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Applying Human Figure Modeling Tools to the RAH-66 Comanche Crewstation Design

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Abstract

Graphical three-dimensional human figure models are widely used to perform ergonomic assessments of vehicle and aircraft crewstation designs. When physical prototypes do not exist or access to them is limited, human figure models can provide an effective yardstick to evaluate the designs against the specified accommodation requirements. In cases where the design requirement has not been met, it is equally important to determine the extent of any modification needed and to provide design change recommendations.

The accuracy of any analysis that uses human figure modeling tools depends not only on the data and method used to construct the figures but also on the posture of the figures when they are positioned in the crewstation. Clothing and equipment worn by the operator, which has an impact on the posture, must also be taken into consideration.

The U.S. Army Research Laboratory (ARL) recently performed a detailed ergonomic analysis of the RAH-66 Comanche crewstations using human figure modeling tools. The details of the methodology used in applying these tools are summarized in this paper.

Background

In the early 1980's, the U.S. Army initiated a program known as light helicopter experimental (LHX) to seek a replacement for its fleet of OH-58 Kiowa scouts and AH-1 Cobra light attack helicopters. That LHX designation eventually became the RAH-66 Comanche program in the early 1990's. Figure 2 shows the RAH-66 Comanche prototype.

Figure 2. RAH-66 Comanche Prototype.

The Comanche helicopter is expected to play a key role in the Army's long-term force structure. Former US Army Chief of Staff, General Dennis Reimer, speaking before Congress, referred to Comanche as "the quarterback of the digital battlefield," putting it at the center of the Army's information-age architecture for land warfare because of its capability to rapidly collect and disseminate tactical reconnaissance (Thompson, 1998).

Comanche features a dual in-line crewstation design that can be piloted from either the fore or aft crewstation. The original anthropometric accommodation requirement for these crewstations was bracketed around the central 90% of the U.S. Army male soldier population, including all mission-essential combat gear and protective clothing ensembles for the pilot and copilot.

In 1993, the U.S. Army changed its policy about women aviators and permitted them to fly combat missions. This policy change resulted in new opportunities for women to qualify in previously male-only aircraft such as the AH-64 Apache, AH-1 Cobra, OH-58D Kiowa and RAH-66 Comanche. As a consequence, the Comanche crewstation requirements also changed from accommodating only a male soldier population to the current requirement of accommodating the central 90% of equally weighted population of Army male and female soldiers.

Problem

The accommodation requirement change occurred after the initial design of the crewstations had been completed. At the same time, new aviation life support equipment (ALSE) items were also entering the inventory. This change in equipment, along with the requirement change, meant that Army aviators at the large and small ends of the population could not be accommodated in the current Comanche crewstation design. Smaller aviators could not reach all critical flight controls and achieve the required over the nose field of view (FOV). Figure 3 shows an example of a reach shortfall problem for small aviators with a locked seat harness.

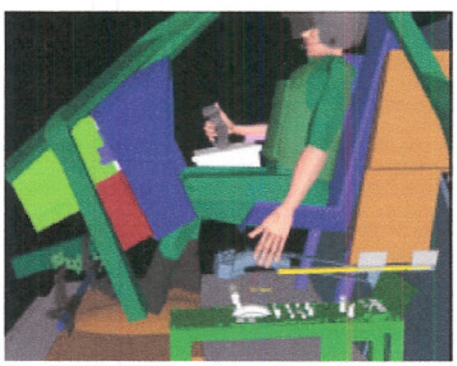

Figure 3. Small female unable to reach the engine control levers (ECLs) located on the Side Console.

Aviators at the larger end of the population no longer had sufficient knee clearance because of the added bulk of new ALSE items. The accommodation problem for large aviators is depicted in Figure 4.

