DEVELOPMENT OF A NAVAL AVIATION ANTHROPOMETRY COCKPIT COMPATIBILITY PROGRAM

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ABSTRACT

The present cockpit assignability program assumes that (1) the individual's anthropometric data are correct and (2) that the visual and reach requirements for each cockpit have been correctly defined. Unfortunately, this is not necessarily the case. The three-pronged effort to resolve this problem includes: (1) improving the quantity and quality of individual anthropometric data; (2) standardizing cockpit measurement techniques; and (3) combining the data from both of the above into a decision making model. The end result of these actions should be more appropriate assignments to aircraft cockpits and better data for use in analysis of accidents and ejections.

INTRODUCTION

Anthropometry is a critical element in the design of aircraft cockpits. Traditionally, cockpits, operator consoles, and other workspaces have been designed such that clearances, reach distances, and other critical dimensions will accommodate individuals having all their anthropometric features within a percentile range such as 5th to 95th (Roebuck et al, 1975, Damon et al, 1966). Since 1978, the requirement to accommodate at least 90 percent of the user population has been imposed (Military Standard MIL-STD-1472B). However, populations change with time due to an overall growth trend and the influx of new members (women, minority groups) into the population. Therefore, data adequately describing the changing user population need to be provided. In addition to these traditional uses of anthropometric data, within the military, anthropometric data are used for:

a. Developing Entrance Standards. Entrance standards are determined primarily by the size of the cockpits intended for use by new aviators. However, when new aircraft are to be acquired, the anthropometric features of the intended user population need to be considered. Presently, the available population is being redefined as more specialities are opened to women. Needless to say, entrance standards are also influenced by supply and demand considerations.

b. Evaluating the Impact of Anthropometric Features on System Performance. The critical question is "Has the performance of the system been reduced by anthropometric incompatibility?" As will be discussed in subsequent sections, issues such as required visibility and reach limitations while restrained need to be addressed.

c. Analyzing Accident Data. Because of the high costs involved, all aircraft accidents are investigated to determine if the inability to see a particular warning or to reach a control contributed to the loss. Additionally, any ejection related injuries sustained due to anthropometric features should be identified by postaccident analysis.

d. Assigning or Restricting Personnel from Cockpits. By comparing an individual's anthropometric features with the visual and reach requirements of critical controls, a decision can be made regarding the assignment to or restriction of that individual from a cockpit. This assignment or restriction would be made at the time of initial entrance into Naval aviation and, among other considerations, may determine if an individual entered the jet, propeller, or helicopter pipelines. The individual's anthropometric data would be considered in subsequent assignments within a pipeline (e.g., when transferring from flight training to A-6's or F/A-18's). Early recognition of anthropometric incompatibility leads to cost savings (individual would be restricted from an inappropriate pipeline) and more effective use of training assets (an incompatible individual would not occupy a training position which should be occupied by a compatible individual).

e. Determining Size of Flight Equipment Required. Because of the assortment of flight equipment worn by Navy aircrew personnel - torso harnesses, survival vests, life preservers, anti-G suits, etc. - it is essential that anthropometric data be available. From a cost and logistics point-of-view, it is desirable to minimize the variety of sizes required.

All of the issues addressed above involve some cost considerations and tradeoffs. For example, if performance data suggest that reach requirements are not being satisfied, then a change could be made in cockpit assignability and/or flight gear and/or cockpit layout; ultimately, a change might be made in entrance standards.

Presently, an effort is underway to improve the utilization of anthropometric data in Naval aviation. The three-pronged effort focusing on the elements contained in figure 1 consists of:

I. Improving the Quality and Quantity of Anthropometric Data Being Collected.

II. Identifying Critical Issues in Cockpit Measurement.

III. Improving the System for Identifying Anthropometrically Incompatible Personnel.

Each of these issues is discussed separately below.

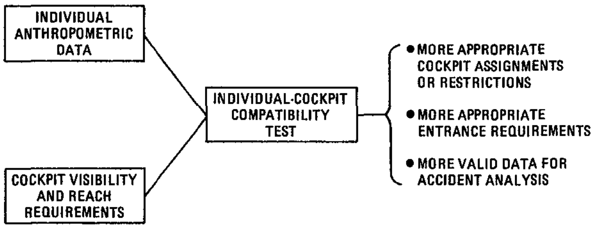

Figure 1 - The Naval Aviation Anthropometry Cockpit Compatibility System

I. Improving the Quality and Quantity of Anthropometric Data Being Collected.

Table 1 lists both the anthropometric measurements presently being recorded and those which should be recorded in the future. Among the presently recorded data, Functional Reach and Buttock-Heel Length are the least reliably recorded. Therefore, an effort is being made to improve the techniques for recording both Functional Reach and Buttock-Heel Length. Additionally, Downward Vertical Reach has been added since it is needed to determine the ability to operate the collective in helicopters and side panel switches in most aircraft. Buttock-Heel Length is being replaced by Functional Leg Reach. This is because Buttock-Heel Length (the horizontal distance between the buttocks and the heel) is not as useful a measure as Functional Leg Reach (the straight line distance between buttock and heel).

