APPLICATION OF ERGONOMIC PRINCIPLES IN THE DESIGN OF A COCKPIT WORKSTATION

Low Chuen-Yeung, Brendan

SCHOOL OF MECHANICAL AND PRODUCTION ENGINEERING
NANYANG TECHNOLOGICAL UNIVERSITY

2001

APPLICATION OF ERGONOMIC PRINCIPLES IN THE DESIGN OF A COCKPIT WORKSTATION

SUBMITTED

BY

LOW CHUEN-YEUNG, BRENDAN

SCHOOL OF MECHANICAL AND PRODUCTION ENGINEERING

A final year project report
presented to the
Nanyang Technological University
in partial fulfilment of the
requirements for the
Degree of Bachelor of Engineering
Nanyang Technological University

2001

ABSTRACT

The design of aircraft cockpits is to enable the pilots to maximise performance and improve safety has always been a top priority in the design of an aircraft. This is even more important today, as aerospace technology has pushed the performance of aircraft beyond the physical limits of human capability for manually control. Ergonomics can aid in the design of aircraft cockpits by providing knowledge of human performance data and application of this knowledge to achieve a design that allows the pilot to fly the aircraft to the limit of performance without sacrificing his safety and well being.

Aircraft cockpits are always designed and tested specifically to meet the specifications of the range of pilots who using the aircraft. However as the aircraft manufacturers export their aircraft overseas, because the aircraft were not specifically design for the local population, there may be problems in the physical fit of the local pilots to the imported aircraft. Therefore, there is a need to understand various aspects of anthropometric fit in the aircraft.

This aim of this project was to identify the various factors involved in designing a helicopter cockpit workstation, especially with respect to anthropometric fit. The helicopter characteristics were based on the AH-64 Apache helicopter. Various aspects of fit were considered and analysed, and the relevant anthropometric dimensions identified. Basing the anthropometric measurements on data from the Defence Medical Research Institute, a cockpit design was specified, on ergonomic principles, and other standards and guidelines. Testing methods were then recommended to evaluate the design in a computer environment.

It was discovered that the anthropometric fit of the cockpit is an important component of cockpit design, but many other related factors also influence the design of the cockpit. A systems approach would be a good approach to an understanding of such complex problems. Furthermore anthropometric fit by "pen and paper" methods can only yield approximate results, which must be further validated by physical testing.

ACKNOWLEDGEMENTS

The author wishes to express his most sincere appreciation to the supervisor of this project, Assistant Professor Chui Yoon Ping, for her invaluable advice and guidance throughout the project. Her patience and understanding have been the major contributing factors to the success of the project.

The author would also like to thank the staff of the Defense Medical Research Institute, especially Mr Mark Chan Wai Herng, Mr John Soo Kok Tiong, and Dr Naresh Kumar, for the use of their facilities and providing data for this project. Their advice and guidance have also contributed greatly to the success of this project.

Finally the author would like to thank all those who have in one way or another contributed to this project.

LIST OF FIGURES

		Page
Figure 2.1	Information Flow Loop (adapted from Galer, 1987)	7
Figure 2.2	Additional interactions between the user, machine and environment	7
Figure 2.3	The SHEL model illustrating the interrelationships between the three types of system resources and their environment. (Edwards, 1988)	8
Figure 2.4	Three Dimensional SHEL model. (Edwards, 1988)	9
Figure 2.5	Anthropometric measurements using an anthropometer. (Roebuck, 1995)	11
Figure 2.6	Men's grasping reach to a horizontal plane through the seat reference point (SRP). (NASA, 1978)	12
Figure 2.7	Model of human perception and cognition. (Lim, 2001)	14
Figure 2.8	Generic Tandem Seat Helicopter. (MIL-STD-250D, 1974)	17
Figure 2.9	HOTAS controls (Wykes, 1988)	18
Figure 2.10	MFD displaying fuel status (Wykes, 1988)	18
Figure 2.11	Helmeted-mounted display, IHADDS system for AH-64 helicopter.	19
Figure 2.12	Basic Parts of a Helicopter (AH-64 Apache)	20
Figure 2.13	Lift generated by rotor spinning (Westland, 2001)	21
Figure 2.14	Forward motion by rotor tilt (Westland, 2001)	21
Figure 2.15	Aerofoil lift	21
Figure 2.16	Torque compensation by tail rotor (Westland, 2001)	22
Figure 2.17	Basic Flight Controls	23
Figure 2.18	Summary of Design Information	25
Figure 3.1	Summary of Anthropometric data of National Service men and the Singapore populace. (dimensions 1-41)	29
Figure 3.2	Summary of anthropometric data between National Service men and the Singapore populace. (dimensions 42-67)	30
Figure 3.3	Tandem crew compartment of AH-64.	31
Figure 3.4	View from pilot compartment of AH-64. (The Jolly Rogers)	31
Figure 3.5	Anthropometric dimensions	34
Figure4.1	Anthropometric Multivariate Models, USAF (Kennedy,2001)	36
Figure 4.2	Aspects of pilot accommodation in the cockpit.	38

Figure 4.3	Seat Angle Parameters(See APPENDIX D for design reference definitions.)	42
Figure 4.4	Seat Size Parameters A	43
Figure 4.5	Seat Size Parameters B	44
Figure 4.6	Seat Pan Specifications	45
Figure 4.7	Diagrams of Seat Specifications	46
Figure 4.8	Backrest Specifications	47
Figure 4.9	Layout of cockpit interface	48
Figure 4.10	Layout of cockpit interface (MIL-STD-250D)	49
Figure 4.11	Design Eye Point (Humanscale, 1988)	49
Figure 4.12	Field of vision including head rotation (MIL-STD-1472D)	50
Figure 4.13	Display angle with respect to line of sight (MIL-STD-1472D)	50
Figure 4.14	Cockpit geometry specifications	51
Figure 4.15	Calculation of visual zone	52
Figure 4.16	Optimum viewing area	53
Figure 4.17	Overall Centre Console Size	53
Figure 4.18	Side Panel Specifications	54
Figure 4.19	Side Panel Dimensions	55
Figure 4.20	Reach Zones (MIL-STD-1333B)	56
Figure 4.21	Common Controller Configuration (Hart, 1988)	57
Figure 4.22	Cyclic control stick motion (Woodson, 1981)	59
Figure 4.23	Cyclic Control Stick Level	60
Figure 4.24	Cyclic control with curved / offset stick (Collective Control, 2001)	60
Figure 4.25	Cyclic Control Grip Position	61
Figure 4.26	Cyclic control stick specifications	61
Figure 4.27	Diameter of cyclic control grip	62
Figure 4.28	Anthropometric Dimensions Determining Cyclic Grip Size.	62
Figure 4.29	Anthropometric Dimensions Determining Minimum Cyclic stick Envelope	63
Figure 4.30	Horizontal Reach and Clearance to Cyclic	64
Figure 4.31	Cyclic grip Motion Envelope	65
Figure 4.32	Top view of approximate collective position	67

Figure 4.33	Side view of the collective hand position	68
Figure 4.34	Geometrical representation of arm reach to collective	68
Figure 4.35	Collective grip layout and related anthropometric dimensions	70
Figure 4.36	Pedal operation and related anthropometric dimensions	71
Figure 4.37	Minimum pedal distance from the seat reference point	72
Figure 4.38	Maximum pedal distance from the seat reference point	73
Figure 4.39	Range of Pedal adjustment from aft seat position	73
Figure 4.40	Pedal sizing specifications	74
Figure 4.41	Detailed list of Flight controls and displays	77
Figure 4.42	Front instrument panel layout	79
Figure 4.43	ADI which makes use of colour.	80
Figure 4.44	Vertical tape displays	80
Figure 4.45	Radar Diagram Display Concept	81
Figure 4.46	Cockpit general instrumentation layout	82
Figure 5.1	Characteristics of multivariate models, general(Kennedy,2001)	86
Figure 5.2	Modified table of dimensions for this project	86
Figure 5.3	Table of limits of accommodation	87

TABLE OF CONTENTS

		Page
ABSTRACT		i
ACKNOWLEDGEMENT		ii
LISTS OF FIGURES		iii
CHAPTER ONE		
INTRODUCTION		1
1.1	Background	1
1.2	Objectives	3
1.3	Scope	3
1.4	Organisation	4
CHAPTER TWO		
THEORY AND LITERATURE REVIEW		5
2.1	Workstation Design	5
2.2	Design process – A systems approach	6
2.3	The information flow loop concept	6
2.4	SHEL model of system resources	8
2.5	Anthropometry – ergonomic considerations	10
2.6	Perception and Cognition – ergonomic considerations	12
2.7	Cockpit Technologies	17
2.8	Helicopters	19
2.9	Flight Tasks	24
2.10	Summary	25

CHAPTER THREE

DESIGN INFORMATION 26

3.1 Anthropometry of the user population 26
3.1.1 Data Collection 26
3.1.2 Analysis 26
3.1.3 Tables 29
3.2 The Crew Compartment 30
3.3 User 32

CHAPTER FOUR

DESIGN
4.1 Anthropometric Accommodation 35
4.2 Analysis 38
4.3 Seating 42
4.3.1 Objective 42
4.3.2 Discussion 42
4.3.3 Analysis 43
4.3.4 Design 44
4.4 Cockpit Geometry 48
4.4.1 Objective 49
4.4.2 Discussion 49
4.4.3 Analysis 51
4.4.4 Design 52
4.5 Reach Zones 56
4.6 Cyclic Control 56
4.6.1 Objective 57
4.6.2 Discussion 57
4.6.3 Analysis 58
4.6.4 Design 59
4.7 Collective 66

4.7.1 Objective 66
4.7.2 Discussion 66
4.7.3 Design 67
4.8 Anti-Torque Pedals 71
4.8.1 Objectives 71
4.8.2 Discussion 71
4.8.3 Design 72
4.9 Flight Displays 75
4.9.1 Objective 75
4.9.2 Discussion 75
4.9.3 Design 76

CHAPTER FIVE

TESTING METHODS
5.1 CAD and Human Modelling Software 84
5.2 Testing 85

CHAPTER FIVE

CONCLUSIONS AND RECCOMMENDATIONS
5.3 Conclusions 88
5.4 Recommendations 89

REFERENCES 90

APPENDIX A: Summary of Design Tables
APPENDIX B: Summary of Anthropometric Tables
APPENDIX C: Design References

CHAPTER ONE INTRODUCTION

1.1 BACKGROUND

In our daily life, we often use tools, equipment and facilities, which we believe are designed perfectly for our own use. When we experience discomfort or difficulty in such use, it is often taken for granted that the various things that we interact with and use in the physical world are the way they and cannot be changed, and accept that we must adapt to them. However, in an age where mankind spends increasing amount of time in man-made environments of our own design, i.e. sitting in workplaces and motor vehicles, where incidence of injury and pain has increased, there is a need for things to be better to suited for human use. Through the application of ergonomics in the design of these "machines", these workstations can enhance productivity and safety, and at the very least, reduce injury and ill health.