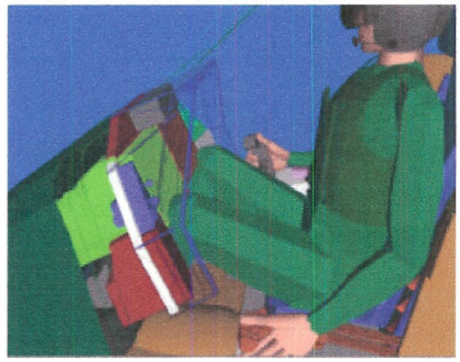

Figure 4. Large Male With Insufficient Knee Clearance to Lower Section of the Instrument Panel.

Goal

In order to meet the new crewstation requirement, the extent of specific modifications to crewstation components had to be determined. Also, in order to accommodate the larger aviators, a determination had to be made as to whether the outer mold line (OML) of the fuselage would have to be expanded to provide the additional space required.

Methodology

To date, two Comanche prototypes, known as aircraft #1 and aircraft #2, have been built for flight testing purposes. However, the availability of these aircraft for use in performing an ergonomic analysis of the crewstations was extremely limited because of the testing schedule. Also, availability of a sufficient number of pilots that would be representative of the target population was difficult to assemble and synchronize with the availability of the prototype aircraft.

For these reasons, human figure modeling was considered a logical tool for the evaluation of the crewstation design and as a means of determining the extent of the design modifications needed to meet the accommodation requirement. Additionally, design changes could be easily tested by modifying the crewstation computer aided design (CAD) files, whereas design changes to the prototypes would be much more difficult to implement and test.

Transom Jack version 2.0 software was selected as the human figure modeling system to represent the U.S. Army helicopter aircrew. The Transom Jack software is an interactive tool for modeling, manipulating, and analyzing human and other 3D articulated geometric figures (Badler, Phillips, & Webber, 1993).

However, because control and adjustment mechanisms inside a helicopter cockpit must accommodate many critical body dimensions simultaneously (e.g., sitting height, leg and arm segment lengths), a univariate percentile approach could not be used to size the human figure models for the design evaluation. Uniformly large and small models, such as 5th and 95th percentile figures, do not necessarily describe the analyst's worst case scenario. Instead, combinations of extremely large and extremely small values in the same subject may be critical to the design evaluation (Roebuck, Kroemer, & Thompson, 1975; Bittner et al., 1987; Hendy, 1990; Zehner, Meindl, & Hudson, 1992). For this reason, a multivariate statistical method was used to generate the boundary forms representing the target population. These boundary forms represent "worst case" extremes of body size and body proportions that must be accommodated in order to capture the desired percentage of users.

The U.S. Army Natick Soldier Center supplied the data set used to generate the boundary forms that were used to construct the human figure models for this analysis, using the Principal Components Analysis (PCA) method. Some human figure boundary models are shown in Figure 5.

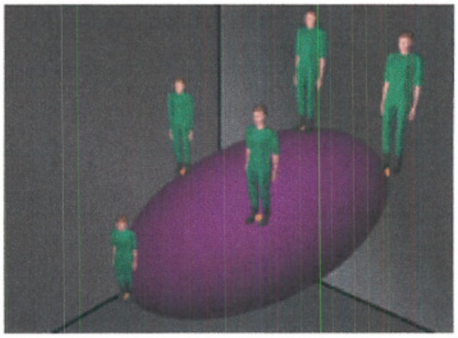

Figure 5. Boundary Models on the Surface of the Ellipsoid Representing an Accommodation Envelope.

PCA reduces the dimensionality of the accommodation envelope from n-space (where n is the number of body dimensions that are critical for the design accommodation) to a smaller number of dimensions that account for a large proportion of the original variation by using linear combinations of the original measurements. Further, PCA identifies important "large-small" body dimension combinations when they are important in the covariance structure, and the method generally creates one or more principal components that actually measure such extremes of shape.

