A THEORETICAL AND PRACTICAL DESIGN INVESTIGATION OF THE FUTURE MILITARY COCKPIT

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Abstract

In recent years there has been a significant trend towards increasing complexity in the military cockpit. This has been brought about largely as a result of developments in weapon systems which demand increasing participation on the part of the pilot. Two factors have consequently resulted. The first is the engineering difficulty of accommodating the necessary equipment controls and displays within the contrained space of a cockpit. The second results from this and relates to the workload imposed on the pilot in attempting to handle the system. The need has clearly arisen to consider from a fundamental standpoint the capabilities and limitations of the pilot and, with these in mind, configure the cockpit to simultaneously maximise pilot capability while keeping workload to a minimum.

The paper commences with a review of pilot anthropometric measurements and the major factors which influence the geometrical constraints of the cockpit. Statistical data will be presented relating the main physical measures. The problems of interpreting and using the data in design terms will be discussed. The major factors associated with understanding the pilot is that of psychomotive capability. This relates to the way in which the pilot takes in information via his senses, principally the eyes, and processes data to achieve the necessary control actions. Models of this have been developed in the past with varying degrees of success.

To demonstrate the applicability of such models to a cockpit environment, the design philosophy of the future generation of military cockpits is described. This makes use of CRT's, keyboards and controls with data buses. Dynamic mockups of such concepts have been built and are described.

The paper concludes with a discussion of some of the more important mechanical aspects of the cockpit which affect pilot/machine interface. The first is the seat which for current high 'g' aircraft makes use of the reclined position. A description of an engineered dual position articulated seat is given. This is followed by a discussion of the escape techniques which make use of Miniature Detonating Cord to blow open the canopy immediately prior to ejection. Finally the mocked up cockpit conditioning system specially designed to produce a low noise environment which also enables the display electronics to be cooled is described.

I. Introduction

During the late 1960's, it was becoming apparent that the cockpits of existing military aircraft were becoming unduly cluttered largely as a result of the addition of new types of operational equipment. This equipment took the form of additional displays and associated controllers within the cockpit and various sensors and EW units located around the aircraft. The result of this development was a considerable increase in pilot work load coupled with a significant worsening in cockpit ergonomics. By way of example a current Harrier G.R.3 cockpit has a large number of instruments and equipment controls are located where possible.

The need to integrate many of the functions previously handled by individual instruments has long been recognised and for this purpose, electronic displays have been adopted. The Sea Harrier for example, see Figure 1, makes use of a single CRT located on the right hand side of the instrument panel and is primarily for display of the radar picture. This sort of cockpit represents the state of art of mixed instruments and electronic displays.

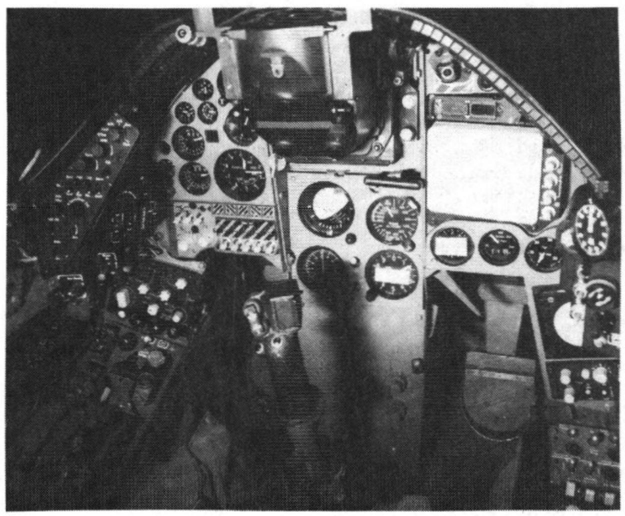


Figure 1 Sea Harrier Cockpit

The next generation cockpit will attempt to considerably improve the ergonomic aspects by adopting where relevant those techniques which can really help the pilot. In this regard consideration is being given to the greater use of electronic displays to enable only that information which is relevant to the pilot at the time to be displayed. This enables data to be located in more optimum positions relative to the pilot's field of view and, with appropriate formatting, better presentation of information can also be achieved.

Significant changes have also recently taken place in the control aspects of aircraft. The advent of Active Control Systems with their computerised control laws and lack of mechanical rods eases significantly the problem of location of controllers. The adoption of ministicks now becomes a possibility. Additionally, the axis decoupling features introduced with manoeuvre demand systems together with the need for reduced control activity on the part of the pilot significantly lowers his workload.

