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ANTHROPOMETRIC CONSIDERATIONS FOR A FOUR-AXIS SIDE-ARM FLIGHT CONTROLLER

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INTRODUCTION

This investigation is the first in a series of studies to generate a data base on multiaxis side-arm flight controls. The rapid advances in fly-by-light technology, automatic stability systems, and onboard computers have combined to create flexible flight control systems which could reduce the workload imposed on the operator by complex new equipment. This side-arm flight controller combines four controls into one unit and should simplify the pilot's task. However, the use of a multiaxis side-arm flight controller without complete cockpit integration may tend to increase the pilot's workload.

Background

One of the purposes of developing a multiaxis side-arm flight controller is to eliminate the three flight controls (cyclic stick, collective lever, and yaw pedals) required to control a helicopter and combine their functions into a single control. The new flight controller should reduce the piloting task by freeing the pilot's left hand for other tasks.

Fly-by-light technology is being developed through a combined effort of the Army's Aeromechanics Laboratory and Boeing Aircraft Corporation and through the advanced digital/optical control system (ADOCS) program. This technology uses encoded signals which are transmitted over fiber optic cables. The main purpose of the ADOCS program is to demonstrate that an Army helicopter can be flown with a multiaxis side-arm controller and fly-by-light technology. The impact on the pilot's workload has not been addressed.

Because of rapid technological advances in flight controls, there is not yet a data base for crew station designers and evaluators to work with. We believe that many positive benefits may be realized through the use of the multiaxis side-arm flight controller in Army aircraft. The controller will have a strong influence on aircrew station design. There will be more flexibility in seating posture and airframe design, and fabrication will be simplified. A greater range of male and female personnel may be able to fly; and control inputs can be "tuned" to each pilot, airframe, aircraft, flight phase, and mission phase for optimum effectiveness.

Two possible drawbacks to this new technology are that the piloting task may be increased and current operational capabilities may not be fully realized. The standard cyclic and collective control heads contain a significant number of switches which are used to operate various subsystems onboard the helicopter; the ADOCS programs have not addressed the issue of where to locate these switches if a single flight controller is used.

In addition, normal mission and piloting tasks have not been imposed on the simulation studies.

The U.S. Army Human Engineering Laboratory (HEL), through the use of its simulation and computational facilities, has designed a series of investigations to develop the data base and to determine if the side-arm flight control concept is operationally beneficial.

In a following investigation, pilots will fly the HEL simulator with the controller adjusted either orthogonal to the airframe or for the comfort of the pilot. If it can be shown that a position based on comfort is suitable, fatigue may be reduced and the piloting task simplified.

OBJECTIVES

The main objectives of this investigation were to: (a) determine the physical location of the multiaxis side-arm flight controller and armrest which is the most comfortable in a static situation and (b) determine the effects of CB protective gear on those location parameters.

METHOD

Description of Multiaxis Controller

Figure 1 shows the multiaxis controller used during this investigation. It is a small deflection force controller with characteristics as shown in Table 1. The design is not based on any specific Army requirement and was purchased off the shelf.

Figure 2 shows the test setup. Both the armrest and multiaxis controller could be adjusted in rotation and position with respect to each other and with respect to the seat reference point (SRP) as defined by MIL-STD-1333. A nonform-fitting armrest provided consistency within the investigation by not forcing the forearm into a particular position.

Figure 3 shows a pilot in partial mission-oriented protection posture (MOPP). The pilots were fully covered except for their faces. Masks were carried to their left side.

Subjects

Seventy nonpilots and seven Army helicopter pilots were picked from available personnel. Ten percent of the subjects were left-handed and twenty-three percent were female. Included in the subject sample were military personnel assigned to the HEL. All pilots were male. Anthropometric measurements indicate that the subjects were representative of the population as a whole. All subjects were cooperative and did not appear to introduce any artifacts into the data.

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Figure 1. Multiaxis controller.

TABLE 1

CONTROLLER CHARACTERISTICS

MODEL 404-G717 MEASUREMENT SYSTEMS, INC			
PARAMETER	X & Y AXES	Z AXIS	TORQUE AROUND Z
FORCE OVER LINEAR RANGE	+/- 20 lbs	+/- 40 lbs	+/- 60 in-lb
MAXIMUM ALLOWED FORCE	+/- 160 lbs	+/- 528 lbs	+/- 1056 in-lb
SENSITIVITY +/-10%	0.5 volts/lb.	0.25 volts/lb.	0.17 volts/in-lb
DEFLECTION AT MAX OPERATING FORCE	+/- 0.4 in	+/- 0.1 in	+/- 4.0 degs/in-lb

Figure 2. Test setup.

