FOUR

International Anthropometric Variability and Its Effects on Aircraft Cockpit Design

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The anthropometric characteristics of consumer populations play an important role in the design of many products. A myriad of items from space capsules to earth movers, bathrooms to milling machines, and theodolites to submarines require variable levels of accommodation to the sizes and proportions of the human body. Great effort is generally devoted to this end, particularly when the product is to be sold on a competitive market. If the product is rather simple the effort is usually relatively inexpensive and successful. On the other hand, if the product is a highly complex system, such as an aircraft, the attainment of a high level of accommodation almost invariably requires expensive economic and engineering trade-offs with varying levels of success.

This paper is concerned with high performance, single seat, military aircraft cockpits and the problems encountered in accommodating them to the anthropometric requirements of foreign military users. These problems often are very difficult. Design changes invariably required to cope with any significant anthropometric differences are fraught with seemingly insurmountable economic and engineering problems. Still, malaccommodation in aircraft not only produces a condition in which the product is inconvenient to operate, but one in which the user's safety and the basic mission of the aircraft can be compromised.

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THE SERIOUSNESS OF THE PROBLEM IN AIRCRAFT

At times it may be difficult to imagine the seriousness of the problems encountered when a cockpit is not designed specifically for the using population. One can brush these problems aside in the name of patriotism, expedience, or whatever, but in the final analysis missions fail and aircraft and air crews may be lost as a direct consequence of a relatively "inconsequential" or "unimportant" anthropometric design consideration.

The following is a fictional account composed of factual ingredients. It illustrates how the interplay of apparently minor inadequacies of design can and does lead to tragic accidents.

Imagine a pilot on a flying mission of 9 to 10 hours. Such missions are not uncommon. After a few hours in the air the pilot wishes he could stand and walk around a little to relieve the pressure on his backside and legs. He squirms in his seat, first sitting on one buttock, then the other. After a while he tries to push himself forward in the seat but is held back by the lap belt. He lowers, then raises the seat to change the angulation of his knees and to relieve the ache beginning to bother him under one of his thighs. In a little while the pain increases and spreads throughout both thighs. After another 2 hours it begins to become unbearable. He is counting the minutes to touch-down, wondering if he can bear the discomfort that long. Three more hours yet to go. The pain has now traveled to the small of his back. The small changes in body position possible in the seat no longer help relieve the pain.

When he finally makes his approach, one of his two engines dies. To maintain his course requires the immediate application of full left rudder and left aileron. Because his legs are so painful, he cannot maintain the necessary rudder pedal force, and his extended left leg prevents him from obtaining full left aileron.

He crashes off the side of the runway. He and his crew are severely injured.

Discomfort in this aircraft was viewed in the usual manner, that is, as relatively unimportant. In this instance, however, the pilot's discomfort was protracted over a long period of time and became so unbearable that it consumed his thoughts. The pain was eventually replaced by numbness. When it became necessary to apply a relatively large but manageable force to the rudder pedal to maintain the course of the aircraft, the required strength simply was not available.

Eighty-two kg (180 lbs) of force are required on this particular aircraft to depress a rudder pedal after the failure of one engine. Such a force is not too great, even for the smaller American and European pilots, under normal circumstances. In the situation just described, however, circumstances were far from normal. In addition to applying full rudder to compensate for the engine failure, it was also necessary to apply full aileron in the same direction. When a pilot's leg is fully extended to obtain full rudder, full aileron is unavailable to a substantial number of pilots for two reasons:

1) Control wheel movement in both directions is interfered with by the *normal* positioning of the pilot's thighs. The interference is compounded when the pilot extends his leg to apply full rudder.

2) The control column is displaced to the left of the centerline of the pilot's seat, thereby increasing the restriction to aileron control on that side.

At least two general classes of problem were responsible for the unfortunate results in this account: comfort and accommodation to the anthropometry of the pilot. However, these are separate problems only in theory. In practice they merge at so many points, insofar as the aircraft cockpit is concerned, that they must be considered together. Comfort cannot be achieved without the application of sound engineering anthropometric design techniques. Even so, providing an optimum dimensional relationship between the pilot and the structures and equipment within a cockpit does not assure comfort. In the case of very long flights, ordinary standards of comfort are not good enough. Flights of long duration require the development of new devices to provide for extra margins of comfort far beyond that which is adequate for short flights. Here, however, I shall not be concerned with comfort per se, but with the anthropometric considerations essential to the basic geometric layout of cockpits for selected national populations.