Products and technology acquired from other countries are specially suited to that country's user population, and these could pose a poor fit between the new local users and the imported products. A number of factors need to be considered in such a technology transfer (Ong, 1991), and ergonomics can be of help in identifying these areas of concern. There is a need in matching the new users to the product so that the product brings the promised benefits without detriment to the users. With the maturation of the defense industry in Singapore (Tan, 2000), and ventures into foreign markets, there also a need to take ergonomics in to account when enabling its own technology transfers to other countries.

The fundamental requirement to design an ergonomic workstation for the user is through the use of the anthropometric data of the user population. Physiological and cognitive abilities and needs of the user must also be taken in to account in designing the equipment for the user. This is most critical in the area of aircraft cockpit design, especially military aircraft, where there are the physical constraints of the airframe and increasingly complex task of controlling the aircraft. In addition, military situations require the handling of weapons systems, and surviving combat with the enemy, thus putting even greater physical and mental load on the operator than any other workstation. However, in developing or newly industrialized nations, such data may not be easily available or ergonomic aspects may not have been considered.

As the Singapore Armed Forces actively betters its defense capability through the upgrading of defense technology, there is a need to better integrate these “machines” with the “users”, that is, the men of the Singapore Armed Forces. Ergonomics or (Human Factors as it is more widely known in the USA) can help us evaluate and achieve a better fit for the local population so as to achieve the efficiency and performance as required by military missions. This will also minimise error, system failure and accidents, which in the military context, can be very costly.

In this final year project, the anthropometric data of National Service enlistees was collated and analysed. The data was then used in the analysis and design of anthropometric accommodation in a helicopter cockpit, based on the AH-64 Apache helicopter that was recently purchased by the Singapore Armed Forces (SAF) (Straits Times, 21 August, 2001).

Attention is drawn to the fact that the aircraft currently under use are made for U.S.A aviators, and bought “off the shelf”, to be used by Singapore aviators. Obviously, there is potential for problems to occur in fitting the user to the machine. These will be discussed herein.

Through the use of computer models of the cockpit and the user, rapid analyses of the man-machine systems can be done, which translates into many advantages in terms of cost and time savings, and contributions to the design process (Porter et al, 1999). However this can only be done effectively when there is an understanding of the design problem and the fidelity of the systems used. The use of such tools for ergonomic evaluations and design will be investigated and discussed.

1.2 OBJECTIVES

The aims of this project are as follows: -

1) To apply ergonomics principles in the area of workstation design for a helicopter cockpit.
2) To understand the approach and methodology involved in the use of ergonomics for workstation design, particularly anthropometric accommodation.
3) To investigate and apply computer software as an aid in the analysis and evaluation of the workstation design.

1.3 SCOPE

The scope of this project is as follows: -

1) This project presents the use of ergonomic principles in the workstation design of a helicopter cockpit, in order to understand better the various factors involved in such a design.
2) A systems approach to design was used as a framework to logically and systematically study the workstation problem. The helicopter requirements and functionality are based on the Boeing (McDonnell Douglas)(formerly Hughes) AH-64A Apache attack helicopter, with the use of anthropometric data of National Service men of the Singapore Armed Forces collated in 1988.
3) In view of the fact that only anthropometric data of the user population was available, analyses and considerations that involve other key data of human characteristics like, biomechanical performance, physiology and psychological data, control response performance, and information processing (Woodson, 1981) are outside the scope of this project, unless

such characteristics apply generically to the majority of the human race. Thus only analyses and considerations based on the anthropometric data will be considered as the basis for the design of the workstation.

4) The anthropometric data will be analysed to come up with meaningful values, and the workstation objectives and functions defined; and then applied to the workstation design of the helicopter cockpit. Task analysis will be considered on a general level as it pertains to workspace layout only.
5) This project also aims to discuss CAD and Human Modelling software as an aid to analyse and evaluate the specified workstation design. The use of these tools will allow a quicker and less costly design of the workstation by reducing redesign and allowing for a more pro-active approach to ergonomic design (Porter et al, 1999).

1.4 ORGANISATION

The first part of this report describes the approach to defining all the factors that need to be considered in the design of a helicopter cockpit. The different cockpit technologies available will also be explored and reviewed.

The next few sections will then be devoted to the design of the helicopter cockpit, in the form of calculations and recommendations, using the anthropometric data of the Singaporean National Service men.

The results of the design will be discussed, and recommendations or possible future work that can be done to improve knowledge or methods in this area will be suggested.

CHAPTER 2 THEORY AND LITERATURE REVIEW

2.1 WORKSTATION DESIGN

The design methodologies for workstation design may vary from workstation to workstation depending on workstation needs, however they primarily have the same goals, that is, the optimum accommodation of the body size variance of the user population. The main technique for fitting the user population to the workstation is through designing a range of adjustability into the workstation so that it will be able to accommodate the body size variance.

According to McConville, (1978), the workstation design can be described in a series of steps as follows: -

1. Determine the characteristics of the potential user population and select the appropriate anthropometric database for analysis.
2. Establish what the equipment must do for the user (form, function, interaction).
3. Select the form of the interface between the users with the equipment.
4. Establish the anthropometric design values to be used in fabrication.
5. Design and evaluate a mock-up and revise design as necessary.

Before attempting to design the workstation, information and understanding of the function of the equipment and the relationship to the user must first be gathered and understood.

Ideally, for aircraft cockpits, anthropometric data, functional arm reach data and body link data would be needed to accurately specify the design. However, in this project only anthropometric data was available for use, thus limiting the accuracy of the specifications. Nevertheless, the process of analysing the important anthropometric parameters for the design, and how these parameters interact with the workstation components, can be useful as a benchmark for the systematic analysis of key dimensional needs (Roebuck, 1995)

2.2 DESIGN PROCESS – A SYSTEMS APPROACH

Applying ergonomics to an aircraft with many issues and interrelated factors requires a rigorous approach to logically and systematically study the system. Such an approach is the systems or systems engineering approach. This is especially so for helicopters, because their range of manoeuvres and control requirements is much wider than fixed wing aircraft. Helicopters are able to move in any direction, hover stationary while airborne, and land and take off vertically, require continuous control and monitoring, and are inherently unstable without automatic stabilization systems therefore posing additional perceptual and motor demands on the pilot. Added to that, the environmental climate of engine noise, vibration and heat, together with increased job and mission demands, and designing an ergonomic cockpit workstation offers many challenges to the designer and the pilot (Hart, 1988).

The approach to design that the author has chosen is a formal method of analysis known as the systems approach (Galer, 1987), which starts with a simple model of a control loop in the man-machine interface, and then goes on to the SHEL model of system resources (Edwards, 1988). A systems design process will be discussed and outlined in this chapter to show how ergonomics principles can be effectively implemented in workstation design. This approach is not new, and is employed in military, electrical, aviation industries. (Sheriden, 1988; Galer 1987; Chapanis, 1996)

2.3 THE INFORMATION FLOW LOOP CONCEPT

To conceptualise the basic relations between people and the tasks they carry out, consider the situation where a person is interacting with a machine. This interaction is made possible by the use of displays, which pass information to the person while the person relays information back to the machine through the use of controls. This completes the information flow loop. Thus in an ideal flow loop, there must be proper functioning of all the different parts without any delay or stoppage of flow to ensure safe, efficient and successful use of the machine by the person.