Figure 3. Pilot in partial MOPP gear.

Procedure

The investigation was conducted in two phases which separated the pilot personnel from the nonpilot personnel. We anticipated that data generated from pilots would be influenced by flight experience and any experience with side-arm tracking controls which would have biased the perception of comfort.

The purpose of the investigation was explained and a series of anthropometric upper body measurements were taken of each subject. The subjects then sat in an AH-64 helicopter seat mock-up with the adjustable controller and armrest at their immediate right side. The subjects were told to sit squarely with their backs in contact with the back of the seat. They were then asked to relax but not to slouch forward. If the seated subjects lowered their right shoulder as if to anticipate contact with the armrest, they were asked to reassume a squared position. The experimenter adjusted the controller and armrest to where the subjects felt them to be comfortable. Once each subject was satisfied with the position of the controller and armrest, a film record was taken of the subject holding the control. Pilots would then wear MOPP and a second film record was taken.

The film record was obtained through the use of three orthogonal data cameras located at the subject's right side, top, and front. The cameras were started simultaneously and ran for approximately 3 seconds. Film records were read on a film analyzer and individual point coordinates were fed directly to the computer, where the data were reduced and analyzed.

RESULTS

Tables 2 through 9 summarize the data obtained in this investigation. Angular data are presented in degrees, while position data are presented in centimeters and referenced to the seat reference point (SRP). Figures 4 through 7 display the sign convention for measurements.

The statistical program used to generate the results was SAS, a statistical and data handling package from SAS Institute, Incorporated. The distributions presented in the summary tables were generated by the SAS univariate program, and the Q_1 and Q_3 values are the first and third quantiles using definition 4. For small sample sizes, the maximum and minimum values replace the quantiles. Selected individual comparisons were accomplished by _t_ test using a pooled variance and assuming a normal distribution.

$$T = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\dfrac{\sum X_1^2 + \sum X_2^2}{N_1 + N_2 - 2}\left(\dfrac{N_1 + N_2}{N_1 * N_2}\right)}}$$

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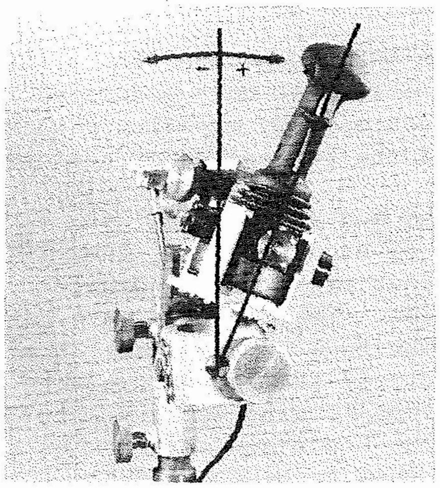

Figure 4. Angular conventions as viewed form the front.

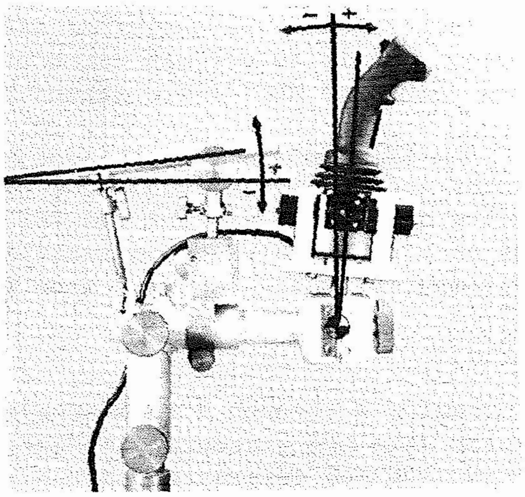

Figure 5. Angular conventions as viewed from the right side.