The ever increasing manoeuvre performance of modern aircraft imposes severe 'g' loading on the pilot such that for the next generation fighter, at low level, around 8 'g' can theoretically be sustained for some minutes. To help the pilot tolerate such loading, there is interest in providing him with various protective measures. These include a 'g' suit to support his limbs, positive pressure breathing to sustain his lungs and possibly a reclined seat to reduce the hydrostatic head from the aorta to retina. The adoption of the last measure can have significant effects on cockpit layout and its implications will be discussed.

The overall consideration for cockpit design is the human factor element. A considerable reduction in piloting difficulty must be achieved with the next generation fighter. As indicated, potential techniques are available to achieve this but a sensible overall engineering solution can only be achieved with a systematic investigation of the relevant piloting factors - some of the techniques used to evaluate the cockpit are desibed later.

II. Human Factors

The fundamental problem involved in laying out a cockpit is the anthropometry of the range of potential pilots together with his visual requirements. The large range of pilot sizes is usually expressed as a percentage, such that a small man may be described as 5 percentile and the large man 99 percentile. In practice, this description is inadequate since a pilot with say 5 percentile arm length could have a 99 percentile leg length. The major physical dimensions affecting cockpit design are summarised in Figure 2. It is seen that different combinations of dimensions are important for differing aspects of cockpit design. For example, the reclined seating posture places great emphasis on the buttock to eye height and buttock to knee length.