Table 1 - Anthropometric Variables Presently Recorded Contrasted with Those Which Should be Recorded

Presently Recorded	To Be Recorded in Future
Stature	Stature
Weight	Weight
Sitting Height	Sitting Height
Acromial Height, Sitting	Acromial Height, Sitting
Bideltoid Diameter	Bideltoid Diameter
Functional Reach	Functional Reach
	Downward Vertical Reach, Sitting
Buttock-Knee Length	Buttock-Knee Length
Buttock-Heel Length	
	Knee Height, Sitting
	Functional Leg Reach

A review (Guill, 1982) of the Navy's aircraft accident records to identify interactions between anthropometric features and injuries sustained on ejection revealed unique "anthropomorphs" within the data. Figure 2 illustrates the extreme values associated with functional reach, while figure 3 illustrates the maximum shoulder width found in the data. Obviously, there are erroneous data which unfortunately dilute an already sparse data base. In an effort to minimize these problems, a new more reliable, automated anthropometric measuring device is being developed. This device incorporates a microprocessor which screens the data to ensure that (1) the measurements collected on the individual fall within the limits established by the entrance standards, (2) differences between anthropometric features are reasonable, and (3) using regression equations predicts anthropometric features (if the reported data do not fall within the limits established about the predicted data, that measurement is flagged for reevaluation).

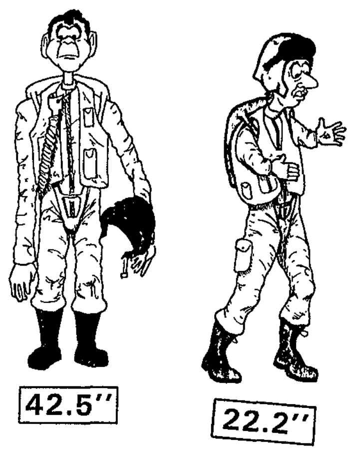

Figure 2 - Extreme Values Associated with Functional Reach

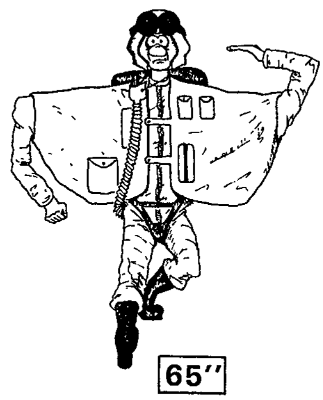

Figure 3 - Extreme Value Associated with Shoulder Width

II. Identifying Critical Issues in Cockpit Measurement.

The anthropometric characteristics required to ensure safe operation of a particular crewstation are defined by eye position, reach, and leg length.

Eye Position

Adequate over-the-nose vision is a prerequisite for safe operability. The general Navy specification for carrier-based aircraft is shown in figure 4. The fuselage angle at minimum approach speed tends to increase during the final design and development phase of a new aircraft. This factor may impact the forward visibility to the point that a major redesign is required. A classic example of this phenomenon is depicted in figure 5. A radical redesign of the entire nose section of the prototype F7U Cutlass was required because adequate vision had not been provided for by the initial configuration. In the real world, it is not unusual to discover that an aircraft simply cannot be operated safely with the pilot's eyes placed at the "manufacturer's design-eye" position and this engineering point is of limited value once an aircraft reaches the flying stage.