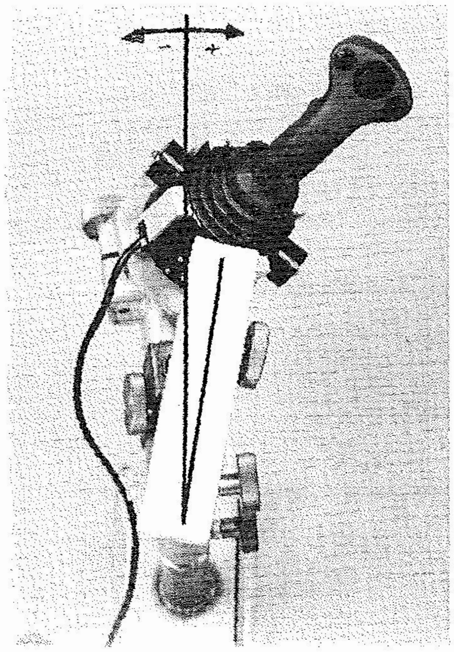

Figure 6. Angular conventions as viewed from the top.

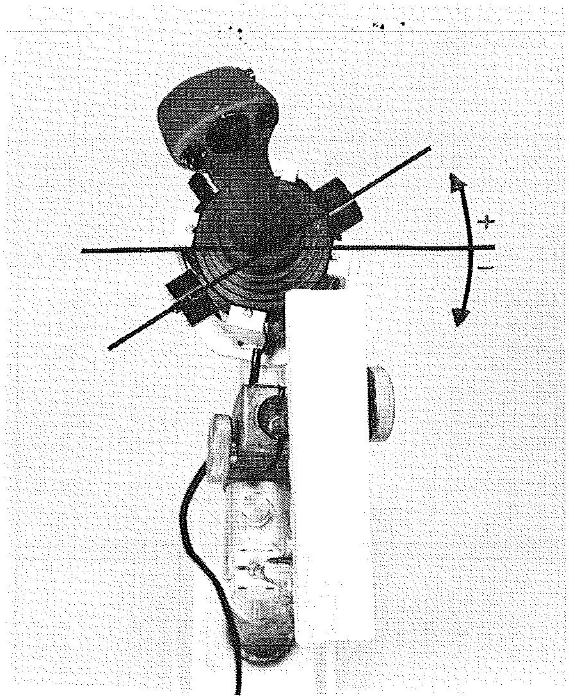

Figure 7. Controller rotation convention as viewed from the top.

Figure 8. Hand attack angle showing a typical 10 deg. offset from the controller rotation.

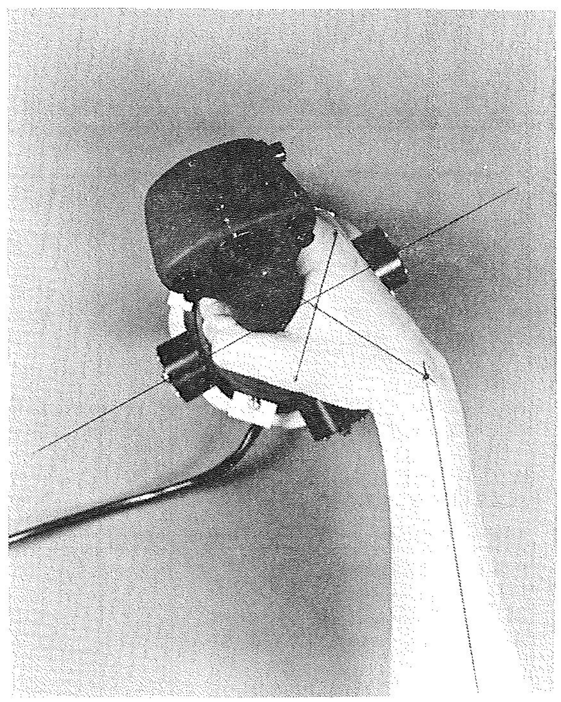

TABLE 2

CONTROLLER ROTATION
(degrees)