Table 1 illustrates a PCA conducted on seven critical cockpit design variables: seated acromion height, biacromial breadth, buttock-knee length, seated eye height, popliteal height, sitting height, and thumbtip reach. The analysis was conducted on U.S. Army females measured in the 1988 ANSUR Survey (Gordon et al., 1989), with subjects weighted to match contemporary Army age and race distributions. A similar PCA was conducted on U.S. Army males, with similar results. All analyses were conducted using Stata 6.0 statistical software (Stata Corp, 1999).

Table 1. Principal Components Analysis of US Army Females (n=3470)

PC	1	2	3
Eigenvalue	3.92030	1.72986	0.68351
Difference	2.19040	1.04635	0.36998
Proportion	0.56000	0.24710	0.09760
Cumulative	0.56000	0.80720	0.90480

Design Variable	PC 1	PC 2	PC 3
ACRHTST	0.38207	-0.42619	-0.19959
BCRMBDTH	0.30255	0.20036	0.91033
BUTTKLTH	0.35517	0.40740	-0.19645
EYEHTSIT	0.42136	-0.39206	0.02965
POPHGHT	0.37169	0.36640	-0.24438
SITTHGHT	0.42038	-0.39885	0.03717
THMBTPR	0.37937	0.40644	-0.17575

As can be seen in Table 1, the first three PC's together account for 90.5% of the variation present in the original seven variables. PC1, which captures 56% of the original variation, describes overall body size: the largest values of PC1 occur when all body dimensions are large. PC2, which accounts for an additional 24.7% of the original variation, contrasts limb lengths with torso height: the largest values of PC2 occur when a soldier has long limbs and a short torso. PC3, which accounts for an additional 9.8% of the original variation, primarily describes variation in shoulder breadth and contrasts it with arm/leg lengths and shoulder height. The largest values of PC3 occur when a soldier has broad shoulders and a relatively short trunk and limbs.

Once the PCA is completed, database subjects are scored on the new composite variables (PC's), which now describe the most important components of variation in both size and shape. Subject PC scores are plotted in 3-D PC space (see Figure 6), and an ellipsoid capturing a specified percentage of subjects is fit to their distribution. The surface of the ellipsoid represents the accommodation envelope associated with the percentage of subjects chosen. Twenty-six boundary forms on the surface of the ellipsoid at major axis intersections and midpoints between intersections can then be used to represent extremes of size and shape present in a certain percentage of users for the original *n* body dimensions considered simultaneously.

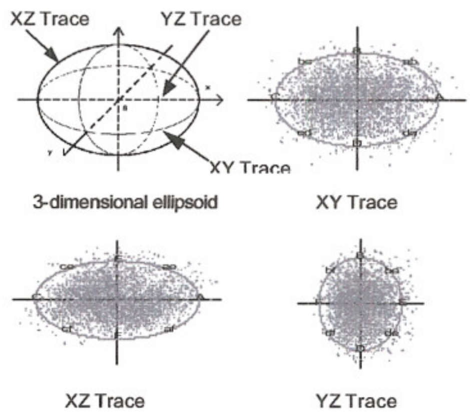

Figure 6. A 90% Ellipsoid Capturing Variation in Three Principal Components.

In addition to the data used to construct the human figure models, a second key element in the analysis was the determination of an accurate seated posture. The Comanche, unlike previous Army helicopters, does not use a center cyclic control for flight operation. Instead a side arm controller (SAC), incorporating the functionality of a center cyclic, is operated by the aviator on the right side of the crewstation. Aviators flying helicopters equipped with a center cyclic tend to maintain a posture in which they lean forward and steady the lower arm on top of the thigh. On the other hand, SAC-equipped cockpits do not require the aviator to rest the arm on the thigh and as a result, aviators fly with a posture that is more upright when a SAC is provided.

In order to position the human figures in a posture that more accurately reflected that of actual pilots, posture data were collected. The FARO arm, a portable coordinate measuring machine (CMM), was used to digitize body landmarks and scan body limb positions of eight pilots seated in the fore and aft crewstations of aircraft #1. Use of a FARO arm to collect posture data is shown in Figure 7.

Figure 7. Collecting Aviator Posture Data with FARO Arms.

