANGLES(y)

Estimate 1	Estimate 2	Estimate 3	Estimate 4	***Estimate 5***	Eye-Level(**x**)	Angle(**y**)
8.612739654	9.113989737	8.836399729	8.164120265	***7.532144047***	93	6.20627
8.612739654	9.409332105	9.050024634	8.986580695	***8.003436352***	93	6.20627
9.235682424	9.773186955	10.0708539	10.4253835	***9.794254133***	95	9.33242
9.235682424	10.08989086	10.47518756	10.21231044	***9.670404699***	95	9.08472
9.235682424	9.773186955	9.475519399	10.6288242	***9.549718348***	95	9.08472
9.235682424	10.08989086	9.704595379	8.754615264	***9.432300339***	95	8.84988
9.235682424	9.773186955	10.0708539	9.636562663	***10.69081669***	95	8.84988
9.235682424	10.08989086	10.47518756	10.4253835	***11.05651287***	95	8.84988
9.235682424	9.773186955	9.475519399	10.21231044	***10.75421617***	95	8.84988
9.558159395	10.44219374	10.04344511	10.99994469	***12.11672748***	96	9.83036
9.558159395	10.11443166	10.42249207	9.060295091	***8.358946894***	96	9.83036
9.888087007	10.80263636	11.21515025	10.31728525	***9.188559992***	97	11.25185
9.888087007	10.46356062	10.14486596	11.16182805	***10.48611598***	97	10.98058
9.888087007	10.80263636	10.39012377	10.9337036	***10.35351787***	97	10.98058
9.888087007	10.46356062	10.78225464	11.37963971	***10.22430629***	97	10.72215
9.888087007	10.80263636	11.21515025	9.373037472	***10.09859393***	97	10.72215
10.92342559	11.55915455	11.20709075	11.39756332	***12.64447339***	100	14.82182
11.28400767	12.32766575	11.85691794	12.73756523	***13.50866891***	101	16.20469
11.28400767	11.94072202	12.3044067	12.477236	***13.13932768***	101	15.46601
12.02888677	13.14143873	13.64326308	13.84336499	***15.2488295***	103	18.12620

APPENDIX E

SOLUTION APPROACH FOR A BETTER EXTERIOR VISION

Table 1. Calculation of Eye Levels

	$y = 0,4143x+92,3$			
Eye Distance	**0.4143**	**92.3**	**Index**	**Eye Level(?)**
35	14.5	106.8	0.871252596	93.050213
36	14.9	107.2	0.875827789	93.9017013
37	15.3	107.6	0.883442879	95.0841619
39	16.2	108.5	0.881750584	95.6326403
41	17.0	109.3	0.880087137	96.1814669
43	17.8	110.1	0.878407776	96.7257845
45	18.6	110.9	0.892029881	98.9649172
47	19.5	111.8	0.896570623	100.211581
49	20.3	112.6	0.893145382	100.568795
50	20.7	113.0	0.903413594	102.099287

Table 2. Calculation of Angles

	$y = 0,005x^3 - 0,1281x^2 + 1,2248x + 5,2868$					
Eye Level	**0.005**	**-0.1281**	**1.2248**	**5.2868**	**Index**	**Angle(?)**
93.050213	4028.3	-1109.1	114.0	3038.4	0.002483	7.5455112
93.901701	4139.9	-1129.5	115.0	3130.7	0.002639	8.261073
95.084162	4298.3	-1158.2	116.5	3261.9	0.003011	9.8227336
95.63264	4373.1	-1171.6	117.1	3324.0	0.002973	9.8831176
96.181467	4448.8	-1185.0	117.8	3386.9	0.002936	9.9444923
96.725784	4524.8	-1198.5	118.5	3450.0	0.0029	10.005434
98.964917	4846.3	-1254.6	121.2	3718.2	0.003287	12.221934
100.21158	5031.8	-1286.4	122.7	3873.4	0.003399	13.16755
100.5688	5085.8	-1295.6	123.2	3918.7	0.003307	12.957159
102.09929	5321.5	-1335.3	125.1	4116.5	0.0036	14.818572

Table 3. Calculation of Eye Levels (Trial and Error)