ANTHROPOMETRIC DIFFERENCES AMONG VARIOUS POPULATIONS

Unfortunately, anthropometric data on all potential manufacturing and using populations are not readily available. Data on the populations of Central and South American and African nations are very difficult to find. Similarly, data on Near and Far Eastern populations are sparse, except for those of Iran (Noorani & Dillard 1971), India (Mookerjee & Bhattacharya 1956), Korea (Kay 1961), and Japan (Oshima, Fujimoto, Oguro, Tobimatsu, Mori, Watanabe, & Alexander 1965). Some Southeast Asian nations, particularly Thailand (White 1964*a*) and Vietnam (White 1964*b*), have been well studied. The Australian population has also been reasonably well described (Aird, Bond, & Carrington 1958; Carrington 1959). Good data are available for most North American (Alexander, Garrett, & Flannery 1969; Alexander & Laubach 1968; Ashe, Roberts, & Bodenman 1943; Clauser, Tucker, McConville, Churchill, Laubach, & Reardon 1972; Climatic Research Laboratory 1947; Daniels, Meyers, & Worrall 1953; Freedman, Huntington, Davis, Magee, Milstead, & Kirkpatrick 1946; Garrett 1968, 1970*a*, 1970*b*, 1971*a*, 1971*b*; Gifford, Provost, & Lazo 1965; Hertzberg, Daniels, & Churchill 1954; Hertzberg, Emanuel, & Alexander 1956; O'Brien & Shelton 1941; Randall & Baer 1951; Randall, Damon, Benton, & Patt 1946; Snow & Snyder 1965; White 1961) and West European populations (Ducros 1955; Evrard 1954; Hertzberg, Churchill, Dupertuis, White, & Damon 1963; Laboratoire d'Anthropologie 1965; Morant & Whittingham 1952; Udjus 1964), except for those of Mexico, Spain, and Portugal. Among East and Southeast European countries, Bulgaria (Bulgarian Academy of Sciences 1965) and Greece (Hertzberg et al. 1963) have been best studied. Anthropometric data on Russian populations are not complete. Anthropometric data from most available international sources have been collated by Garrett and Kennedy (1971).

A serious deficiency of almost all anthropometric data is that they have been obtained primarily for military populations. In general, the civilian populations of the world have been neglected.

What are the principal anthropometric differences among the populations of the world? For design purposes, are the differences significant? Are some differences irrelevant to designers? To answer these questions, it is instructive to consider some differences among various national military populations.

STATURE

Figure 1 shows comparative percentile values for stature for military populations of the United States (unpublished data), West Germany (unpublished data), France (Laboratoire d'Anthropologie 1965), Italy (Hertzberg et al. 1963), Japan (Oshima et al. 1965), Thailand (White 1964*a*), and Vietnam (White 1964*b*). The U.S. Air Force flight population is among the largest, anthropometrically, of all Western nations that manufacture and export aircraft. Since it is also one of the most thoroughly studied populations, I have used it as a standard against which to compare the others. The percentile values on the left in Figure 1 are for U.S. flight personnel and are based on unpublished data gathered in 1967. The other countries are arranged from left to right in descending order of their values for the 50th percentile in stature.

It is customary in the United States Air Force to design for the central 90 percent of the population. In the case of stature this means from the 5th percentile (167.3 cm) to the 95th percentile (187.7 cm), a design range of 20.4 cm. The 5 percent of the population above the 95th percentile and the 5 percent below the 5th percentile would not be specifically accommodated. This does not mean that 10 percent of the population is necessarily excluded. Fortunately, in a great many cases, the human body can make some accommodation to an inadequately designed system. There are, however, some instances in which very nearly all those not specifically accommodated will not be able to operate the aircraft safely. Examples are the reach distance to critical hand controls, ejection clearance, rudder pedal distance, and seat-to-canopy distance.

The United States, Germany, France, and Italy are representative of the North American and Western European populations where we find the