The data points collected on the subjects were imported into the Comanche CAD model and were analyzed to determine the relationship of the subject's hips to the seat reference point (SRP) and the eyes to the design eye point (DEP) (Roebuck, 1995). These relationships in turn, formed the basis for establishing the slump of the human figure model's hips and head, which was used to position them in the seat.

The third element of the analysis involved consideration of the impact of ALSE items on crewstation accommodation. Frequently, analyses using human figure models are performed with unclothed body models. While clothing bulk and encumbrances are disregarded for some types of workplace analyses, they are an important factor in many other applications such as an aircraft crewstation where space is at a premium. Recent advances in aircraft operational demands and capabilities have necessitated additional protective equipment. In addition to the traditional flight gear and life support equipment for altitude, acceleration, and hearing protection, aircrews are now being laden with systems for nuclear, biological, and chemical (NBC) warfare, enhanced acceleration protection, passive anti-drown capability, helmet-mounted electro optical devices, and laser/flash blindness protection (Wright, Hanson, & Couch, 1996). Included among the inventory of ALSE clothing and equipment are NBC protective suits, ballistic armor, micro-climate cooling vests, cold weather gloves and outer garments, as well as equipment packs or harnesses that are worn on the chest, back, or hips. Some of the ALSE items impact not only the aviator's range of motion or FOV, but also the posture they would assume. For example, during over-water missions, one of the ALSE items included is an inflatable raft pack that is placed between the seatback cushion and the lower back of the aviator. This raft pack forces the hips of the aviator forward in the seat by about 50 mm, and consideration of this impact is essential when one is examining crewstation accommodation. An Army pilot wearing over-water mission equipment is shown in Figure 8.

Figure 8. Army Pilot Seated in the Comanche Wearing an Over-Water Mission Ensemble.

The problem is how to model the increased bulk attributed to the clothing and equipment. A fairly simple method for representing clothing bulk is to expand the human figure body segments uniformly by some dimension. The expanded body segment method is shown in Figure 9.

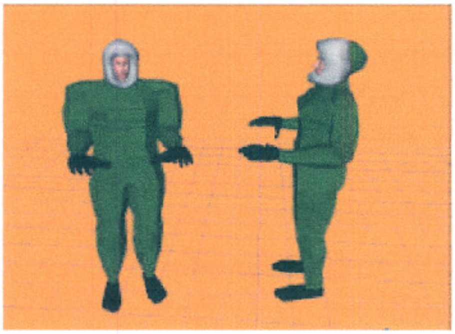

Figure 9. Human Figure with Cold Weather Clothing, Constructed Using the Expanded Segment Method.

However, a drawback to this method is that it usually leads to an exaggerated looking figure with dimensions that are out of proportion in some areas of the body. In actuality though, the clothing bulk thickness is not uniformly distributed over the entire body such as the lower torso when the figure is in a seated posture. This incorrect addition of segment thickness to the lower portion of the upper leg and lower torso segments, for example, can lead to positioning of the human figure that would be slightly higher and more forward in the seat than would actually be the case. This of course would depend on the amount of uniform expansion to the body segments.

The approach used for the Comanche crewstation analysis was to digitize the actual ALSE items and place them on the human figure model. Several key features were given consideration in the development of the clothing and equipment models. Foremost among these features was the ability to place the clothing models on the human figure and still be able to move and manipulate the limbs and torso without overburdening computer processing and graphics resources. Second, clothing models should represent the correct thickness and bulk over the entire body for the posture analyzed. Third, the clothing and equipment should be scalable in order to develop models that fit a wide range of human figure body types and sizes. A collection of 20 ALSE clothing and equipment items was made available for this analysis. These items were used to develop the 3D clothing and equipment models:

- Arctic coat with liner and hood
- Survival armor recovery vest including packets (SARVIP)
- Aircrew integrated recovery survival armor vest & equipment (AIRSAVE)
- Extraction harness
- Equipment belt
- Life preserver unit (LPU-34P) with low profile collar
- Combat boots
- 9-mm Beretta pistol
- Shoulder holster for pistol
- Aviator battle dress uniform (BDU) coat
- Aviator BDU trousers