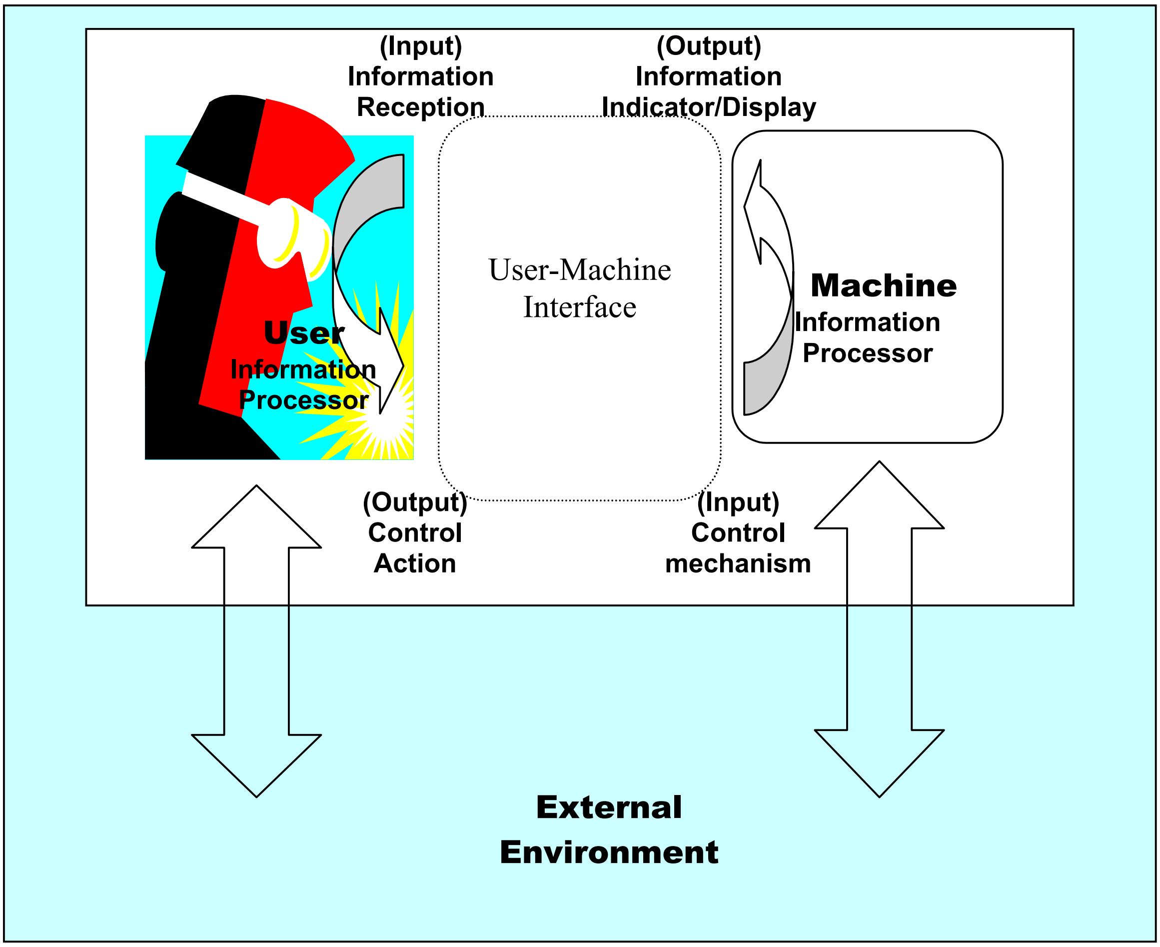


Figure 2.1 Information Flow Loop (adapted from Galer, 1987)

In considering an aircraft cockpit, apart from the user-machine interface we can see that there are also interactions between the

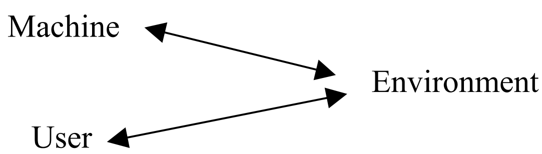


Figure 2.2 Additional interactions between the user, machine and environment.

The human being is thus considered an integral part of the overall system that is functioning. This is in line with the ergonomic concept of user-centred design, in which the characteristics of the user is considered and the workstation design is fitted to the user based on these characteristics.

These interactions between the three components of user / liveware (L), the machine/ hardware (H), environment (E) and software (S) is more adequately illustrated in the SHEL model of system resources.

2.4 SHEL MODEL OF SYSTEM RESOURCES

Within this framework there are three kinds of resources available in the system. The first consists of physical things, like equipment, materials, etc … which can be termed "*hardware*". The next resource is the human beings, which can be termed "*liveware*", and finally there are the resources that govern systems behaviour, like regulations, operating procedures, practices, and laws. These can be termed the *"software"*.

S – software
H – hardware
E – environment
L – liveware

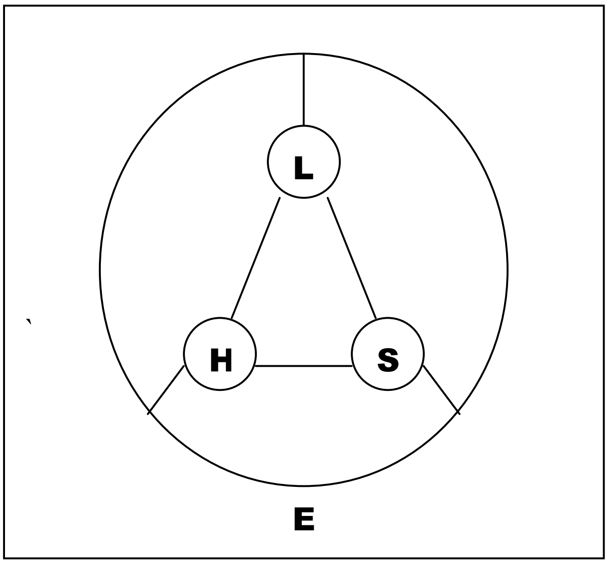


Figure 2.3 The SHEL model illustrating interrelationships between the three types of system resources and their environment. (Edwards, 1988)

The lines joining the different system components represent the interfaces between the components, through which information and energy flow, similar to the above information flow loop concept, Another aspect of this approach to workstation design can be seen when there are several of the same type of resource. The SHEL model shows the added H-H interface and S-S interface, and finally the L-L interface, for example, in communications or task allocation in an aircrew.

With this model in mind the main areas of the system design where ergonomics principles can most effectively be applied is in the L-H interface, the L-S interface, and to a lesser extent, the L-L and L-E interfaces.

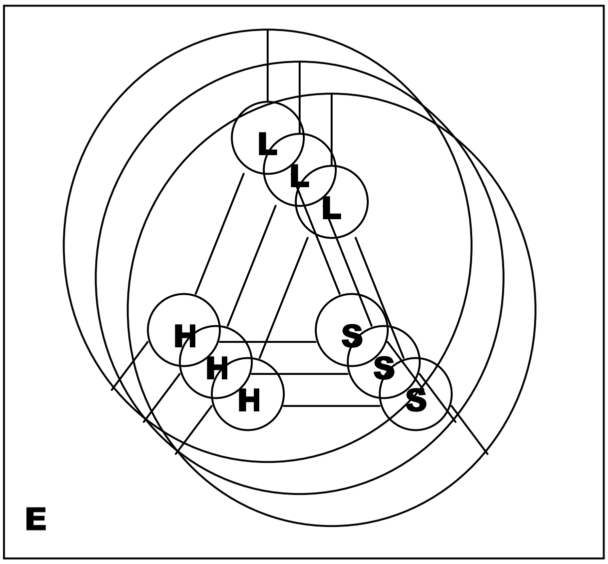


Figure 2.4 Three Dimensional SHEL model.

In an aircraft cockpit, the L-H interface is probably the most basic area where ergonomics can be applied, accommodating the varying anthropometry of the pilots to make sure they can reach the controls, fit into the cockpit and attain the required range of external vision.

In the L-S interface, the pilot is required to conform to a fixed set of rules, regulations, conventions and operating procedures, for example, the procedures for the various emergency conditions that may happen. The skills associated with these "software" are usually acquired during the pilot's basic flight training, and on the job. However, the information presented to the pilot in the employment of these skills is usually in the physical form, such as checklists, maps, charts and tables. How the information is presented can influence the pilot response and thus performance. In this respect, knowledge about cognitive abilities can be applied, to maximise acquisition and processing of the information.

The L-E interface includes those external factors over which there is no control. The most immediate environmental conditions are those in which the aircraft operate - weather, temperature, radiation, aircraft vibration, and so on. Military aircraft have to also contend with the enemy as added factor. These factors can at best be anticipated and measures implemented to protect or isolate the pilot from discomfort or damage that these environments can cause. These include pressurized cabins, thermal, noise and vibration insulation, and armour protection.

Finally in the L-L interface, this has to do with the interactions between the pilot and other aircrew, or external personnel, such as air traffic control or other aircraft. Because there are two “liveware” to consider in such an interaction, there is a higher level of uncertainty involved. Radio communications is an area where this can be seen. Wrongly set frequencies, failure to follow proper radio voice procedure and vocabulary can often contribute to accidents. In the military helicopter context, team work, coordination and training is even more important, where often there is coordination between aircraft flying and hovering in close proximity, providing many opportunities for accidents to occur (Flight Fax, March 1997). Ergonomics can contribute to the design of communication interfaces, tools and processes.

From the above areas, ergonomics is a discipline that is based on the study and knowledge of the L component of the system, and the application of this knowledge to the design and management of the interfaces that include the L component, the L-H, L-L, L-E and L-S interfaces. Using the systems approach, due consideration may also be given to the influence of other system factors.

2.5 ANTHROPOMETRY - ERGONOMIC CONSIDERATIONS

Anthropometry is a branch of the science of ergonomics, which deals with the measurement of dimensions and physical characteristics of human beings, particularly their sizes and shapes. Usually, with the numerical data that is gathered of the target population, statistics is applied so as to come up with useful values that can be applied to design. Pheasant (1986) describes ergonomics not just as a relay to which anthropometry contributes as a basic science and which then contributes data, concepts and methodologies to the design process, but also as two way information flow channel, where new practical problems in design also pose new questions about the human body for investigation.

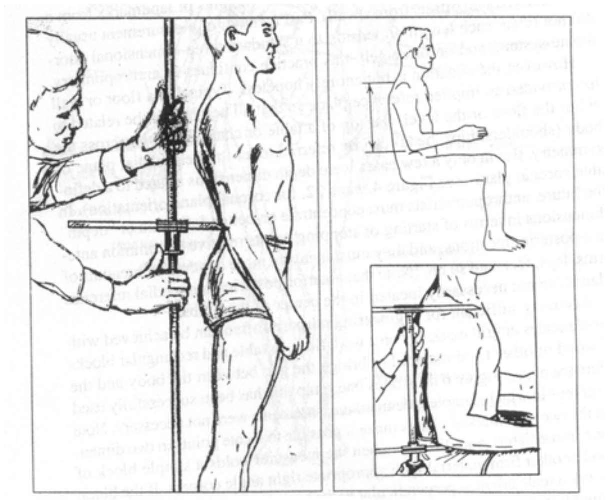


Figure 2.5 Anthropometric measurements using an anthropometer. (Roebuck, 1995)

Anthropometry assembles such numerical data and provides values like means and percentiles, which enable designers to design things so that there is an acceptable match for the greatest number of users and perhaps an optimum match for the average user.