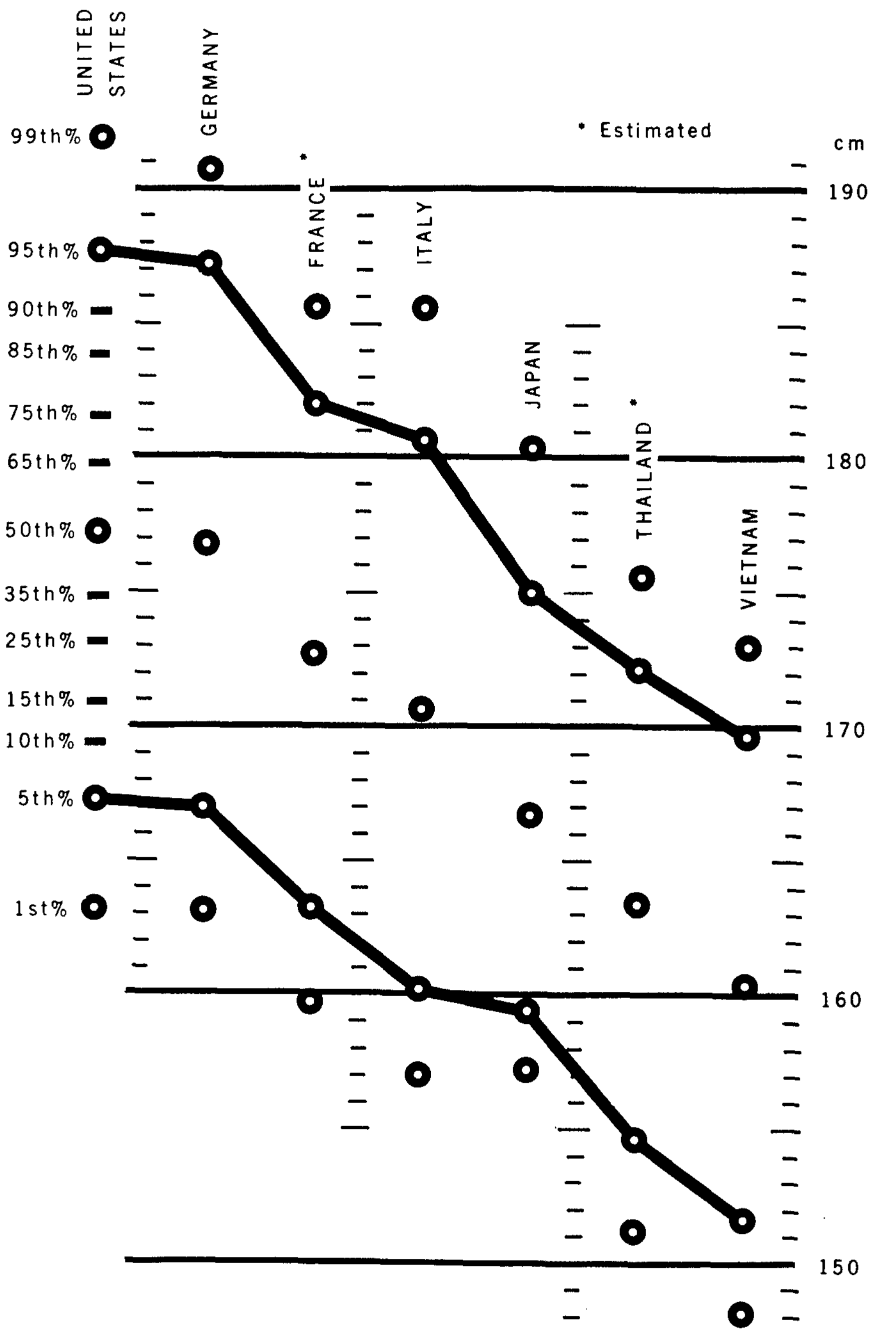

Fig. 1. Statures of seven military populations. The percentile values on the left are for U.S. Air Force flight personnel. The interval between the 1st and 5th percentiles should be approximately equal to the interval between the 95th and 99th percentiles. Since they are not in the case of the Japanese data, there is some question about the validity of these 1st and 99th percentiles.

tallest of the industrialized peoples. Thailand and Vietnam represent those nations where we find the smallest of the industrialized peoples. Comparisons among these groups are startling to the designer. For instance, the 5th to 95th percentile design range for Americans would accommodate essentially the same percentage of Germans (6th to 96th percentile), but only approximately the upper 80 percent of the French (19th to 99th percentile), 69 percent of Italians (30th to 99th percentile), 43 percent of Japanese (57th percentile to the top of the range), 24 percent of Thai (76th percentile to the top of the range), and 14 percent of Vietnamese (86th percentile to the top of the range). On the other hand, if we use the French 5th to 95th percentile range for design purposes, we would accommodate approximately 77 percent each of Americans and Germans (1st to 78th percentile) 83 percent of the Italians (13th to 96th percentile), 76 percent of the Japanese (24th percentile to the top of the range), 51 percent of the Thai (49th percentile to the top of the range), and about 30 percent of the Vietnamese (70th percentile to the top of the range).

Notice the position of the Japanese population. The 50th percentile for stature is almost exactly midway between that for Italy and Thailand. The 95th percentile Japanese is only slightly shorter than the 99th percentile Thai, and the 95th percentile Japanese is equivalent to the 76th percentile Italian.

SITTING HEIGHT

Figure 2 gives data on the sitting heights of the same populations as those in Figure 1. Sitting height is a far more critical dimension in laying out the geometry of the aircraft cockpit, since it must be considered in determining the depth of a cockpit, that is, the distance from the underside of the canopy to the heel-rest line (HRL). We see in Figure 2 a relationship among the various populations similar to that for stature in Figure 1. One prominent exception is that for sitting height the Japanese are slightly taller than the Italians and very nearly as tall as the French. For stature (Fig. 1), the Japanese are significantly shorter than both the Italians and the French. This raises a new consideration that must be taken into account when a Western (or non-Japanese) engineer is designing a cockpit to accommodate the Japanese user. Whereas almost all other populations are, more or less, scale models of each other, the Japanese are not. Japanese torsos are proportionately longer than their legs, as compared to most other populations. This implies, for instance, that an aircraft designed by the French for French use could meet the cockpit depth requirements for the Japanese, but would probably not be adequate in terms of rudder pedal distances. In general, a French aircraft could be adapted to the Japanese with fewer changes than could one designed by and for Americans or Germans.

THE RATIO OF SITTING HEIGHT TO STATURE

Differences among the proportions of various populations are more clearly illustrated in Table 1, which gives ratios between mean sitting height and mean stature among selected populations. This ratio is a measure of body proportions. Populations at the top of the list have proportionately longer legs, those at the bottom, proportionately shorter legs. The ratios for the populations selected fall naturally into three groups. To some extent the gaps in Table 1 are artifacts of selection that may not exist, or that may at least be greatly diminished, in actual fact. However, the separation between the Turks and the Japanese is unquestionably significant. Japanese body proportions are significantly different from those of most other populations, and this makes interchangeability of equipment with the Japanese very difficult.