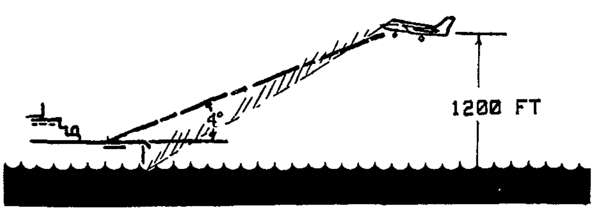

Figure 4 - Over-the-Nose Vision Requirement for Carrier-Based Aircraft

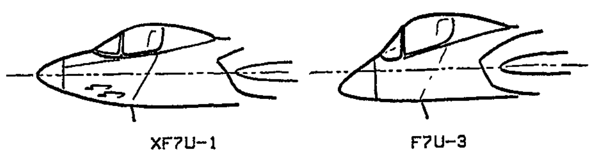

Figure 5 - Design Change Required to Ensure Visibility from F7U

The minimum safe eye position can be determined by using the actual approach fuselage angle relative to the horizon added to the glide slope angle. This position may not (and indeed usually does not) equate to the "desirable" eye height for a particular cockpit; it is simply the case that more vision is better. A pilot will tend to elevate himself in the cockpit until some coincident factor limits his upward travel. Some of the most common limiting factors are listed in table 2. The general pattern of eye positions for individuals with varying sitting heights is shown in figure 6. It is a problem for most pilots to attain a position which is optimal for both external and internal (within the cockpit) vision. The glare shield angle and the optical axes of gunsights and head-up symbology are optimized toward the "design-eye" position and, hence, obscuration of the upper instrument panel and inability to visualize or "get down to" the optical presentations are characteristic of most of our tactical aircraft. This results in a compromise of safety and frequently expensive engineering changes.

Table 2 - Factors Establishing the Highest Acceptable Head and Eye Positions

- INTERFERENCE WITH CANOPY
- INTERFERENCE WITH FLIGHT EQUIPMENT AND EJECTION SEAT STRUCTURE
- COMPROMISE OF REACH TO CONTROLS
- VISUAL INTERFERENCE
  WINDSCREEN BOW
  OBSCURATION OF INSTRUMENTS BY GLARE SHIELD
  INABILITY TO ALIGN WITH HUD OPTICAL AXIS
- LOSS OF "FUSION" WITH THE AIRCRAFT

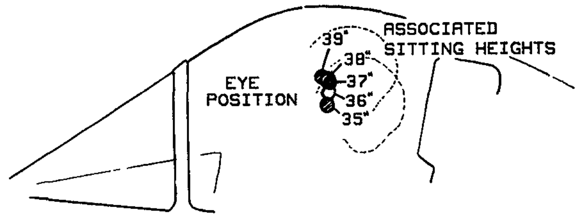

Figure 6 - Locus of Eye Positions Associated with a Typical Tactical Aircraft

Reach

The relationship of body component sizes and the ability to operate various controls is exceedingly complex. The Navy design specifications for crewstations (MIL-STD-1333A) are based upon a proportionality of sitting height, shoulder height, and functional reach which simply does not occur in nature (and underrepresents the "worst-case" situations). In addition, the specifications are referenced to the same "design-eye" point which may not represent actual operating conditions.

In the interest of safety, certain controls should be easily operated with the shoulder harness in the retracted and locked position. Such controls as the landing gear handle, emergency generator, and stores jettison switch must be easily accessible for the safe operation of a catapult-launched aircraft.

To assess reach requirements, the shoulder position, which may vary widely among individuals with similar sitting heights, must be accurately defined. Careful evaluation of a particular cockpit will yield a family of bivariate curves involving a sitting height, shoulder height, and arm length. The relationships can become quite complex and even appear paradoxical at first inspection. Figure 7 demonstrates the reach requirement to the lower collective control and the overhead mounted rotor brake in a fixed-seat helicopter as a function of variable shoulder height. When seat adjustability in two planes is added, the relationships are even more complex and must include at least sitting eye height.

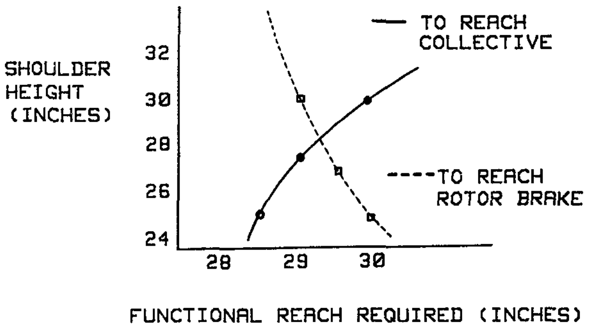

Figure 7 - Reach to Collective and Overhead Rotor Brake in a Fixed Seat Helicopter as a Function of Shoulder Height

Specific cockpit factors and the type of flight equipment carried for certain missions may have a profound effect on the reach of a certain individual. One example is shown in figure 8; the specific shoulder harness geometry determines the limit of the same individual's maximum stretching reach.