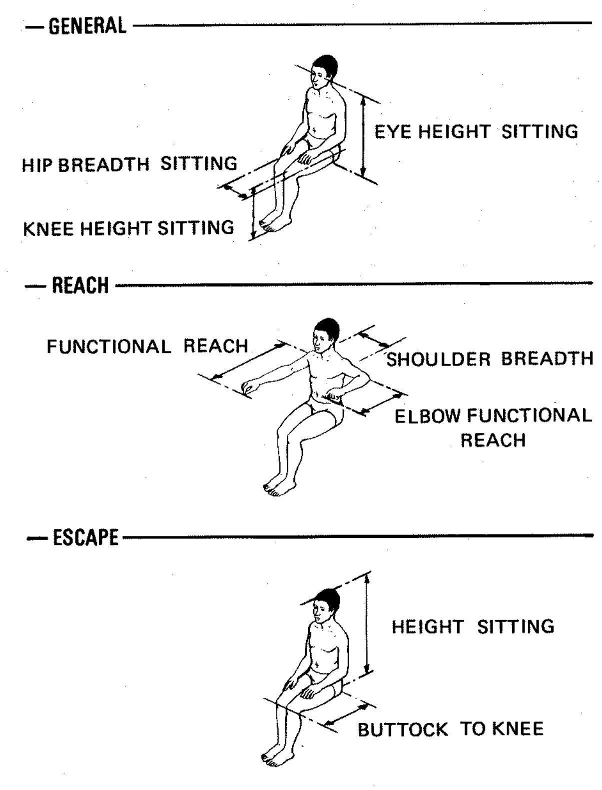


Figure 2 Critical Anthropometric Variables

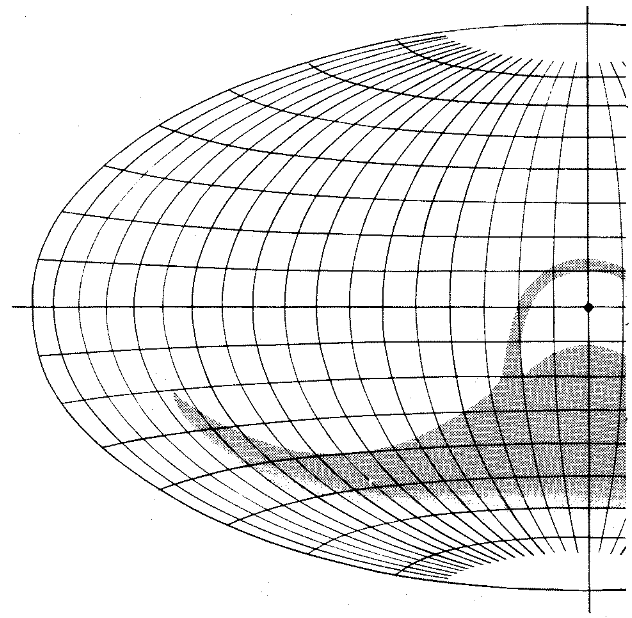


Figure 3 MIL-Standard Cockpit

External view is of major importance in the design of a combat aircraft. There currently exists a MIL-Spec standard for defining this view and Figure 3 summarises this. A practical cockpit based on an evaluation of our own mock ups is shown in Figure 4. It is seen that generally the majority of requirements can be met. Look angle over the nose can be difficult to achieve with reclined seat cockpits but the approach adopted in this mock up allows a 15° look angle to be achieved. Rear view is limited usually by the head box of the ejection seat provided that seat reclination still permits the pilot to roll about his shoulders. Other factors contributing to obscuration include canopy arches, the position of which must be carefully selected to avoid as much as possible loss of target sighting in air combat, and windscreen pillars which hamper air-ground viewing. A way round the latter problem is the adoption of cylindrical or conical sectioned screens provided they can be kept clean and have adequate bird strike resilience.

Within the cockpit the pilot must have a clear view of all displays and instruments. In the forward area i.e. in the near peripheral field of view, every effort should be made to avoid controls since these take up valuable real estate yet contribute nothing to perception. The controls should be positioned on the cockpit consoles within easy reach of the hands and as visible as possible within practical constraints. Display switching should be possible with the head up virtually all the time.

Confirmation of switching operations is achieved on the displays themselves. In this way, there is little danger of disorientation occurring from viewing down in the cockpit.

In practice flying the aircraft involves the pilot within the control loop using essentially visual clues to control the dynamics of the aircraft. Resultant aircraft motion provides the changing visual inputs from which the pilot takes corrective action. The workload imposed on the pilot depends on the difficulty of the aircraft dynamics themselves, the required accuracy of tracking and the degree of pilot training. This provides the primary flying task.

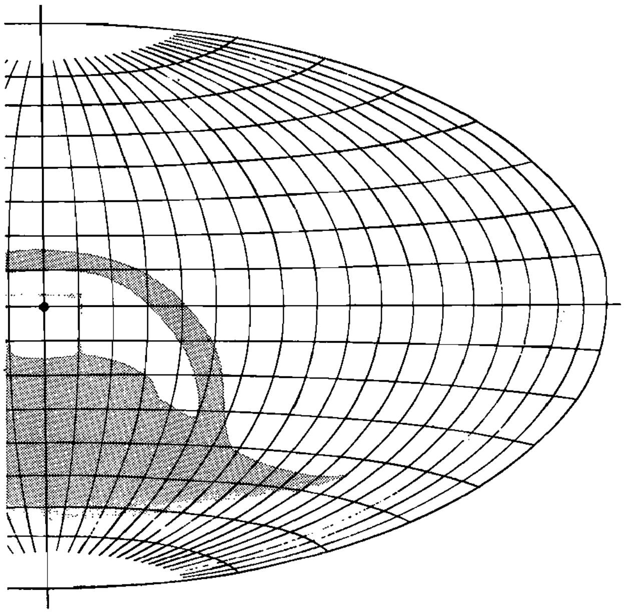
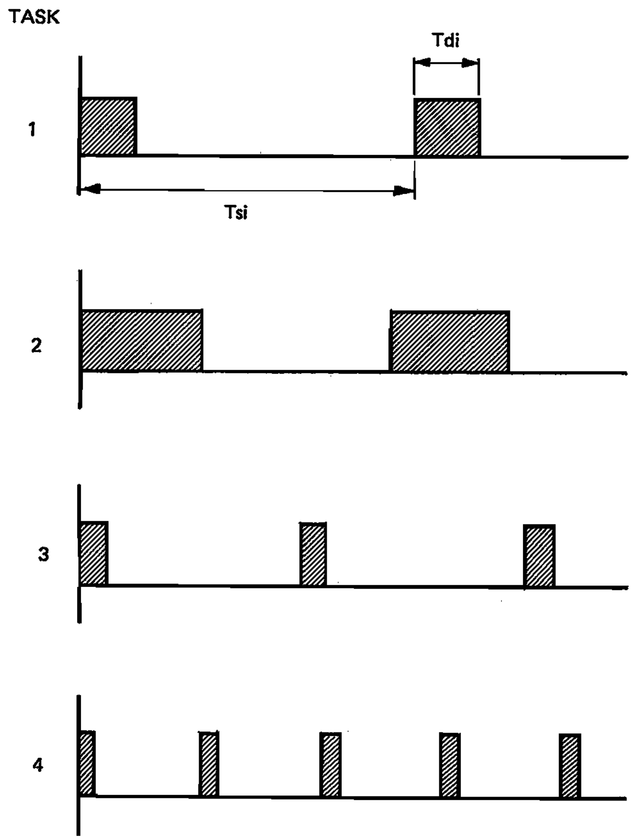


Figure 4 Proposed Cockpit

Additional tasks such as reaching for and operating controls form secondary tasks imposed on the primary flying task. There is a body of experimental evidence to suppose that a pilot scans between a number of tasks in a time sampled fashion in order to optimise some criterion such as minimum control error. Figure 5 shows this principle. The desired sampling intervals are determined by the task time varying properties. The time to complete the task are dictated by the information content of the task i.e. the task difficulty.