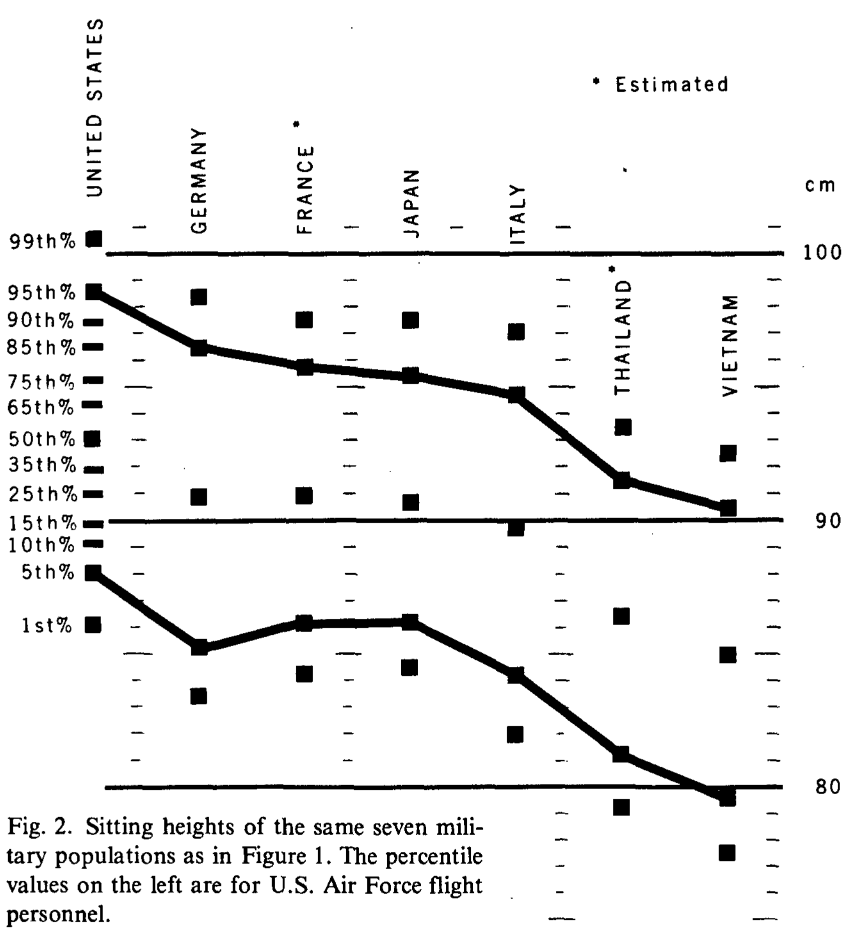

Fig. 2. Sitting heights of the same seven military populations as in Figure 1. The percentile values on the left are for U.S. Air Force flight personnel.

Table 1. Ratios of mean sitting height to mean stature for various national groups

	Men	Women		Men	Women
Germany (military)	0.514		France (military)	0.526	
Bulgaria (civilian)	0.522[a]	0.528[a]	United Kingdom (military)	0.526	
United States (civilian)	0.522	0.529[a]	Korea (military)	0.528[a]	
Norway (civilian)	0.522		Thailand (military)	0.529[a]	
Canada (military)	0.525		Greece (military)	0.529	
United States (military)	0.525	0.528[a]	Vietnam (military)	0.530[a]	
France (civilian)	0.526		Turkey (military)	0.530[a]	
Italy (military)	0.526		Japan (military)	0.544[a]	

[a]Indicates those populations for which the mean stature is less than the 20th percentile of the U.S. military population.

Those populations whose mean stature is smaller than the 20th percentile USAF stature are indicated by a superscript. These discrepancies are important in designing personal equipment, for example, pressure suits, a problem that will be discussed later in this paper. To anticipate, however, fitting problems are successively greater among those populations toward the bottom of the list and are magnified with a population such as the Japanese, who are not only differently proportioned but also quite different in overall body size.

APPLICATIONS TO COCKPIT DESIGN

To determine the effect of these anthropometric differences on cockpit design, let us assume that the USAF military standards for the basic dimensions of the cockpit are optimum for the population of U.S. pilots. While this assumption may be argued, the standards provide us with accepted cockpit geometries from which we can determine the changes necessary to accommodate other populations. Figure 3 gives the essential dimensions taken from one of these standards, Military Standard 33574, concerned with stick-controlled, fixed wing aircraft cockpits (Department of the Air Force 1969).

BASIC AMERICAN COCKPIT GEOMETRY

The basic reference points used generally throughout the American aircraft industry are the design eye position (DEP) and the neutral seat reference point (NSRP). The DEP may be taken as the primary reference point, since for a pilot to be properly positioned within the cockpit, he must raise or lower his seat so that his eyes are brought to the horizontal-vision line. The DEP is the average for all such positions along this line. The aircraft is designed so that when a pilot's eyes are brought to the DEP, he will have the best overall vision out of his aircraft, toward his instrument panel, and to special sighting devices and visual displays. At this adjustment he also has the minimum acceptable helmet clearance beneath the canopy. The DEP is located 25 cm perpendicularly from the back tangent line (BTL) and 80 cm above the NSRP.

The NSRP is a point within the cockpit and is part of the cockpit, not of the ejection seat. It is that point to which the ejection seat is adjusted during installation. The NSRP coincides with the Seat Reference Point (SRP) of the seat when the latter is at its midpoint of vertical adjustability. The SRP of the seat is defined as a point in the midline of the seat at the intersection of the depressed seat cushion and seat back. For positioning the pilot in the seat, it is convenient to consider that the pilot also has a SRP, when seated. The pilot's SRP is defined in essentially the same way as is that for the seat.