	$y = 0,005x^3 - 0,1281x^2 + 1,2248x + 5,2868$					
Eye Level(?)	**0.005**	**-0.1281**	**1.2248**	**5.2868**	**Index**	**Angle**
118	8215.2	-1783.7	144.5	6581.3	0.002483	16.343782
119	8425.8	-1814.0	145.8	6762.8	0.002639	17.845359
120	8640.0	-1844.6	147.0	6947.6	0.003011	20.921923
121	8857.8	-1875.5	148.2	7135.8	0.002973	21.216812
122	9079.2	-1906.6	149.4	7327.3	0.002936	21.514401
123	9304.3	-1938.0	150.7	7522.2	0.0029	21.815202
124	9533.1	-1969.7	151.9	7720.6	0.003287	25.377969
125	9765.6	-2001.6	153.1	7922.4	0.003399	26.932189
126	10001.9	-2033.7	154.3	8127.8	0.003307	26.874754
127	10241.9	-2066.1	155.5	8336.6	0.0036	30.009891

Table 4. Calculation of Eye Distances

	$y = 0,4143x+92,3$			
Distance (?)	**0.4143**	**92.3**	**Index**	**Eye Level**
104	43.1	135.4	0.871253	117.95645
106	43.9	136.2	0.875828	119.30158
107	44.3	136.6	0.883443	120.70489
109	45.2	137.5	0.881751	121.20429
112	46.4	138.7	0.880087	122.06949
115	47.6	139.9	0.878408	122.92834
114	47.2	139.5	0.89203	124.46511
114	47.2	139.5	0.896571	125.09868
117	48.5	140.8	0.893145	125.73084
118	48.9	141.2	0.903414	127.55062

APPENDIX F
SELECTIONS OF 8 PILOTS FOR THE LOCATION OF EACH INDICATOR

Fuel pressure	Fuel pressure	Fuel Quantity	Fuel Quantity	Torquemeter	N1	N1	Torquemeter	Airspeed	Attitude	Altimeter	Variometer
Engine Oil Press.	Fuel pressure	Engine Oil Temp.	Fuel Quantity	....	N1	Torquemeter	Torquemeter	Attitude	Airspeed	Altimeter	Altimeter
Fuel pressure	Fuel pressure	Fuel Quantity	Fuel Quantity	Torquemeter	N1	....	Torquemeter	Airspeed	Airspeed	Variometer	Altimeter
Fuel pressure	Fuel Quantity	Fuel Quantity	Fuel pressure	N1	N1	Torquemeter	Torquemeter	Airspeed	Airspeed	Altimeter	Altimeter
Engine Oil Temp.	Engine Oil Temp	Engine Oil Press.	Engine Oil Press	EGT	EGT	Dual Tachometer	Dual Tachometer	Attitude	Airspeed	Variometer	Altimeter
Fuel pressure	Engine Oil Press	Tran. Oil Temp.	Engine Oil Temp	EGT	EGT	....	Dual Tachometer	Airspeed	Variometer	Variometer	Attitude
Engine Oil Press.	Engine Oil Press	Engine Oil Temp	Engine Oil Temp	N1	Dual Tachomete	Dual Tachometer	....	Attitude	Attitude	Altimeter	Variometer
Engine Oil Press.	Engine Oil Press	Engine Oil Temp	Engine Oil Temp	EGT	Dual Tachomete	Dual Tachometer	EGT	Attitude	Attitude	Variometer	Variometer
Tran. Oil Temp.	Tran. Oil Temp.	Tran. Oil Press.	Tran. Oil Press.	....	....	Radio Compass	....	....	Radio Compass	....	Variometer
Tran Oil Press.	Tran. Oil Press.	Fuel Quantity	Tran. Oil Temp.	N1	....	Dual Tachometer	....	Radio Compass	Radio Compass	....	Clock
Tran. Oil Press.	Tran. Oil Press.	Tran. Oil Temp.	Tran. Oil Temp.	EGT	EGT	....	....	Radio Compass	Radio Compass	Clock	Clock
Tran. Oil Press.	Tran. Oil Press.	Tran. Oil Temp.	Tran. Oil Temp.	....	....	Radio Compass	....	Clock	Radio Compass	....	....
Main loadmeter	Main loadmeter	DC Voltmeter	DC Voltmeter	....	....	Magnetic Compas	Clock	Clock	....	....	Magnetic Compass
Main loadmeter	Main loadmeter	DC Voltmeter	....	Clock	DC Voltmeter	....	....	Magnetic Compass	....	....	Magnetic Compass
	Main loadmeter	DC Voltmeter	DC Voltmeter	Main loadmeter	....	Magnetic Compas	....	....	....	....	Magnetic Compass
Main loadmeter		....	DC Voltmeter	DC Voltmeter	Main loadmeter	....	....	....	Clock	Magnetic Compass	Magnetic Compass