By way of illustration, an experiment conducted to determine reach times in a projected cockpit is shown in Figure 6. This indicates how the left hand console is subdivided into reach zones and reach times recorded on a freeze frame video system can be presented in a matrix form. Using Fitt's expression for the index of difficulty which is the logarithim to the base 2 of the ratio of reach distance to the size of control, reach times can be plotted, see Figure 7, as a function of the task difficulty expressed in bits.



Tdi = DWELL TIME ON TASK i

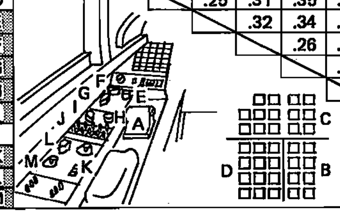
Tsi = SAMPLING INTERVAL ON TASK i

$$\text{WORKLOAD INDEX} = \sum_{i=1}^{n} \frac{Tdi}{Tsi}$$

Figure 5 Workload Analysis

TO

FROM	A	B	C	D	E	F	G	H	I	J	K	L	M
A		.45	.42	.50	.53	.51	.46	.43	.46	.41	.45	.45	.49
B			.31	.27	.36	.39	.40	.37	.46	.56	.45	.50	.51
C				.25	.37	.43	.48	.47	.50	.56	.51	.53	.54
D					.25	.31	.35	.41	.43	.46	.45	.47	.51
E						.32	.34	.35	.35	.41	.42	.45	.48
F							.26	.35	.35	.43	.47	.47	.52
G								.27	.29	.41	.41	.44	.48
H									.28	.39	.36	.37	.41
I										.32	.37	.35	.37
J											.22	.23	.30
K												.26	.32
L													.25
M													



A : Throttle
B : Flight Segment Keys
C : Systems Keys
D : Numeric Keys
E : Display/Weapon Selector
F : Weapon Option Selector
G : Attack Profile Selector
H : Channel Selector
I : Frequency Selector
J : C.A.S.S.
K : Mode Selector
L : Destination Selector
M : Display Selector

Denotes a Pinch-grasped control

Figure 6 Cockpit Reach Times

The slope indicates a pilot data transmission capability of around 9.3 bits/sec which compares well with other similar experiments for full pre-viewing task situation. For typical tracking tasks where the pilot must react to inputs with no preview, the effective filter bandwidth is in this case halved and typical processing rates are as expected around 5 bits/sec.

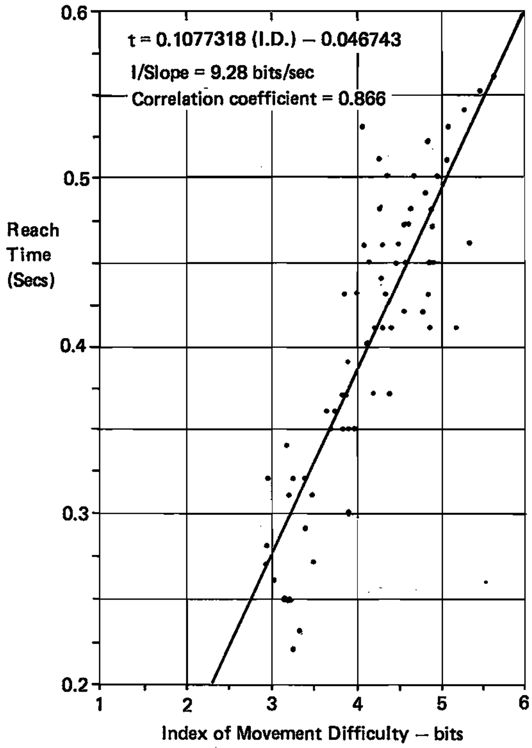
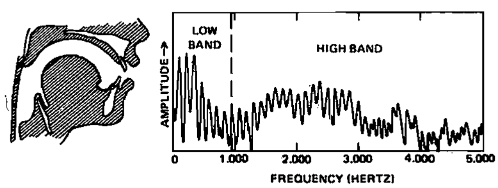
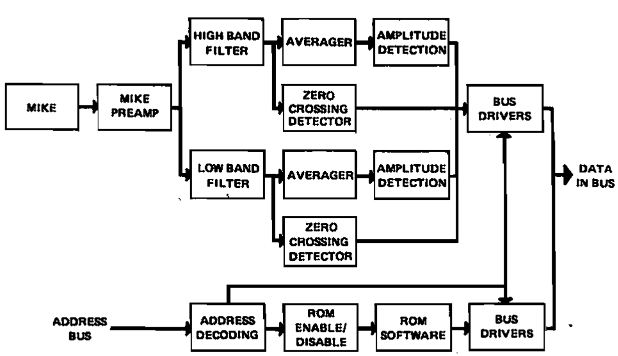