American engineers generally consider it easier to use this system of seat reference points than the DEP. Their reasoning is as follows: The NSRP is a fixed point within the cockpit; it is not the average of a series of points. When the midpoint of vertical movement of the SRP of the seat and the SRP of the operator are brought into coincidence with the NSRP, the NSRP is tied to structure as well as to the operator. On the other hand, the

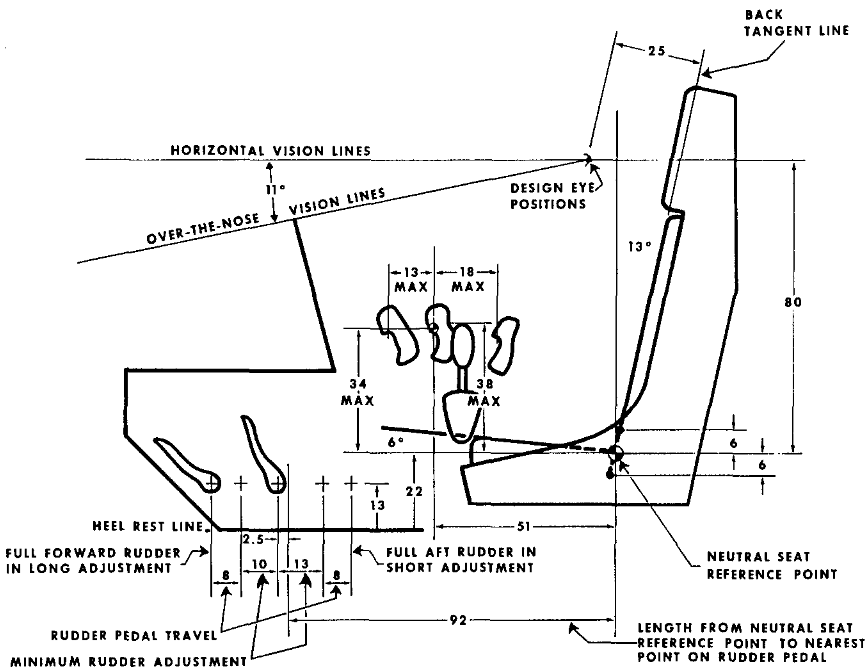

Fig. 3. Basic cockpit dimensions for a USAF stick-controlled, fixed-wing aircraft according to Military Standard 33574.

DEP is a point in space, unconnected to aircraft structure. In addition, as the pilot moves around in his seat during normal operation of the aircraft, his personal SRP remains reasonably stationary relative to the seat SRP and to the NSRP, that is, his own SRP moves within a relatively small envelope. His eyes, of course, move through a very much larger envelope. The SRP reference system is not, by any means, perfect. However, it is much more desirable from the designer's standpoint if hand- and foot-operated controls can be referenced to a point that remains relatively stationary.

When the pilot raises his seat, he raises his own and the seat's SRPs above the NSRP, carrying him away from the rudder pedals. Lowering the seat has the opposite effect; it brings him closer to these controls. The positions of the rudder pedals must, therefore, be adjustable fore and aft to compensate for such movements. In Military Standard 33574, the rudder pedal reference point is 92 cm forward of the NSRP and 13 cm above the heel-rest line. The latter is 22 cm below NSRP. Rudder pedal adjustability of approximately 10 cm forward and 13 cm aft is considered adequate. The standard further recommends that fore and aft rudder pedal movement during operation be limited to about 8 cm in each direction.

Since the control stick and other hand-operated controls do not move with the seat, they should be made adjustable or should be located so that they can be conveniently operated at all seat adjustments. In actual fact, hand-operated controls in American aircraft of this type are not made adjustable. The control stick reference point is generally located at a maximum of 34 cm above and 51 cm forward from the NSRP. This is sufficiently high in the cockpit and sufficiently close to the operator so that the stick can be conveniently reached by a high percentage of our population at any seat position. At the same time the stick is sufficiently far away to provide adequate clearance between the pilot's thighs and to provide full travel throughout its full movement envelope. The episode recounted at the beginning of this paper illustrated the consequences of not providing sufficient clearance between the pilot's thighs for full control movement. Hand controls other than the stick are located in reach zones dictated by their importance and the probable level of restraint of the pilot during operation.

In our high performance aircraft with ejection seats, we require that the seat be adjustable 6 cm above and below the NSRP along a line approximately parallel to the back tangent line, but exactly parallel to the ejection line. This requirement is necessary to maintain the seat-and-pilot center of mass at a constant distance from the ejection line. However, it introduces a very severe design problem in these aircraft. The very pilots who find it necessary to raise their seats to reach the horizontal-vision line are those of shorter torsos and, usually, correspondingly shorter limbs. Since the adjustment is invariably up and away from (or down and toward) his controls, it forces the smaller pilot *away* from and the larger pilot *toward* the aircraft controls, the exact opposite of what is required. Further discussion of this aspect of cockpit design would take us far afield from the immediate subject. It is, however, an extremely disconcerting feature of cockpit-design requirements. Multiposition cockpits of larger, slower aircraft, not equipped with ejection seats, generally provide both vertical and fore and aft seat adjustability, so the pilot can position himself more appropriately in the cockpit.

ADAPTATIONS OF THE AMERICAN COCKPIT TO OTHER NATIONALITIES

Figure 4 illustrates some of the basic dimensional changes that would be required in this American standard to accommodate the cockpit to the requirements of the Japanese and Vietnamese. The changes are drastic ones. The 13° back angle, 6° seat angle, and 22 cm heel-rest line are maintained without change. Because of the smaller sitting eye height among both the Japanese and Vietnamese, however, it would be necessary to lower the horizontal-vision line (and DEP) by approximately 3 cm for the Japanese and 7 cm for the Vietnamese, to 77 and 73 cm respectively, above the NSRP. It might also be possible to move this point one or two cm aft, since head length for these populations is somewhat shorter than for Americans. The latter design change would depend to some extent on their sitting posture and would require that special high-altitude helmets be designed to accommodate their generally smaller heads.