	N	MIN	5%	Q1	MEAN	Q3	95%	MAX
NONPILOT PERSONNEL								
ALL	70	-23.6	-15.4	-4.0	4.4	11.4	30.0	38.4
ALL MALE	52	-23.6	-15.8	-3.1	5.8	14.4	31.9	38.4
ALL MALE RIGHT-HANDED	46	-23.6	-15.9	-4.0	4.9	13.9	30.8	38.4
ALL MALE LEFT-HANDED	6	0.8	0.8	0.8	12.8	24.5	31.9	31.9
ALL FEMALE	18	-15.1	-15.1	-5.2	0.1	7.7	11.7	11.7
ALL FEMALE RIGHT-HANDED	16	-15.1	-15.1	-5.6	-0.1	7.2	11.7	11.7
ALL FEMALE LEFT-HANDED	2	-4.7	-4.7	-4.7	2.2	9.0	9.0	9.0
ALL RIGHT-HANDED	62	-23.6	-15.6	-4.3	3.6	11.4	27.8	38.4
ALL LEFT-HANDED	8	-4.7	-4.7	0.8	10.1	19.4	31.9	31.9
PILOT PERSONNEL								
ALL NOT WEARING CB GEAR	7	-15.8	-15.8	-2.3	0.2	6.7	7.7	7.7
ALL WHILE WEARING CB GEAR	7	-6.6	-6.6	-6.4	0.8	6.7	6.8	6.8

When viewed from the top a counterclockwise rotation is positive.

TABLE 3

CONTROLLER ANGLE FORE/AFT
(degrees)

	N	MIN	5%	Q1	MEAN	Q3	95%	MAX
NONPILOT PERSONNEL								
ALL	70	-11.9	-3.3	3.6	8.6	13.8	24.2	30.0
ALL MALE	52	-3.2	-2.3	4.1	10.0	16.1	16.1	30.0
ALL MALE RIGHT-HANDED	46	-2.6	-1.7	4.1	10.8	17.9	27.8	30.0
ALL MALE LEFT-HANDED	6	-3.2	-3.2	-0.7	4.0	7.6	8.6	8.6
ALL FEMALE	18	-11.9	-11.9	1.7	4.5	9.3	16.7	16.7
ALL FEMALE RIGHT-HANDED	16	-11.9	-11.9	1.3	4.6	9.5	16.7	16.7
ALL FEMALE LEFT-HANDED	2	2.1	2.1	2.1	4.1	6.2	6.2	6.2
ALL RIGHT-HANDED	62	-11.9	-3.3	3.8	9.2	15.0	25.2	30.0
ALL LEFT-HANDED	8	-3.2	-3.2	-3.2	4.0	7.6	8.6	8.6
PILOT PERSONNEL								
ALL NOT WEARING CB GEAR	7	-3.3	-3.3	-0.6	8.1	19.5	22.7	22.7
ALL WHILE WEARING CB GEAR	7	2.6	2.6	3.6	11.1	20.1	21.4	21.4

When viewed from the right side, a clock-wise rotation is positive.

TABLE 4

CONTROLLER ANGLE LEFT/RIGHT
(degrees)

	N	MIN	5%	Q1	MEAN	Q3	95%	MAX
NONPILOT PERSONNEL								
ALL	70	-1.9	2.9	9.9	16.6	24.0	35.6	39.6
ALL MALE	52	-1.9	2.9	9.8	15.7	20.6	38.3	39.6
ALL MALE RIGHT-HANDED	46	-1.9	2.7	7.8	15.2	19.7	35.4	39.6
ALL MALE LEFT-HANDED	6	9.7	9.7	10.0	19.5	28.3	38.8	38.8
ALL FEMALE	18	0.1	0.1	13.3	19.2	26.4	33.5	33.5
ALL FEMALE RIGHT-HANDED	16	0.1	0.1	14.8	19.2	25.5	30.2	30.2
ALL FEMALE LEFT-HANDED	2	5.7	5.7	5.7	19.6	33.5	33.5	33.5
ALL RIGHT-HANDED	62	-1.9	2.5	9.6	16.2	23.7	30.3	39.6
ALL LEFT-HANDED	8	5.7	5.7	9.8	19.5	31.3	38.8	38.8
PILOT PERSONNEL								
ALL NOT WEARING CB GEAR	7	-7.2	-7.2	2.3	6.2	0.7	25.7	25.7
ALL WHILE WEARING CB GEAR	7	-8.2	-8.2	-8.0	4.2	12.3	18.3	18.3

When viewed from the front, a clockwise rotation is positive.