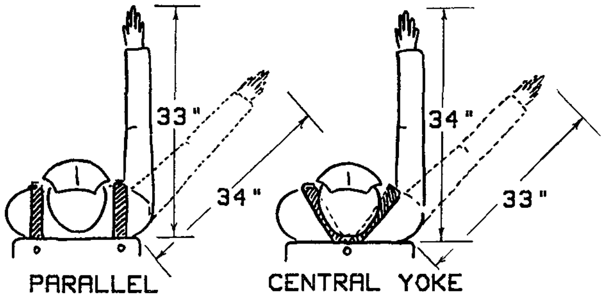

Figure 8 - Effect of Harness Configuration on Maximum Reach for the Same Individual

Leg Length

An individual must be able to actuate the rudder and brake pedals while maintaining sufficient clearance from the lower panel structures. The legs must be protected from contact with adjacent structures during the ejection phase. These parameters must apply for the range of seat adjustments associated with the coincident vision and reach requirements. It does little good to demonstrate satisfactory leg clearance with the seat full-up if, in so doing, an individual is wedged into the canopy.

The effects of specific geometrical relationships between pedals, seat bucket level, and position of the instrument panel can yield some interesting results. For a given seat height adjustment, a bivariate relationship exists between tolerable buttock-knee length and total leg length. This can be expressed as a series of "if-then" statements as shown below:

With Seat Full Down:

If BK = 25.5", Tolerable Leg Length = 49.0".
If BK = 26.0", Tolerable Leg Length = 48.0".
If BK = 26.5", Tolerable Leg Length = 47.0".

This is shown in graphic form in figure 9.

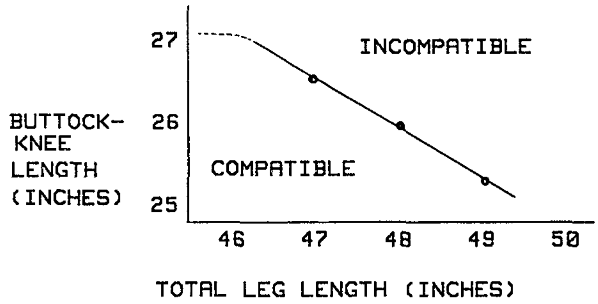

Figure 9 - Buttock-Knee and Total Leg Length Interaction for a Typical Cockpit

In certain systems, the worst case for the long-legged individual may not occur with the seat adjusted full-down but rather the "point of closest approach" of his shin to the panel may occur with the seat partially elevated.

The dominant enhancing design features to ensure optimal leg accommodation at both ends of the size spectrum are large amounts of pedal adjustability (7" to 10") and relatively small pedal operating excursions ("throws").

III. Improving the System for Identifying Anthropometrically Incompatible Personnel.

After the critical cockpit dimensions have been identified, as described immediately above, they will be compared, by means of a microprocessor, with an individual's anthropometric features and a decision will be made regarding the compatibility of the individual's anthropometric features with the cockpit of interest.

Univariate comparisons will be made first: for example, comparing an individual's buttock-knee length with the minimum clearance required for safe ejection. If no conflict was noted, the next critical comparison would be made. If a conflict was noted, then that conflict would result in the individual being excluded from that cockpit. Bivariate comparisons would follow; specifically, emphasizing functional arm and leg reach requirements. The measured Functional Reach does not reflect reach capability unless the point-of-origin of the reaching arm is considered. That is to say, reach capability is determined by the interaction of Functional Reach, Vertical Reach, and Acromial Height, Sitting. Analogously, Leg Reach capability is determined not only by leg length but by where the individual's seat is located in the vertical plane. These dimensions would be compared with the cockpit dimensions required and, if any incompatibility was noted, it would result in the individual being excluded from that cockpit.

Finally, multivariate comparisons would be made which would allow for the interaction of all factors to be examined. The Computerized Assessment of Reach (CAR) Model or extension of Bittner's (1976) Computerized Accommodated Percentage Evaluation (CAPE) Model would be utilized. With CAR, the appropriate X, Y, Z location of surfaces to be reached would be preloaded into the computer and the individual's anthropometric data would be entered. The system would then determine the ability of the individual to reach the required controls. A modified version of CAR would be used to ascertain that visual requirements would be met.

CONCLUSIONS

It is expected that the steps described above will (1) lead to more appropriate assignments to or restrictions from aircraft cockpits and (2) will provide a more reliable data base for use in the investigation of accidents and ejections.

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