With anthropometry, one is able to get an accurate picture of the actual anthropometric characteristics and the range of variability of the target population, and also understand the ways in which these characteristics can pose constraints on the design, and determine the criteria to define an effective match between the product and the user.

Anthropometric data can be classified into two forms, namely static and functional (dynamic) data. Static data provides information on the static dimensions of the human body in standard postures, but in certain cases these data cannot describe the functional performance capabilities of the user such as reach or strength where the whole body functions in concert to perform the task.

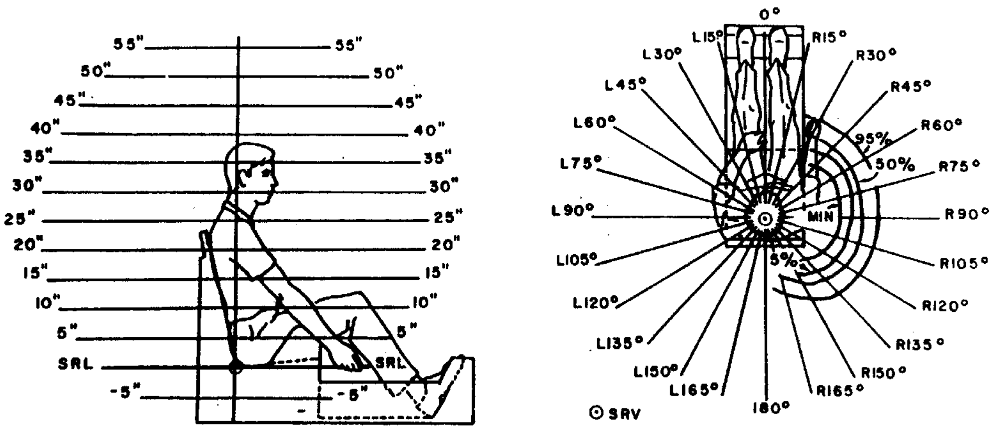


Figure 2.6 Men's grasping reach to a horizontal plane through the seat reference point (SRP). (NASA, 1978)

This is where functional data comes in. These are usually in the form of specific actions like grasping an object while seated in a certain position. Often functional data must be gathered as the situation arises.

Not only are the dimensions important, but the relations between the various body parts and the object are equally important in the selection of data that is to be used, and the relations between the points to be classified. That is the case whether we are designing for clearance, reach, posture or muscular control / strength.

With regard to the anthropometric data available to the Asian population, the only sources available at the NTU Library are from the NASA Anthropometric Source Book (1978), which contains a compilation of anthropometric data of mainly military personnel from Japan, Thailand Korea and Vietnam. Data of Japanese civilians was also included. Other sources of information include ergonomics textbooks or handbooks (Granjean, 1997), Pheasant (1986), Kroemer (1997).

For the local Singaporean anthropometric data, yearly general statistics only publish the mean weights and heights of the local population. A search of published data shows that there have been five local anthropometric surveys conducted so far. It is known that the Singapore Armed Forces (SAF) has done three anthropometric studies (1987,1995, 1997) on military personnel, as is common for military forces around the world for fitting equipment and clothing, but no published data was available. Anthropometric data on the Singapore populace was done in the 1980s (Lim, 1988) as well as a survey on Singaporean female VDT operators (Ong, 1986).

There is little published local information on aircraft cockpit design; only a single dissertation on the ergonomics of fighter cockpit ejection seats through the comparison of anthropometric data (Singh Khosa, 1987) is available. There is also a comparison of anthropometric lengths of Singaporean aviators with foreign aviators (Singh, 1995). (Singh Khosa, 1987) has already shown that fighter plane ejection seats are ill fitted to the anthropometry of Singapore aviators. So there is a need to validate such conclusions and explore other considerations like reach and vision through the use of simulation.

2.6 PERCEPTION AND COGNITION - ERGONOMIC CONSIDERATIONS

Though anthropometric fit is fundamentally important to the design of the cockpit workstation, other human performance information like sensory perception and information processing are equally important.

This is because much of the operation of the cockpit is not just physical manipulation of the controls and visual monitoring of the displays. There is a large amount of information that needs to be conveyed to pilot via the cockpit displays and controls. The physical layout and design of the various controls and displays influence how fast and how easily the information is sensed and processed. Therefore an understanding of how humans sense and process data will aid in designing a cockpit that will maximise correct information absorption and reduce mental workload.

The way stimuli and information can be perceived and processed can be modelled in a human as below (Lim, 2001): -

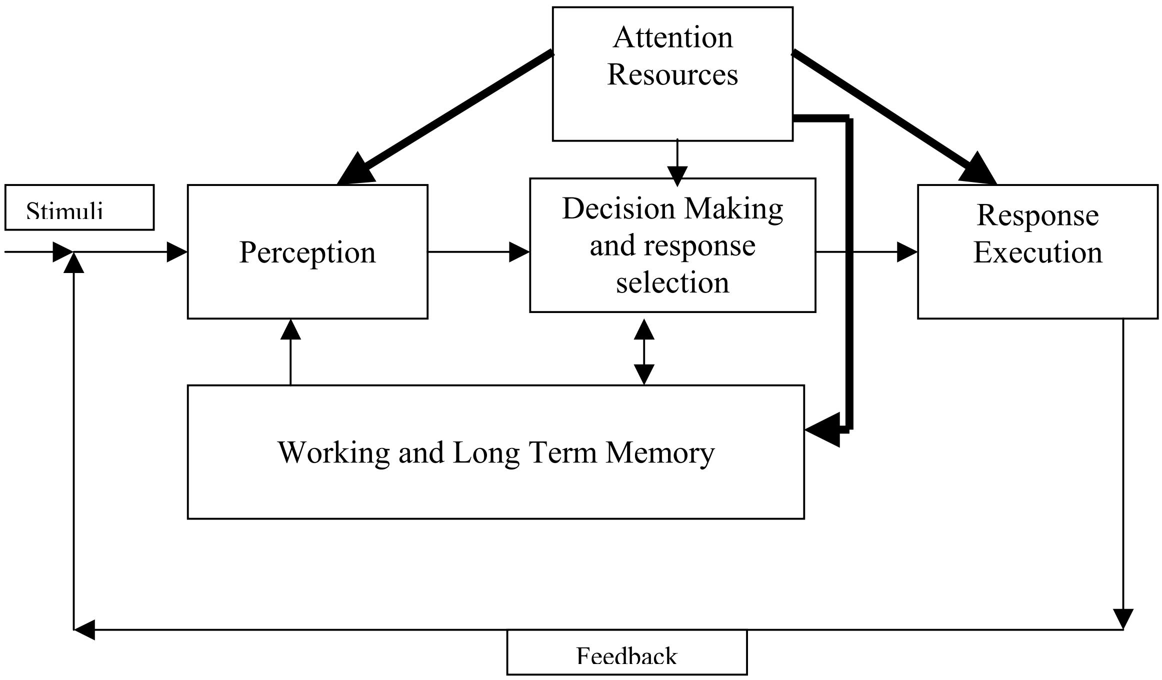


Figure 2.7 Model of human perception and cognition. (Lim, 2001)

From the figure above, we can see that attention resources are needed to sense, process and respond to any stimuli. These draw resources from a common pool, which is limited. Therefore there is a need for the human to allocate these resources effectively. Once these resources are used up, the human might not detect the stimuli or detect it incorrectly. Like wise, decision-making and response could be delayed or incorrect. However, learning and practice reduce the amount of resources needed while selective filtering allows the human to direct attention resources to certain information.

The human in this context, can be thought of as an information processor much like a computer. The three main interacting sub-systems are:

1. Perceptual Sub-System – The main means of sensing is through visual, auditory and proprioceptive stimulus. Other senses like taste, smell and touch also used.

2. Cognitive Sub-System – Processing of the information to produce a suitable response.

3. Motor Sub-System – Execution of the appropriate response by activating body actions.

Each of the sub-systems has its own characteristic storage capacity, storage length and coding method for the information (Wickens, 1984).

In the case of a aircraft cockpit, there is a large amount of information flow from the cockpit controls and displays, as well as the external environment. Due to the speed at which the aircraft fly, there is also a limited time to respond. The potential for information overload or incorrect perception of the information is considerable, with possible fatal consequences. If pilot ability is held to be constant, then to eliminate such problems, ergonomics knowledge of perception and cognition can be applied to interface design so as to design a cockpit workstation, which reduces the attention resources needed by the pilot for perception, information processing and memory. This frees up resources for other tasks, reduces pilot fatigue and error and enhances performance.

According to (Singh Khosa, 1988), the various inputs to the pilot from the system and environment can be viewed in terms of several sensory inputs: -

Visual

⇒ External Vision (View of the outside world).

⇒ Instrument Displays

- Engine Parameters
- Navigation Parameters
- Weapons Parameters

⇒ External Environment via Radar/ Video / MFD / FLIR / PNVS

Auditory

⇒ Ground control

⇒ Other aircraft

⇒ Co-pilot gunner

⇒ Noise from engine

⇒ Through body from vibration of aircraft

Proprioceptive

⇒ Pilot's perception of balance and orientation

⇒ Feedback from Flight Controls

The pilot has to integrate all the information from these inputs, process the information, and then send appropriate physical movement to move the controls of the aircraft. These inputs are primarily across the L-H interface mentioned earlier. Therefore designing for the L-H interface incorporates both anthropometric fit and the perceptual and cognitive fit.

In the cockpit design, the controls and displays should be laid out such that the inputs or information to the pilot is presented in a form that is easy to perceive and integrate by the pilot.