- Standard flight suit overalls
- Mustang over water suit
- Armor plate (ceramic)
- Mission-oriented protective posture (MOPP) IV NBC protective suit
- Life raft with container bag
- Blower motor and filter for mask
- Helicopter emergency egress device (HEED) regulator bottle
- Clipboard (thigh mounted)
- Water container

The U.S. Army Aviation RDEC, Ames Research Center, California, provided two additional modeled components. These models included the M-43 protective masks and HGU-56/P flight helmets.

Viewpoint DataLabs (Orem, Utah) was contracted to perform the 3-D digitization of each item to create models that consisted of 3,000 to 5,000 polygons. Clothing items were fitted to a human figure model provided by ARL to Viewpoint. The clothing models were then segmented at the shoulders, elbows, waist, hips, and knees. This procedure allowed for articulated movement of the human figure body segments when fitted with the clothing models. Additionally, this segmenting process allowed the clothing to be scaled to fit other body sizes. Figure 10 shows an example of a human figure with the digitized items.

Figure 10. Digitized ALSE Clothing and Equipment Models Fitted to a Human Figure Model Seated in the Comanche Crewstation.

The use of the digitized ALSE items contributed to a more accurate analysis by helping to portray an aviator-crewstation environment that was closer to actual conditions.

A fourth and final key portion of the analysis was the determination of accommodation criteria for the human figures. That is to say, what set of conditions must be satisfied in order for each model to be considered fully accommodated in each crewstation? The criteria set was defined for Zone 2 conditions, where the pilot is seated with the shoulder harness locked and can only lean forward as much as the locked harness will permit. Ten criteria for the crewstation analysis were developed and agreed upon by ARL, Sikorsky Aircraft, and the Comanche Program Management (PM) office, using Military Standard 1333B (Department of Defense, 1987) as a guideline. The list is as follows:

1) Adjust seat in the Comanche crewstation CAD model to position the seated figure's eye at the established design eye line (DEL) so that the figure can obtain the required 18 degrees over the nose FOV.

2) Maintain at least 38 mm clearance between the figure's body limb segments and the crewstation structure, panels, displays and controls.

3) Provide at least 250 mm circular clearance between a location on the face defined as the midpoint of the biocular breadth measurement of the head and the surrounding canopy frame structure.

4) Position the figure's legs, so that the ball of the foot can be placed on the

center of each brake pedal and the heel can be rested on the floor.

5) Ensure that the figure can reach the SAC grip and operate through the full functional range and be able to steady the lower arm segment on the armrest while maintaining an elbow angle greater than 90 degrees.

6) Reach the collective and operate it through the full functional range while maintaining sufficient clearance between the left arm and rear bulkhead.

7) Reach and operate all flight-critical instrument panel controls and displays, defined to be operated under Zone 2 reach conditions.

8) Reach and operate with the left hand, the ECLs and other flight critical controls on the side console and defined as Zone 2 operational controls.

9) View all instrument panel controls and displays without any visual obstructions.

10) View all side console controls under Zone 2 locked harness conditions without any visual obstructions.

Each figure tested had to successfully meet all criteria simultaneously. Failure to meet one or more of the criteria, meant that the figure could not be considered fully accommodated and therefore, the accommodation requirement was not satisfied.

Results

The human figure modeling analysis led to the generation of seven specific design modifications to the crewstation components. More importantly though, it was also determined that these modifications could be accomplished without having to increase the outer mold line of the front fuselage. A modification of this magnitude would have required a major redesign of the aircraft that would have added a burdensome cost to the Comanche program.