Figure 7 Index of Movement Difficulty

A possible way to improve the operation of say a communication system is to use the voice instead of hand controls. In this way, the delays associated with limb motion can be reduced and hence time is saved. Equipment capable of recognising the voice is now available. It can be trained to



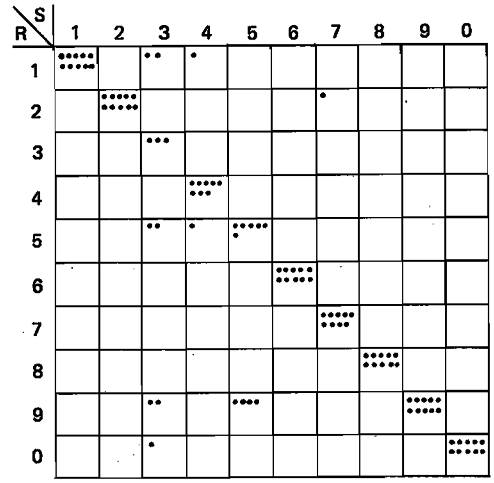
SPECTRUM OF WORD 'HEED'



WORD RECOGNITION EQUIPMENT

Figure 8 Direct Voice Input

recognise a limited number of words (in our case 32). For number insertion this is generally sufficient. With equipment based on the principle shown in Figure 8, a test was undertaken to determine the errors incurred in inserting numerals 1 - 10. For the results presented, Figure 9, it is seen that even in the laboratory environment, errors do occur. Significant experimentation is needed to apply this technique in a practical environment.



S – STIMULUS 10 SAMPLES/NUMBER
R – SYSTEM RESPONSES

DIRECT VOICE INPUT RESULTS

Figure 9 Confusion Matrix

III. Seating and Mechanical Aspects

The anthropometric studies discussed earlier are closely related to the pilot's seating posture. Interest recently has centred on the possible use of reclined seats to improve the 'g' tolerance of pilots when flying future highly manoeuvrable combat aircraft. The basic theory is that if the aorta exit of the heart can be raised closer to the retina of the eye, 'g' tolerance increases since the heart has to work less hard in maintaining adequate blood circulation in the visual system thus reducing the likelihood of black out. Although pilots can sustain high 'g' for short periods of time with little ill effect, prolonged periods at 8 'g' and above lead to significant cumulative fatigue. The adoption of a reclined posture together with additional equipment such as an anti - 'g' suit and a positive-pressure breathing system can significantly reduce heart rate and hence fatigue.

Possible designs for reclined seats are shown in Figure 10. Of these the simplest is the reclined fixed seat though no real 'g' benefit is gained for practical reclination angles. Couch concepts lead to difficult ejection problems. Of the variable angle seats, the most attractive is the articulated seat pan. A careful study of the factors involved ended in a selection of seat back angle of 35°, a seat pan motion of 20° and a nominal 10° of incidence. A practical design based on this concept is shown in Figure 11. The basic seat rails remain as for a standard seat. A new design seat pan incorporating a pivoted shoulder hinge, links on each side to determine the correct angles and a simple linear motion operating jack complete the additional items.