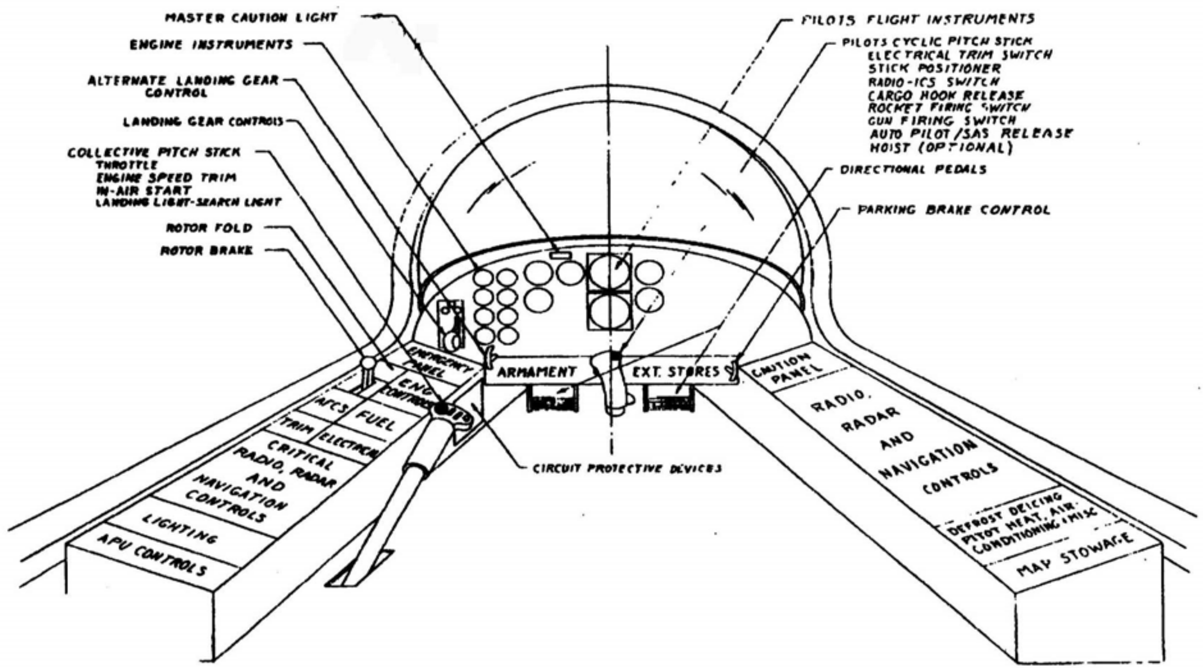


Figure 2.8 Generic Tandem Seat Helicopter- See Appendix C. (MIL-STD-250D, 1974)

Principles such as frequency-of- use, sequence of use, importance-of-use, use-of-stereotypes are basic design rules to follow. However, other perceptual and cognitive characteristics are also important, like visual dominance, auditory and tactile responses, foveal and peripheral vision, colour, pictures, attention, memory and mental models.

2.7 COCKPIT TECHNOLOGIES

Cockpit technology has advanced greatly since the time a piece of string was attached to the cockpit in front of the pilot, to indicate aircraft attitude relative to airflow. These range from the conventional dials and gauges to multi-function displays, to the new “virtual“ cockpits. Advancement of aircraft performance and abilities has extended beyond control of the aircraft manually and continuously. A discussion of two of the most common cockpit technologies used in helicopters and concepts is given below, as well as some future developments.

The HOTAS concept incorporates switches on the flight controls of the aircraft to allow the pilot to control weapons, and other time critical functions without taking the hands off the flight controls.

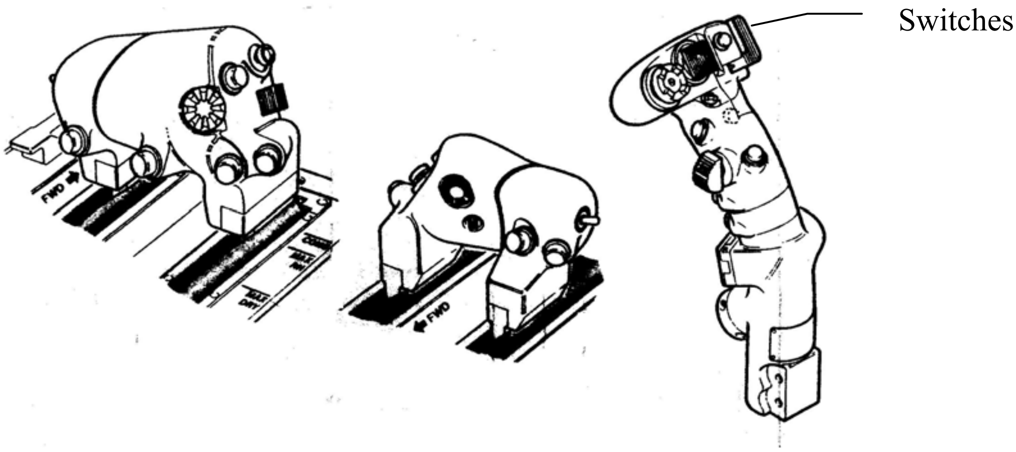


Figure 2.9 HOTAS controls (Wykes, 1988)

Multi-function displays (MFD) make use of flat screen technologies like liquid crystal, electro-luminescent and plasma displays offering better capabilities, reliability, power consumption, size and brightness (Soo, 1990). They also allow a variety of information in different formats to be presented, usually based on different flight tasks and parameters. Shown below is a MFD display of the fuel status. The push buttons allow direct input and selection of functions. The parameters of the buttons change as different formats are selected. This enables a more manageable format hierarchy without the pilot having to access many levels to locate information.

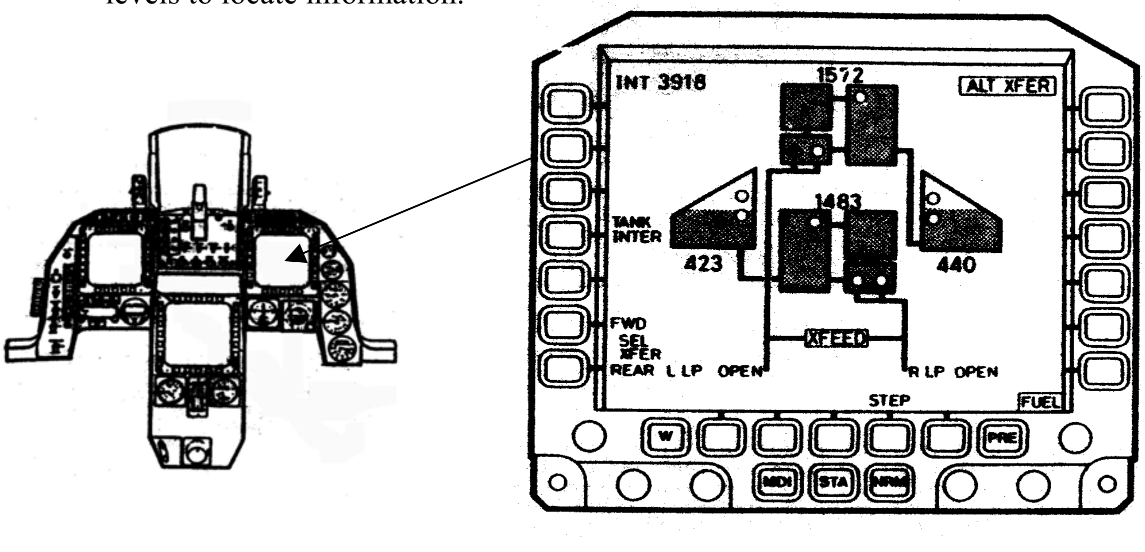


Figure 2.10 MFD displaying fuel status (Wykes, 1988)

MFDs are able to replace the large number of single purpose aircraft dials and controls in conventional displays, thus saving space and preventing clutter.

Other cockpit technologies include auditory displays, which make use of 3D localised sound to warn of threats, computer recognized voice commands, helmet mounted displays (HMD), heads up displays (HUD), and night vision systems and target acquisition systems. These technologies primarily superimpose real-time information in the visual field of the pilot via sensors and head tracking devices. They are specialized display systems in of themselves, and are outside the scope of this project.

An interesting concept for alternative cockpits is the "super" or "virtual" cockpit. These make use of integrated aural, visual and even tactile displays to represent a enhanced three-dimensional virtual world of the external visual scene with added information from sensors usually shown in conventional displays. This has the advantage of providing integrated interpreted information for the pilot. The pilot also does not have to waste time in transition from a heads down position to look at the displays, to the normal heads up position. This is especially important in low-visibility and low altitude conditions, such as encountered commonly in helicopter tasks (Hart, 1988).

Figure 2.11 Helmeted-mounted display, IHADDS system for AH-64 helicopter.

These advanced display and flight control systems may seem very different, but they commonly apply ergonomics knowledge about human perception and cognition to present the information in such a way that the pilot can easily assimilate.

2.8 HELICOPTERS

Helicopters are a unique class of aircraft that achieve flight through the use of rotary “wings” as the airfoil. Its main components consist of the helicopter, main rotor and tail rotor, engine and cockpit. Most helicopters have a single main rotor on top and a smaller tail rotor at the back, controlling the direction the helicopter flies.