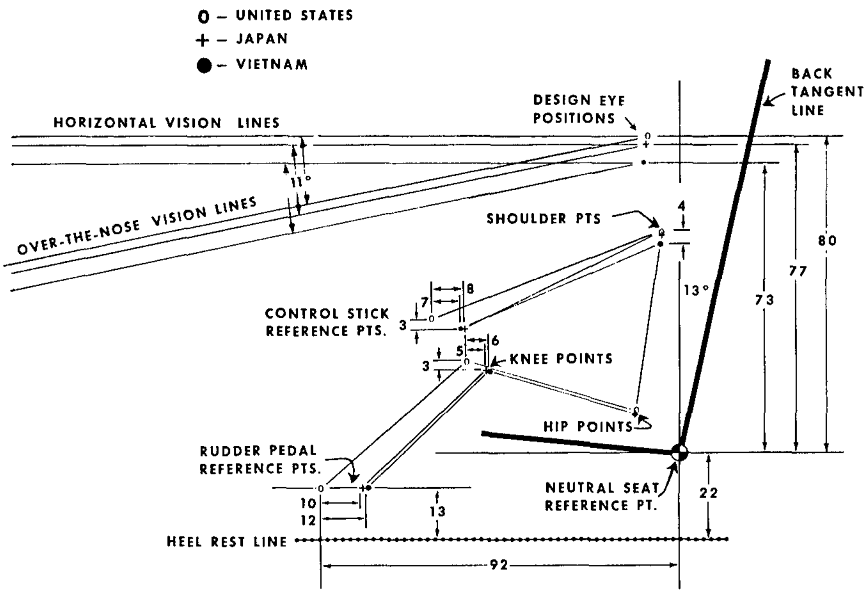

Fig. 4. Modifications in the basic cockpit geometry of Figure 3 required to accommodate Japanese and Vietnamese pilots.

The shoulder point is important for determining the placement of hand-operated controls. This point would undoubtedly be lower for Japanese than for American pilots, but the available anthropometric data are not sufficiently detailed to permit a precise estimate of how much lower. For the Vietnamese this point would be approximately 4 cm lower than for Americans. Again, it might be possible to put both points somewhat to the rear of that for American pilots, depending on the posture of both groups.

The altered shoulder points and shorter reach for these populations make it necessary to move the control stick aft about 8 cm for the Japanese and 7 cm for the Vietnamese. Since the Japanese have longer torsos and a higher shoulder point than the Vietnamese, but have roughly comparable arm lengths, the control stick for the Japanese cockpit would have to be moved slightly further to the rear. All hand-operated controls other than the control stick would require movement closer to the operator by similar amounts, that is by 8 cm and 7 cm, respectively, for the Japanese and Vietnamese.

The hip point for Americans is approximately 10 cm above and 12 cm forward of the SRP for the seat. The hip point for our other two populations is unknown. For purposes of this illustration, I have placed this point 1 cm lower than that for Americans.

The Japanese and Vietnamese are quite a bit shorter than Americans in the length of their legs, and the distance to which their knees extend forward is correspondingly smaller by approximately 5 cm for the Japanese and 6 cm for the Vietnamese. This means that rudder pedals must be moved to the rear 10 and 12 cm respectively. Since in both cases knees do not rise as high as American knees, the control stick could also be moved downward approximately 3 cm.

At first glance, these changes in basic cockpit dimensions may appear negligible. Their overall effect, however, is to produce a significantly shorter and shallower cockpit. Military Standard 33574 specifies that the distance from the underside of the canopy to the heel-rest line should be at least 127 cm. The changes discussed so far permit the canopy distance to be reduced by at least 3 cm for the Japanese and by approximately 7 cm for the Vietnamese. In addition, the shorter legs of both groups would necessitate a reduction in the distance from the NSRP to heel-rest line of about 4 cm, from 22 to 18 cm. The net result of all these changes would be a reduction in required cockpit depth to 120 cm for the Japanese and to 116 cm for the Vietnamese. Any aeronautical engineer would be extremely happy if he were told he could reduce the depth of his cockpit to these amounts, because this one change could bring about a significant increase in aircraft performance.

REACH ENVELOPES

Reach capability to hand-operated controls is obviously an important aspect of cockpit layout. It is often very difficult, even under the best conditions, to find sufficient space in suitable locations for the placement of controls. The factors involved are several and usually conflicting. When the control has an associated visual display, the display and control should be close to one another. As the need for more displays and controls increases, suitable space for their location is at a premium. Miniaturization and integration have provided some relief, but the spatial problems are far from being solved. If reach and visual capabilities permitted, a greater number of instruments could be handled by moving the instrument panel farther away from the pilot. However, since displays and controls must be seen and read as well as reached, there are practical size and distance limitations that must be observed.

For the American population, we can describe in three dimensions the reach envelopes within which controls may be placed and within which controls can be reached by 95 to 99 percent of the population (Kennedy 1964), with and without the effects of encumbering personal equipment (Garrett, Alexander, & Matthews 1970). For the military population of India, such an envelope would have to be reduced in size by about 6 percent; for Koreans, 13 percent. Some other populations would require even greater reductions. Figure 5 illustrates the horizontal contours predicted for these envelopes at the 38-cm (15-inch) level above the SRP. The 5th percentile reach forward at this level is 67 cm for Americans, approximately 63 cm for Indians, and 59 cm for Koreans. The 5th percentile reach to the right at this level is 81 cm for Americans, approximately 76 cm for Indians, and 70 cm for Koreans. In aircraft of equivalent complexity and performance, the requirement to place controls and displays closer reduces the available space even further. The closer controls must be placed to the pilot, the less surface there is available on which to mount them.