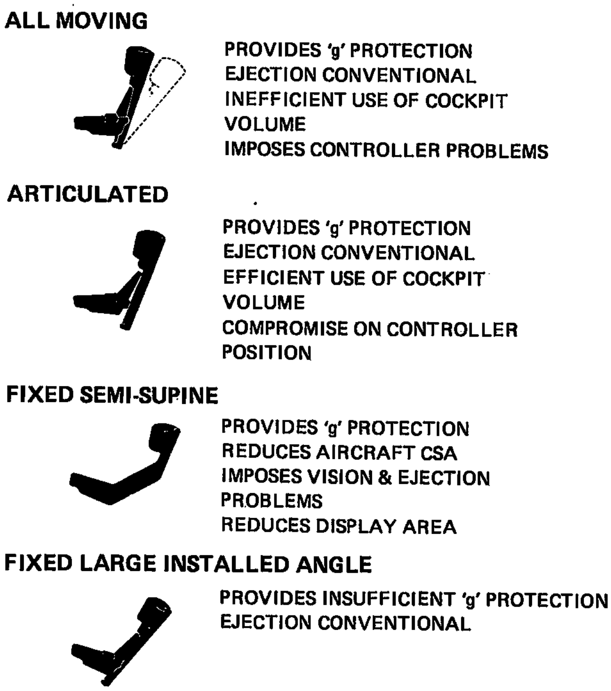


Figure 10 Comparison of Seat Designs

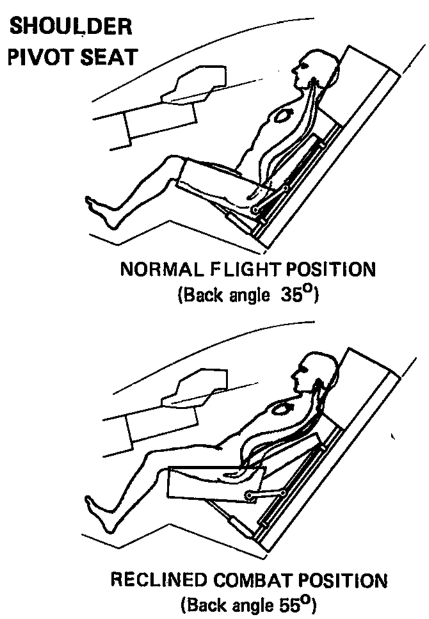


Figure 11 High 'G' Cockpit Concepts

A fundamental question with such a seating arrangement is the problem of escape. Figure 12 shows the sequence involved. If the seat is in the conventional down position, then the ejection is as for an existing seat. Pulling the ejection handle first shatters the canopy by means of Miniature Detonating Cord, MDC. Of the order of 0.3 seconds later, the seat moves up the rails and the pilot passes through the holed canopy. In the case of the seat being in the reclined position when the handle is pulled, the seat pan retracts to the conventional position while the MDC is in the process of shattering the canopy. With this technique there is no additional delay introduced by this novel seating arrangement. A seat based on this concept has undergone evaluation in a mock-up cockpit and a further engineered seat is being prepared for centrifuge trials.

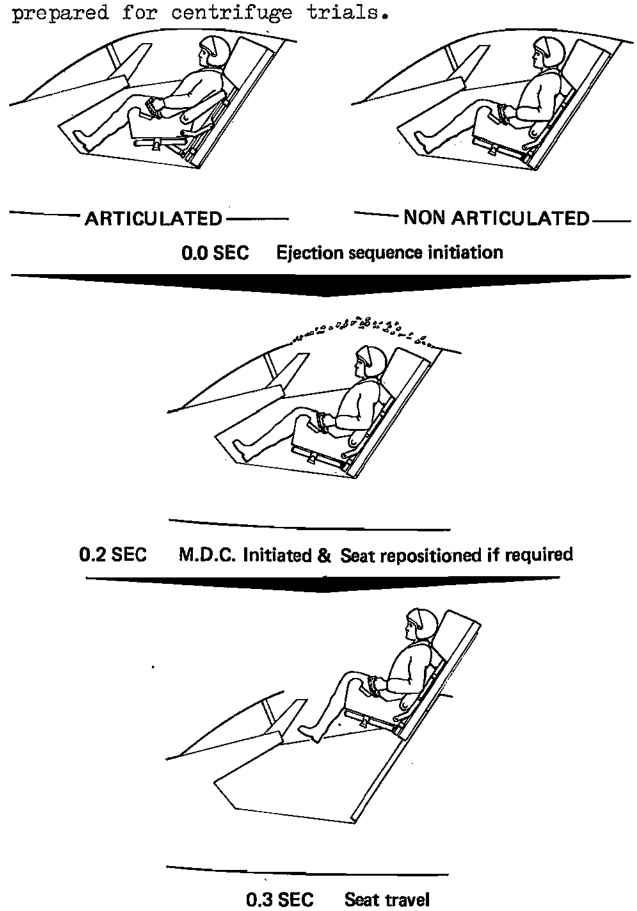


Figure 12 Articulated Seat-Ejection Sequence

Additional mechanical aspects of the cockpit include the canopy design, air conditioning and its attendant noise. The trend in canopy design is towards single piece cylindrical or conical screens and one piece canopies. This is to improve all round vision. In recent years attempts have been made to use polycarbonate material which can be formed into these shapes. Problems have occurred however due to abrasions and bird strikes. MDC effects on polycarbonate are as yet, a relatively unresearched topic. The latest trend is towards polycarbonate with acrylic laminates. Although this may well solve the abrasion problem, shattering by MDC remains unresolved.