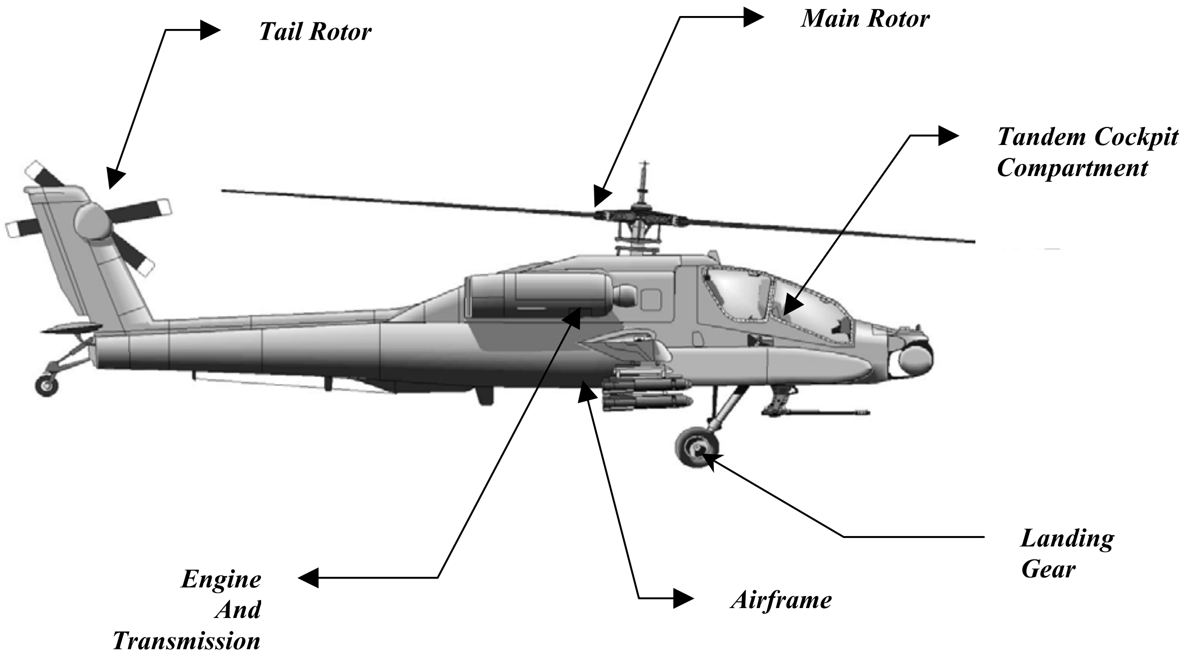


Figure 2.12 Basic Parts of a Helicopter (AH-64 Apache)

Its operational environment ranges from civil air traffic areas to remote and hazardous regions, and from day operations under visual flight conditions to night operations in adverse weather. The helicopter is used in a wide range of areas (Hart, 1988), in passenger transportation, search and rescue, medivac, construction, observation, agriculture, law enforcement, and military missions (attack, gunship, reconnaissance…). Knowledge of how a helicopter flies will inform us of the capabilities of helicopters and aid in the design of the cockpit.

2.8.1 MAIN ROTOR

The rotors produce the lifting force and as they spin they cut into the air and produce lift. Each blade produces an equal share of the lifting force. Spinning the rotor against the air causes lift, allowing the helicopter to rise vertically or hover. Tilting the spinning rotor will cause flight in the direction of the tilt.

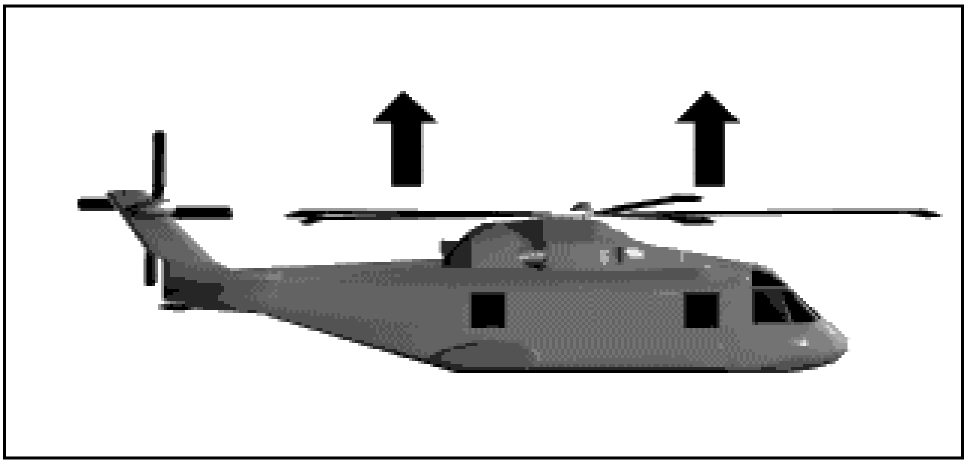


Figure 2.13 Lift generated by rotor spinning (Westland, 2001)

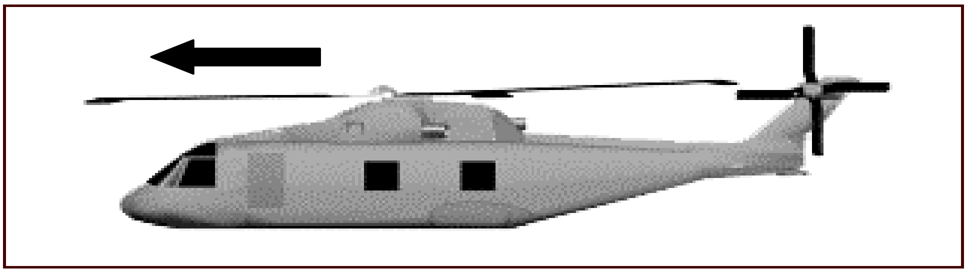


Figure 2.14 Forward motion by rotor tilt (Westland, 2001)

Rotor blades are the helicopter's equivalent of the wings of an aeroplane. Like any wing the shape is very important; it is designed so that the air passing over the upper surface moves faster, causing a difference in pressure between the upper and lower surfaces, creating an upward force known as lift.

.

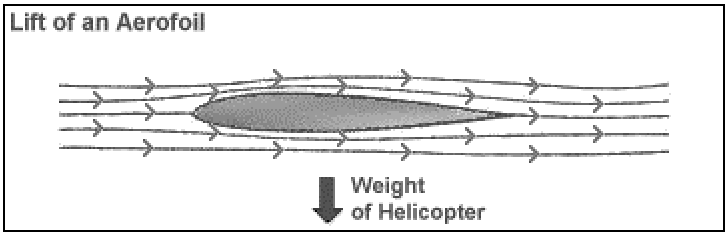


Figure 2.15 Aerofoil lift

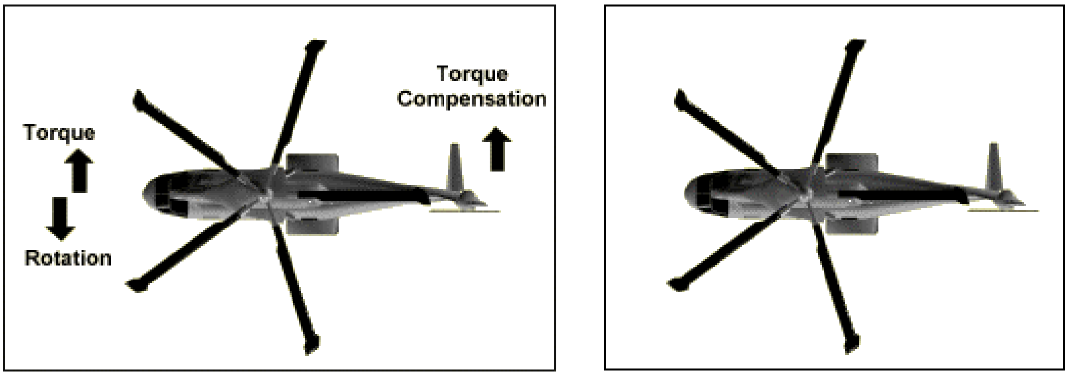


Figure 2.16 Torque compensation by tail rotor (Westland, 2001)

2.8.2 TAIL ROTOR

The tail rotor is an important component in helicopter flight. When the rotor spins, powered by the engine, the rotor will rotate, but the engine and the helicopter will try to rotate in the opposite direction since they are not fixed in position. This is called *torque reaction*.

The tail rotor counteracts this torque reaction, without which the entire helicopter would start spinning. The tail rotor is used like a small propeller, to pull against torque reaction and hold the helicopter straight. By applying more or less pitch (angle) to the tail rotor blades it can be used to make the helicopter turn left or right, becoming a rudder. The tail rotor is connected to the main rotor through a gearbox.

2.8.3 FLIGHT CONTROLS

As can be seen from above, there are three basic components of helicopter flight control. These are the main rotor pitch and engine power, the overall rotor tilt and the tail rotor. The most common combination of flight controls for the control of these variables is the collective pitch control, the cyclic pitch control, and the rudder pedals.

Collective Pitch - this is a control, which is only found in helicopters. Moving this up and down changes the pitch of the main rotors and moves the helicopter up and down. Today this is linked to the engine power. As the pitch is increased more power is required from the engines so that the rotor speed is kept at the same level.

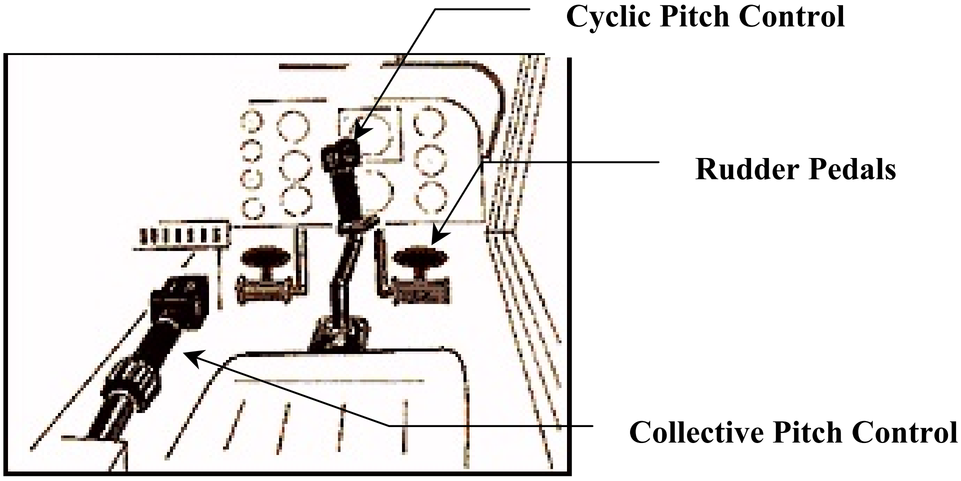


Figure 2.17 Basic Flight Controls

Cyclic Pitch - This is the central control column. Moving the cyclic control forward or back will point the nose of the helicopter up or down. Varying the angle of the rotor blades as they spin tilts the rotor back and forth. When moved left or right the rotor tilts in that direction and the helicopter banks and rolls.