To appreciate how this problem has increased through the years, some single-seat aircraft of World War I had only three controls that the pilot had to reach when he was firmly strapped in the cockpit: the control stick, fuel cocks, and machine gun trigger. Table 2 shows the controls that must now be placed within the primary reach zone of modern military aircraft.

SIZE AND SHAPE OF HAND CONTROLS

The size and shape of hand controls will also require change if they are to be used by foreign military populations. Figure 6 illustrates the USAF standard hand grip, the MC-2 stick-control grip, used almost universally for stick-controlled, fixed-wing aircraft. Some American pilots feel that this hand grip should be somewhat smaller, so that all the switches could be operated without changing the position of the hand on the grip. If American pilots have difficulties operating some of these switches, one can expect these difficulties to be magnified among using populations with smaller hands. The ability to operate these switches seems to be associated with hand length. The longer the hand, the more easily the switches can be reached. Based on differences in hand length, the Turkish,

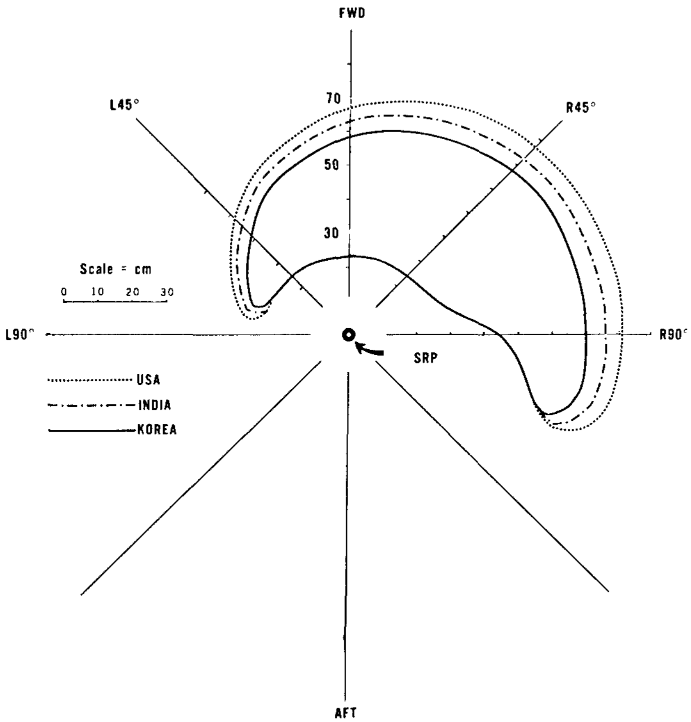

Fig. 5. Horizontal contours of the reach envelopes for three populations 38 cm above the seat reference point.

Greek, and Italian military might require about a 2 percent reduction in overall size of the hand grip; the Japanese and Korean, 4 percent; and the Vietnamese, 8 percent. At what point these reductions become significant is a matter for argument. Similar reductions would be required for controls on the power quadrant, especially since it is often used to mount critical switches.

Although there is a great amount of personal preference involved in the design and acceptance of hand-held multiple controllers, the control situations in which they are used are multiplying. Figure 7 illustrates some currently being manufactured by one company. An overriding consideration governing the size of such multiple controllers is that all switches are enclosed within the body of the grip. Thus, the limit below which a grip may not be reduced in size is determined by the number of switches and the degree to which they can be miniaturized.

PERSONAL-PROTECTIVE EQUIPMENT

The designer of personal-protective equipment, as well as the cockpit designer, must provide for the different body-size requirements of foreign

Table 2. Hand controls that must be placed within the primary reach zone in modern military aircraft[a]

Control stick/wheel	Life-support controls
Power quadrant	Ejection controls
Fuel mixture	Shoulder-harness lock
Propeller speed	Emergency and normal landing gears
Propeller feathering	Arresting-hook drop
Wing sweep	Auto-pilot disconnect
Speed brakes	Bail-out/ditching alarm control
Flaps	Microphone switch
Emergency trim	Emergency electrical power controls
Emergency brakes	Fire extinguishing and shut-off
Emergency canopy jettison	Emergency engine shut-down
Emergency external stores jettison	Primary fuel selector

[a] The pilot is assumed to be sitting with his shoulders back and with his shoulder harness locked.

users. Items such as full- and partial-pressure high-altitude garments, anti-g suits, flight coveralls, and parachute harnesses, play an extremely important role in the overall compatibility between the pilot and his crew station. At least three aspects of equipment design must be considered: (1) the accommodation or fit of the item of equipment to the operator, (2) the degree to which it provides him with the physiological protection intended, and (3) the compatibility of the personal-protective equipment with the layout of the cockpit.

If a foreign-using population is not greatly different anthropometrically from the population for which an article was sized, the problem of fit can be alleviated but not necessarily solved by altering the tariff for the individual sizes. For instance, the USAF height-weight sizing systems (Emanuel, Alexander, Churchill, & Truett 1959) based on data from Hertzberg et al. (1954) for full-body garments such as full- and partial-pressure suits, anti-g garments, and flight coveralls, can fit a large percentage of Italian military personnel between the 5th and 95th percentiles for height and weight. While the USAF population requires more of the sizes in the center of the range (the medium-sized suits), the Italians need more of the smaller sizes and few, if any, of the largest sizes. When a population has measurements that are even closer to American measurements, it could be accommodated in a similar manner. This procedure, however, is less effective when the anthropometric differences from the USAF population are greater. With some populations, such as those of Bulgaria, Turkey, Korea, Thailand, and Vietnam, additional smaller sizes must be added and the largest sizes disregarded.