Techniques are now available which can significantly reduce cabin conditioning noise in a cockpit. Previously, the air outlet nozzles were designed in such a way that they acted almost like organ pipes. Research in recent years has established design principles which significantly reduce this effect, typically a 10 db noise reduction, if these techniques can be accommodated in the early design of the cockpit. In addition, this cabin air can be used for the cooling of equipment within the cockpit if the outlet nozzles are appropriately located near the coaming and exhaust through the display areas, see Figure 13.

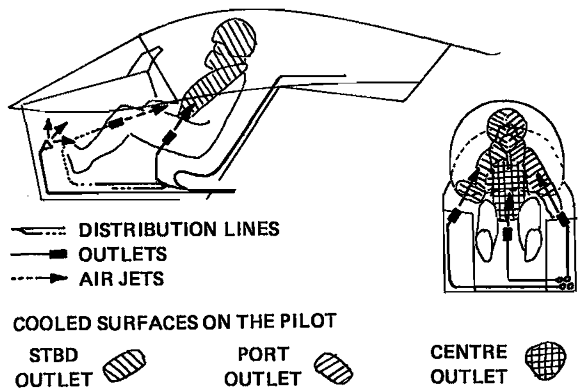


Figure 13 Air Distribution System

IV. Cockpit Displays

It is the development of instrumentation in the cockpit to match the additional operational equipment fit which has led to the ergonomic crisis of modern cockpits. As indicated earlier, the use of electronic displays can help largely overcome this problem. At any one point during a mission, with a conventional cockpit, a large amount of redundant information is displayed. The adoption of electronic displays allows information to be structured into flight modes such as take off, landing, cruise, air-to-air etc. In this way only information relevant to that phase of flight is presented. If other information should be required, it can readily be called up via keyboard access.

A fundamental problem with this mode switching concept is the need to ensure a continuity of vital flight data on the display surfaces so that the pilot can always be sure of finding such parameters as attitude, heading, speed on the same display surface. Information presentation on the displays should be such that the pilot can retain flight control virtually head up all the time. This is achieved by ensuring that after switching operations on the consoles have been completed, confirmatory signals on the display surfaces are presented. Switching is arranged such that it can essentially be accomplished by feel alone. The number of display surfaces is determined by several constraints, the major ones being adequate surface area to accommodate the desired formats and sufficiently independent surfaces to provide adequate integrity.

A current project cockpit undergoing evaluation is shown in Figure 14. This accommodates a reclined seat of the type described earlier. The cockpit size compares with that of the Harrier. A comparison between this layout and that of the Sea Harrier shown in Figure 1 shows the dramatic change in concept which is being proposed. The new cockpit makes use of an all electronic display suite. The Head Up Display - HUD proposed is the latest generation multi-element combiner. This is extremely shallow in depth permitting a Head Level Display - HLD to be installed contiguously. These two displays are the main source of aircraft flight information. The HLD is capable of displaying a moving map picture on which can be superimposed α- numeric information. It also can display cursive graphics and a conventional real time video picture.

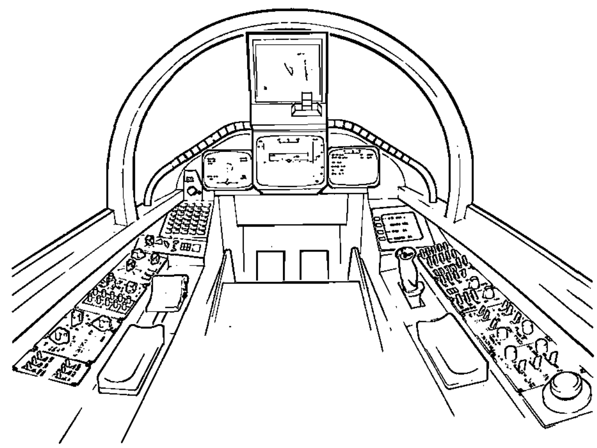


Figure 14 Advanced Cockpit

There are two knee well displays termed Multi-Purpose Displays - MDP1, MPD2 which generally accommodate aircraft systems data, engine information, navigation data and weapons' information. In the event of a warning indicated by red or amber warning lights on the coaming, the depression of the illuminated switch yields pilots notes on the MPD's. The pilot then systematically works through the displayed instructions which are cancelled as each subtask is completed. There are two additional displays. The left hand instrument panel accommodates a small attitude display with additional height and speed information displayed. This is to provide attitude data for the pilot operating the keyboard i.e. essentially the only time he is viewing inside the cockpit for more than a few seconds. The right hand console display is used for selection purposes by presenting various selection options to the pilot. The information presented on the main display surfaces is summarised in Figure 15.