Rudder Pedals – The pedals control the tail rotor by changing the pitch of the tail rotor. Depressing the left pedal rotates the helicopter left and depressing the right pedal rotates it to the right.

In short, it is the cyclic and collective pitch which give the helicopter its unique ability to fly forwards, backwards, sideways, rise and descend vertically and to hover motionless in the air, making it one of the most versatile vehicles known. The increased range of manoeuvres and control requirements of helicopters, together with terrain avoidance, flight path control and navigation tasks when operating at low altitudes thus pose significant visual demands on the pilot.

2.9 FLIGHT TASKS

The pilot in the cockpit of the helicopter, with the cockpit displays and controls surrounding him will need to perform certain tasks with the helicopter. These include: -

1. Takeoff – vertical take-off
2. Cross Country Flight – normal climb, cruise and approach
3. Low-level Flight - constant airspeed and altitude within 200feet of ground.
4. Contour Flight – flight conforming with and in close proximity to ground with varying speed and altitude.
5. Nap-Of-Earth Flight – flight as close to the ground as possible, in between terrain features like buildings trees and bushes.
6. Stationary and Vertical Manoeuvres (hover)
7. Landing

Other tasks or include:

1. Weapons Deployment
2. Engine Performance Monitoring
3. Helicopter Systems Monitoring
4. Communications
5. Navigation

These tasks may be performed in various conditions: -

1. Adverse weather -
2. Night flying
3. Deployment In Enemy Territory

With the degree of manoeuvrability of helicopters, together with the need to fly at low altitudes and low speed near obstacles, these flight tasks impose severe visual demands on the pilot. This is because the pilot not only has to be concerned with the vision ahead but also to avoid obstacles below and around the helicopter which flight instrumentation cannot accurately provide, by estimating lateral, longitudinal, and vertical movement relative to objects in front of them.

2.10 SUMMARY

In conclusion, having discussed the systems approach to designing a cockpit, and using this systems approach to consider different aspects that need to be considered, from interfaces to ergonomics, to flight technology and tasks, the next chapter will detail the design of the cockpit.

Information Needed	Design	Testing
System	L-H, L-E,	Multivariate Models
Anthropometry	Accommodation / Fit	Reach
Perception	Vision Control and Display Layout	Vision
Cognitive	Control and Display Layout	Clearance
Standards and Guidelines	L-S (software) considerations	
Helicopter		

Figure 2.18 Summary of Design Information

CHAPTER 3 DESIGN INFORMATION

3.1 ANTHROPOMETRY OF USER POPULATION

In order to achieve an optimum compromise between variability in anthropometry of the targeted user population and the physical layout of the workstation components, we must first know what the actual dimensions are of the user population.

3.1.1 DATA COLLECTION

The subjects consisted of male National Service enlistees from April 1987 to December 1987, from various army vocations. The age of the enlistees ranged from 18 to 23 years of age.

The population can be considered as representative of the helicopter pilot population as they represent the population from which potential pilots are drawn. Ideally, since the pilot vocation is not constrained to males but also females, the survey should have included a survey of female personnel, though females form a small portion of the personnel.

The data was initially recorded on paper forms and a sample size of about 500 was recorded. However, 240 samples were input into the computer for analysis. This was due partly to insufficient resources to enable all the data to be input, since data entry is done manually.

The data was entered into a spreadsheet for storage, and later exported to the statistical software programme, SPSS for analysis. This facilitated the analysis of summary data and construction of graphs, since SPSS is specialized for statistical analysis. A total of 67 measurements were taken of the individuals (Appendix B).

3.1.2 ANALYSIS

Due to the manual recording process of the anthropometric survey, errors in the data recorded were inevitable. In some cases, the accuracy of a dimension was limited to 0.5 cm intervals, whilst in other record sheets, for the same dimension a value with an accuracy of 0.1 cm was recorded. The accuracy of the The measured values should be taken to the level of accuracy of the measuring instrument.

Systematic errors could also be observed, where a whole record sheet of values were recorded with values consistently off the a estimated reasonable range by 40 cm, as in the case of seated dimensions, where the resultant values are found by the difference between the seat reference height and the measured height, for example, the seated eye height, the acromial height, etc.

Given that the anthropometric range of the population was of a restricted group, of average 20 years of age, who were serving their National Service, the Standard Deviation of each of the dimensions would be expected to be quite low and the distribution would be expected to follow a Gaussian or Normal Distribution. This is because the personnel were of similar fitness and size due to training and selection for the army vocation. Extremes of body types, as in obese or extremely short, handicapped or unfit persons, would have been filtered out in the selection of combat fit personnel.

Therefore values outside a reasonable predetermined range were eliminated to better achieve these results in some of the dimensions. Those dimensions not used in the sample were often ridiculously large or small, and would definitely be excluded. The inclusion of such values would significantly alter the mean and standard deviation of the dimensions.

A comparison was made with an anthropometric survey conducted in 1986-1987 (Lim et al, 1988/89) of Singapore industrial workers. The summarised means, standard deviation and percentile values were used.

As expected, for the majority of the dimensions, the National Service men show smaller variability, probably because of the smaller sample size and range of age groups. This is especially in the dimensions that are related to weight, like the body circumferences, probably because the National Service men undergo physical training and so there are less obese people in the sample.

With regard to the usefulness to design, some of the static anthropometric data is useful especially when accommodating for clearance and clothing size. However in designing for reach of controls, more useful data like functional reach and body link data would be preferred. An example would be Forward Reach, which is measured from the fingertip of the forward reaching upper limb to the shoulder blade. A more useful static dimension would be the functional arm reach, which is measured from the shoulder blade to the tip of the thumb with the index finger and thumb touching, on the upper limb reaching horizontally forward. This would be more useful in approximating reach for controls that require grasping, e.g. collective, cyclic. The values would also be more useful when used in human modelling and biomechanical analysis.

It has been noted by Singh (1995) that the functional arm reach for the 95^{th} % Singaporean aviators is comparable to the 90% UK and US aviators, and that the 5^{th}% functional arm reach for Singaporean aviators is comparable to that of the 5^{th}% US aviators. This would, presumably make it possible to use the functional arm reach data of US aviators (Stoudt, 1978).

3.1.3 TABLES

		IW: Singapore Populace 1988				NS: National Service Men 1987			
	All dimensions in cm	50%		S.D.		5%		95%	
	Dimension	NS	IW	NS	IW	NS	IW	NS	IW
1	Vertical Reach	134.3	[redacted]	5.63	[redacted]	125.9	[redacted]	143.0	[redacted]
2	Sitting Height	89.5	86.8	4.12	4.14	82.8	80.5	96.1	94.0
3	Eye Height	78.1	74.6	4.82	4.36	70.6	68.5	85.2	81.6
4	Mid-Shoulder Height	61.9	58.4	4.93	4.74	55.1	50.2	68.8	65.2
5	Shoulder Height/Acromial Height	58.5	[redacted]	4.05	[redacted]	52.3	[redacted]	64.3	[redacted]
6	Shoulder-elbow Height	32.2		6.35		20.2		39.4	
7	Elbow Rest Height	26.4	23.0	5.20	3.64	18.7	17.5	36.0	29.0
8	Thigh Clearance Height	16.3	14.0	2.26	2.58	13.6	10.8	19.5	19.0
9	Elbow-Fingertip Length	46.0	45.0	2.43	2.65	42.0	40.1	49.9	48.8
10	Elbow-Grip Length	36.5	[redacted]	2.66	[redacted]	32.4	[redacted]	40.2	[redacted]
11	Buttock- Knee Length	54.5	55.9	3.46	3.44	49.1	50.0	59.4	61.0
12	Buttock-Popliteal Length	44.0	45.0	3.09	3.60	39.0	40.0	48.1	51.9
13	Buttock-Heel Length	97.2	100.0	5.25	6.11	88.9	91.6	105.1	110.0
14	Waist Depth	18.8	20.1	2.18	3.03	15.2	16.4	22.2	26.5
15	Popliteal Height	42.7	43.0	2.48	3.36	38.5	37.5	45.9	48.0
16	Knee Height	51.0	53.8	3.03	3.28	46.5	48.2	56.0	59.0
17	Span	170.7		8.27		158.8		181.0	
18	Shoulder Breadth	43.0	43.0	3.28	2.75	39.0	39.0	48.5	47.9
19	Forearm-Forearm Breath	41.0	42.0	4.37	4.26	35.9	36.5	49.0	49.1
20	Hip Breadth	32.5	33.6	3.14	3.86	26.5	26.6	37.4	39.0
21	Overhead Reach	213.5	212.0	8.77	9.86	201.0	197.5	227.7	228.4
22	Stature	169.0	169.0	6.05	6.21	159.8	159.0	177.7	178.0
23	Standing Eye Height	157.0	158.0	6.15	6.30	147.8	147.0	167.0	167.2
24	Crotch Height	77.0	78.0	5.16	5.23	69.9	69.5	87.0	86.8
25	Forward Reach	82.0	82.0	5.93	4.83	71.2	72.4	89.2	89.0
26	Chest Depth	19.5	21.0	2.02	3.02	16.1	17.2	23.0	26.0
27	Standing Waist Depth	17.5	19.1	1.74	3.35	15.1	15.3	20.2	26.0
28	Hip Depth	21.0	22.3	2.71	2.96	16.2	18.4	24.3	26.5
29	Max. Body Width	43.1	44.2	4.12	3.12	38.4	39.5	48.1	50.0
30	Shoulder Circumference	102.0	103.5	5.05	5.85	94.0	95.0	110.0	114.0
31	Chest Circumference	85.0	87.0	4.32	6.40	78.8	79.0	92.4	100.0
32	Waist Circumference	70.5	75.0	4.90	7.55	64.5	65.9	79.5	91.5
33	Hip Circumference	85.0	89.8	4.99	6.99	76.0	78.8	92.5	102.0
34	Thigh Circumference	51.0	51.0	3.74	5.27	45.5	44.0	57.1	60.0
35	Calf Circumference	34.9	35.5	2.53	3.19	30.7	30.0	38.0	40.9
36	Ankle Circumference	22.0	23.5	2.61	2.63	19.6	20.0	25.1	29.0
37	Bicep Circumference	26.0	26.0	2.37	2.65	23.4	22.7	30.9	31.0
38	Forearm Circumference	24.9	25.0	1.93	1.89	22.5	22.0	28.0	28.0
39	Wrist Circumference	16.0	16.0	1.22	1.13	14.0	14.5	18.0	18.0
40	Sleeve Inseam Length	54.0	[redacted]	4.14	[redacted]	46.0	[redacted]	59.5	[redacted]
41	Weight	57.0	60.0	5.98	7.83	49.0	50.0	67.0	76.0

Figure 3.1 Summary of Anthropometric data of National Service men and the Singapore populace.