Perhaps the most significant alteration was the recommendation to change the seat design. The current single axis seat travels up and down on a 15-degree slope. Smaller pilots, in order to sit at the DEL, would have to adjust the seat higher and in return, the seat position would also be slightly more aft from the neutral seat position (NSP) at this location because of the sloped travel. This seat position placed these pilots farther away from the brake pedals and the controls on the instrument panel and side console. Larger pilots, on the other hand, would need to adjust the seat close to the bottom in order to sit at the DEL. This position also placed the seat slightly more forward than at the NSP. This position impinged on the limited clearance between the pilot's legs and the instrument panel. A dual-axis seat that would have fore and aft adjustment in addition to the vertical travel was recommended. This type of seat would allow adjustment of the seat forward to bring the pilots closer to the brake pedals and controls on the instrument panel and side console while still allowing them to sit at the DEL. The larger pilots would be able to adjust the seatback to obtain the required leg clearance and sit at the DEL. A problem was encountered with the recommended change for the aft seat travel needed to accommodate the larger pilots wearing the raft pack for over-water missions. The full amount of the recommended aft adjustment could not quite be implemented. To reduce the amount of aft travel being suggested, the Comanche PM office decided to incorporate the raft pack into the seatback cushion.

Even with the forward seat adjustment, some of the smaller figures tested still had problems reaching controls on the side console. A recommendation was made to raise the height of the side console in order bring the controls within reach.

Raising the side console to the recommended height also proved to be difficult to fully implement. This left some of the tested figures unable to reach and operate the ECLs on the side console. The ECLs were then placed at a position farther aft on the side console within operational reach.

The brake pedals could not be reached by some of the smaller figures, despite having forward seat adjustment. Since additional forward seat adjustment could not be executed, additional aft adjustment of the brake pedals was required.

Adding the extra brake pedal adjustment allowed the figures to reach the pedals, although not all figures could reach the pedals and rest their boot heel on the floor. To remedy this problem, an increase in the height of the heel rests was recommended. However, this increase in heel rest height proved to be a hindrance to the larger figures by raising the knees and limiting the required clearance to the lower section of the instrument panel. It was therefore recommended that the heel rest be adjustable in some fashion. This adjustability would provide the needed heel support to the smaller pilots and yet not interfere with the larger pilots.

As mentioned earlier, pilots who fly helicopters with a center cyclic control find it necessary to steady the forearm on top of the thigh. The Comanche pilots, on the other hand, steady the right arm on the SAC armrest during flight. Some of the figures with long torso and short limb length combinations were unable to rest the right arm on the SAC arm rest without having to lean laterally to the right. An increased vertical adjustment of the armrest was recommended to alleviate this problem.

The last design change recommendation concerned the ability to operate the collective control to the left of the seat. Some of the smaller figures could not reach the collective when it was in the full down position. A dual range collective solution was suggested as a means of solving this problem. This meant that the full down position for the collective control could be rotated to a higher position that could be grasped by the smaller pilots but would still have the same operational range of motion.

With these design changes made to the crewstation CAD model, the boundary figure set, was tested and accomplished all criteria defined to meet the accommodation requirement.

Conclusions

The use of human figure modeling tools to simulate and analyze interactions between pilots and the crewstation environment can be especially useful when one is examining accommodation requirements and whether any design changes would be necessary to meet them. This applies, not only to brand new designs, but even more so to existing designs where modifications are more difficult to implement. As was the case in this analytical effort, an initial design change recommendation could not always be fully implemented or implemented at all in some instances. This required an iterative process of evaluating and testing many different design options before settling on the best solution. For example, weight is a critical issue in aircraft design and although physical space may have been available to implement the design change, the additional weight required to make the change would have exceeded the limit. In other instances, a design change was proposed to solve a reach shortfall problem, but the solution would have interfered with crewstation egress or ingress. Still, in other cases, the change would have been too costly to implement. Human figure modeling analysis provides an effective means to examine and test design options that would otherwise be difficult to perform by modifying a physical prototype. For this analysis, the human figure modeling provided a method to identify the crewstation design modifications that would meet the accommodation requirement without having to make an expensive change to the OML.

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