The flight controllers are located on the consoles. Because of the articulated seat, a centre stick is almost ruled out, hence the side arm ministick. The advent of Active Control Systems with electrical connectors from stick to flying surface now makes this approach possible. The throttle, again electrically connected, is located in its normal position on the left console. Because of this feature, it is smaller than the usual throttle and fits neatly into the console design.

The adoption of a data bus concept permits considerable improvement in the design of switch consoles. Significant integration of hand operations is permitted due to computer sampling of switch positions. This technique reduces system access time and hence workload. In principle the right console accommodates switch on type operations whereas the left hand looks after the inflight switching operations. A typical display format suite for a cruise condition is shown in Figure 16.

V. Conclusions

The paper has attempted to present the trend in the design of future military cockpits. The need to improve the cockpit from the ergonomic design viewpoint has been identified and the use of electronic displays to present and locate the required information in a more ideal position has

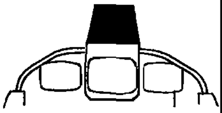
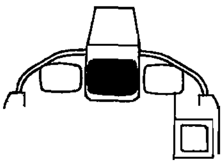
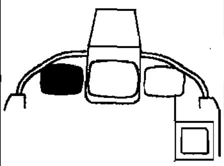
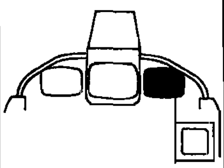
	FLIGHT MODE	CRUISE
DISPLAY	Head Up Display 	A/C Symbol Pull Away Heading Pitch Precision Course Steering Vectors Radar On And Range To Target
	Head Level Display 	<u>MAP SHORT TERM NAV.</u> Map With Waypoints Known Threat Data Targets Present Position Distance To Go Time To Go Heading Speed (Knts) Height
	Multi Purpose Display 1 	<u>LONG TERM NAV.</u> Pre Planned Flight Plan (Grid North Up) Waypoint Update Points Targets Base Present Position Required Heading Actual Heading Nav. System Mode A/C Speed Height Time & Time Next Feature
	Multi Purpose Display 2 	<u>A/C SYSTEMS</u> A/C Speed Height Heading Present Position Fuel Remaining Comms Status Thrust Level Time GMT and E.T. Advisory Warnings

Figure 15 Display Formats

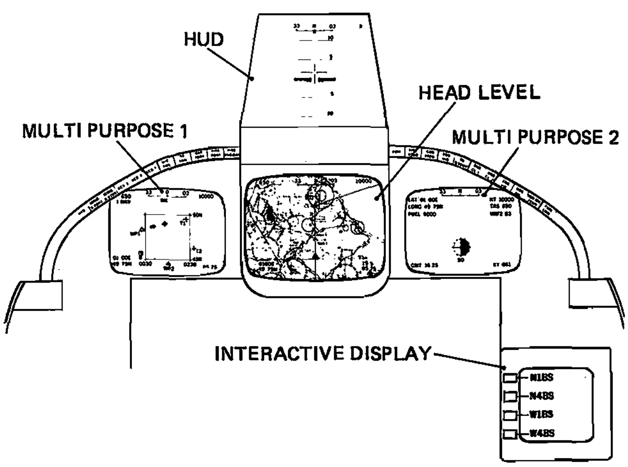


Figure 16 Cruise Mode Formats

been described.

The importance of high 'g' manoeuvring requirements on seat design is described and other mechanical aspects of the cockpit are discussed. These include canopy design, ejection and conditioning noise.

Display implications are discussed from the point of view of presentation of display information and control.

These new cockpit concepts are being studied by a number of design groups. It is certain that many of the techniques will be adopted on the next generation combat aircraft. Which ones will depend on the outcome of the current evaluation work.

VI. Acknowledgement

The author would like to acknowledge the contribution of G. Roe to this paper. Permission to publish this paper is due to British Aerospace.

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