IW: Singapore Populace 1988				NS: National Service Men 1987				
All dimensions in cm	50%		S.D.		5%		95%	
Dimension	NS	IW	NS	IW	NS	IW	NS	IW
42 Head Breadth	15.7	16.1	1.11	1.35	13.5	14.1	16.3	19.0
43 Interpupillary Breadth	6.3	6.5	1.25	0.80	3.8	5.3	7.5	8.0
44 Bitragion Breadth	12.8		0.78		12.0		13.9	
45 Head Length	19.6	20.0	2.01	1.47	15.5	18.0	21.5	22.4
46 Ear-Nose Bridge Depth	8.6	11.1	0.92	1.72	7.1	8.7	10.3	14.0
47 Head Height	22.6	23.6	1.62	2.21	20.4	20.5	25.5	27.0
48 Chin Eye Height	11.2	11.5	1.02	1.07	9.2	9.7	12.2	13.0
49 Head Circumference	55.0	56.5	1.38	2.15	53.0	53.0	58.0	60.0
50 Neck Circumference	35.0	35.4	3.04	2.29	26.6	32.5	37.0	39.1
51 Hand Length	18.0	18.5	1.39	1.02	16.0	16.8	20.0	20.0
52 Middle Finger Length	7.6	8.1	1.11	0.98	5.6	7.0	9.0	10.1
53 Hand Breadth at Metacarpal	8.0	8.0	1.11	0.68	6.2	7.0	9.5	9.0
54 Hand Breadth at Thumb	9.5	10.0	1.12	0.74	7.8	8.8	11.5	11.0
55 Wrist breadth	5.3	5.5	1.01	0.58	3.5	4.8	6.9	6.5
56 Hand Thickness at Metacarpal	3.4	3.0	0.31	0.59	3.0	2.5	3.9	4.4
57 Thumb Length	6.0	6.5	0.87	0.87	4.6	5.5	7.4	8.0
58 Wrist Thickness	3.8	4.0	0.82	0.54	2.0	3.2	4.5	5.0
59 Hand Circumference	20.5		1.31		18.1		22.5	
60 Foot Length	24.7	24.9	2.24	1.33	20.6	22.7	28.0	27.0
61 Instep Length	18.4		2.36		13.1		20.5	
62 Ball of Foot Width	9.5	9.6	1.35	0.66	6.5	8.5	10.5	10.6
63 Ball of Foot Circumference	23.5		1.05		22.0		25.5	
64 Heel Width	5.5		0.55		4.9		6.5	
65 Foot Height	7.8	7.8	1.60	1.62	5.0	4.5	10.0	10.0
66 Inner Hand Grip Diameter	4.9		2.60		4.4		5.3	
67 Trigger Finger Grip Diameter	7.0		0.89		5.5		8.5	

Figure 3.2 Summary of anthropometric data between National Service men and the Singapore populace.

3.2 THE CREW COMPARTMENT

The Boeing (McDonnell Douglas) (formerly Hughes) AH-64A Apache is the US Army's primary attack helicopter. It is a quick-reacting, airborne weapon system that can fight close and deep to destroy, disrupt, or delay enemy forces. The Apache is designed to fight and survive during the day, night, and in adverse weather. The principal mission of the Apache is the destruction of high-value targets.

Figure 3.3 Tandem crew compartment of AH-64.

The cockpit of the AH-64 is a tandem arrangement with pilot sitting above and behind the co-pilot/gunner (CPG) located in the front position. This affords a nearly unobstructed view, through sitting in the rear. The Apache features a Target Acquisition Designation Sight (TADS) and a Pilot Night Vision Sensor (PNVS), which enables the crew to navigate and conduct precision attacks in day, night and adverse weather conditions.

In addition to the bulkhead, a transparent acrylic blast shield mounted between the two positions reduces the likelihood that a breach in the cockpit will eliminate both crewmembers, while still providing no visual obstruction. Crew survivability in the event of a crash is increased due to seats designed to withstand an aircraft impact of up to 42ft/s straight down. The structure of the seats are armoured with Kevlar shielding to provide additional protection against shells and shrapnel.

Figure 3.4 View from pilot compartment of AH-64. (The Jolly Rogers)

A cockpit canopy made up of 7 flat transparent panels covers the crew compartment. The curved canopies of previous attack helicopters have the disadvantage of glinting problems, as the curved surfaces will reflect light in a number of different angles regardless of the attitude of the aircraft. Flat panels do not have this problem. However, the side panels of the canopy are slightly rounded in order to reduce aircraft-induced vibration to the transparencies.

3.3 USER

The pilot is clothed in a flight suit with gloves and flight boots, and also wears a helmet with an imaging system. Many items of personal and survival equipment significantly alter the pilot's position in the aircrew station. Such equipment must be considered at the earliest point in design and additional clearance or adjustments must be provided for in the seat design and the cockpit clearance envelope.

Clothing Corrections.

Clothing Allowance – For normal flight suit, which can be considered negligible unless a G-suit or some other survival gear.

Helmet Allowance – Approximately 4cm above crown of head. Woodson (1984) recommends 1.5 inches.

In the design of the cockpit workstation, more anthropometric dimensions than those mentioned earlier, are needed for the ergonomic guidelines to be expressed into quantifiable specifications needed in an engineering design.

The following page shows the important dimensions needed for specifying cockpit geometry and seat size: -

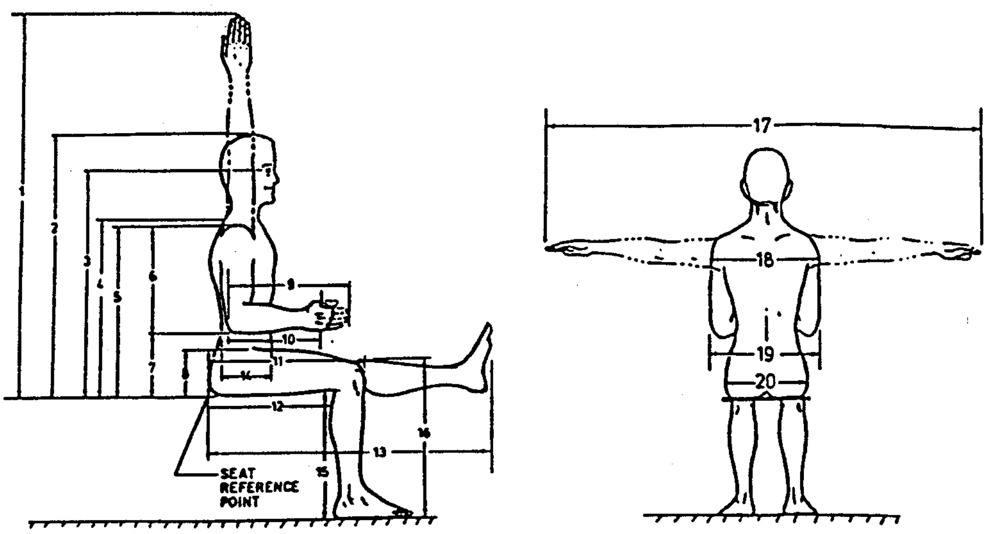
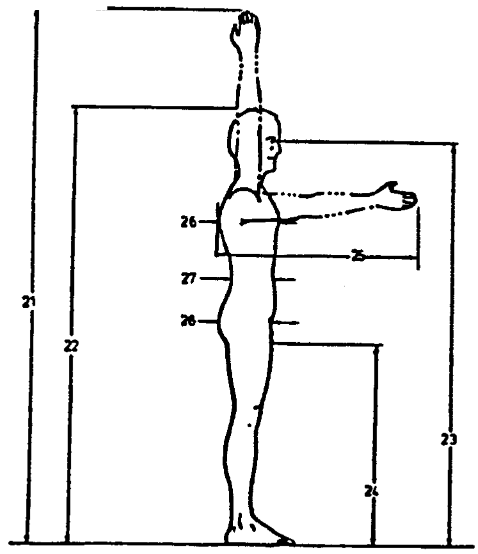


Figure 3.5 Anthropometric dimensions



2. Sitting Height
3. Sitting Eye Height
4. Shoulder Height (Acromial)
8. Thigh Clearance
11. Buttock-Knee Length
12. Buttock-Popliteal Length
13. Buttock-Heel Length
15. Popliteal Height
16. Knee Height
19. Forearm-Forearm Width
20. Hip Breadth
22. Stature
25. Forward Reach

Selected dimensions definitions can be found in APPENDIX B.