In addition to overall differences in body size, differences in body proportions play an important role in the interchangeability of personal equipment. For instance, American-made partial-pressure suits will not fit Japanese pilots. Unfortunately, the arms and legs of the American garments are much too long. In the case of the Japanese, a completely new sizing system had to be introduced to accommodate to their different body sizes and proportions.

The use of personal equipment in the cockpit has significantly increased the complexity of the design process. Pressure suits, for example, create a series of problems that have been among the most difficult to solve. Many of those problems can be traced to two characteristics of these garments: (1) they add a great amount of bulk to the body, and (2) they decrease the mobility of the arms and legs. Inflating the suit magnifies both problems. Increasing the volume of the cockpit to accommodate for increased suit volume and relocating emergency controls closer to the pilot to compensate for his reduced reach capability are diametrically opposed requirements.

If a pressure suit is not properly fitted, mobility, and, therefore, arm and leg reach, are reduced disproportionately. Bulk, of course, is excessive if the garment is too large. It follows that any effort to retrofit or redesign an aircraft cockpit to accommodate a foreign population of significantly different measurements must be systematic. It must deal with all elements of the cockpit, not just those that interface between the cockpit and the pilot.

CONCLUSION

I have presented representative examples of the kinds of problems an American aircraft designer can expect to encounter when he designs a cockpit for selected foreign military populations. I have also discussed

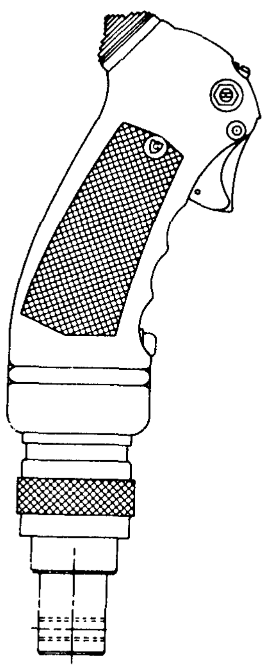

Fig. 6. The USAF MC-2 stick-control grip.

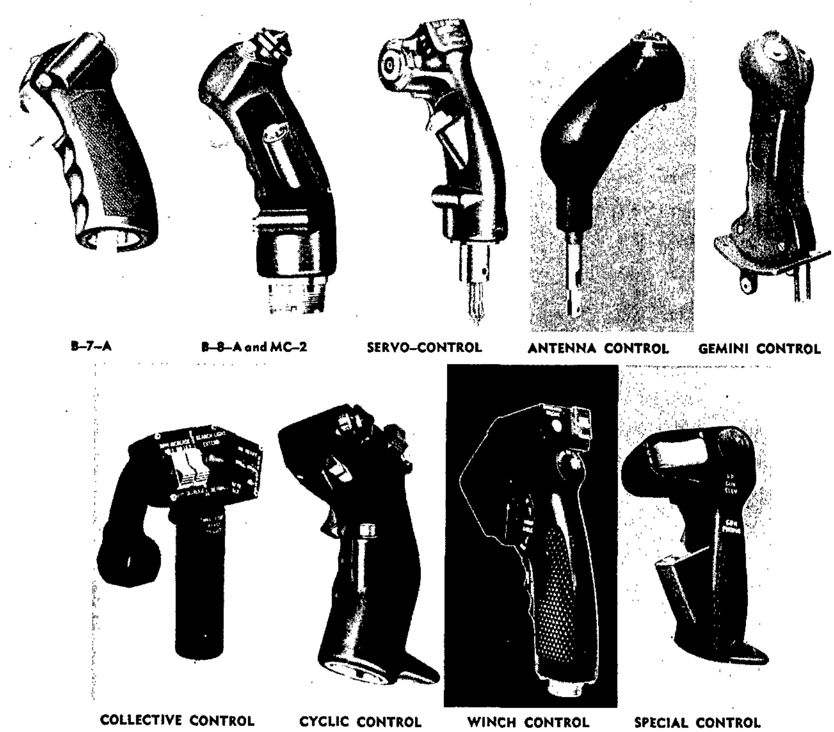

Fig. 7. Some hand-held multiple controllers currently being manufactured by one company.

ways in which some of these problems may be solved. The problems discussed here by no means exhaust those that the designer faces. Others are, unfortunately, difficult to anticipate because anthropometric data are incomplete for most national populations.

The spatial geometry of a cockpit designed for one population can and should be quite different from that designed for another. While this paper has concentrated on military aircraft, much of what has been said applies to civilian aircraft and to a great number of other work places that must fit the human operator, be they in vehicles, shops, or offices. Ideally, a nation should procure aircraft with cockpits specifically designed for its own population. Unfortunately, for reasons of economy, expedience, and performance, to say nothing of ignorance regarding the anthropometric characteristics of one's own national population, aircraft are shipped unaltered across many international borders. This practice usually leads to degradation in the performance of the aircraft as well as that of the pilot. The costs of such degradation in terms of human lives and money fully justify intensive efforts to correct the situation as it exists today.

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