TABLE 5

CONTROLLER POSITION FORWARD OF SRP
(centimeters)

	N	MIN	5%	Q1	MEAN	Q3	95%	MAX
NONPILOT PERSONNEL								
ALL	70	33.2	35.4	39.8	42.8	46.1	51.3	55.8
ALL MALE	52	33.2	34.1	39.6	43.3	46.7	52.3	55.8
ALL MALE RIGHT-HANDED	46	33.2	33.8	40.3	43.8	46.9	52.6	55.8
ALL MALE LEFT-HANDED	6	37.2	37.2	37.8	40.2	42.1	42.3	42.3
ALL FEMALE	18	36.1	36.1	39.5	41.3	42.9	47.9	47.9
ALL FEMALE RIGHT-HANDED	16	36.1	36.1	39.9	41.5	43.1	47.9	47.9
ALL FEMALE LEFT-HANDED	2	38.4	38.4	38.4	40.4	42.3	42.3	42.3
ALL RIGHT-HANDED	62	33.2	34.7	40.1	43.2	46.5	51.8	55.8
ALL LEFT-HANDED	8	37.2	37.2	38.1	40.2	42.2	42.3	42.3
PILOT PERSONNEL								
ALL NOT WEARING CB GEAR	7	35.1	35.1	35.5	40.1	44.8	48.1	48.1
ALL WHILE WEARING CB GEAR	7	39.4	39.4	39.8	42.6	46.4	48.1	48.1

When viewed from the right side, a position to the right of the SRP is positive.

TABLE 6

CONTROLLER POSITION ABOVE THE SRP
(centimeters)

	N	MIN	5%	Q1	MEAN	Q3	95%	MAX
NONPILOT PERSONNEL								
ALL	70	20.1	26.0	30.8	32.6	35.0	37.4	38.1
ALL MALE	52	20.1	24.9	30.3	32.1	34.5	37.3	38.1
ALL MALE RIGHT-HANDED	46	20.1	24.2	30.1	31.9	34.0	37.4	38.1
ALL MALE LEFT-HANDED	6	30.6	30.6	30.8	33.3	35.0	35.6	35.6
ALL FEMALE	18	29.8	29.8	32.2	33.9	35.8	38.1	38.1
ALL FEMALE RIGHT-HANDED	16	29.8	29.8	32.4	34.0	36.0	38.1	38.1
ALL FEMALE LEFT-HANDED	2	30.5	30.5	30.5	32.9	35.4	35.4	35.4
ALL RIGHT-HANDED	62	20.1	25.6	30.8	32.5	35.0	37.5	38.1
ALL LEFT-HANDED	8	30.5	30.5	30.7	33.2	35.2	35.6	35.6
PILOT PERSONNEL								
ALL NOT WEARING CB GEAR	7	26.3	26.3	27.8	29.7	32.3	32.3	32.3
ALL WHILE WEARING CB GEAR	7	28.7	28.7	29.3	31.0	33.0	34.1	34.1

When viewed from the right side, a position above the SRP is positive.

TABLE 7

ARMREST ANGLE UPWARD
(degrees)

	N	MIN	5%	Q1	MEAN	Q3	95%	MAX
NONPILOT PERSONNEL								
ALL	70	-3.7	0.4	3.9	7.5	11.2	15.8	16.5
ALL MALE	52	-3.7	0.9	3.9	7.6	11.5	15.7	16.5
ALL MALE RIGHT-HANDED	46	0.5	1.3	4.2	7.7	11.6	15.9	16.5
ALL MALE LEFT-HANDED	6	-3.7	-3.7	1.9	6.3	10.5	11.7	11.7
ALL FEMALE	18	0.1	0.1	3.9	7.5	10.2	16.3	16.3
ALL FEMALE RIGHT-HANDED	16	0.2	0.2	4.3	8.1	10.8	16.3	16.3
ALL FEMALE LEFT-HANDED	2	0.1	0.1	0.1	2.4	4.8	4.8	4.8
ALL RIGHT-HANDED	62	0.2	1.2	4.3	7.8	11.5	16.0	16.5
ALL LEFT-HANDED	8	-3.7	-3.7	1.0	5.3	9.7	11.7	11.7
PILOT PERSONNEL								
ALL NOT WEARING CB GEAR	7	1.4	1.4	3.5	6.5	12.1	12.7	12.7
ALL WHILE WEARING CB GEAR	7	-1.2	-1.2	-0.2	3.4	7.8	8.6	8.6

When viewed from the right side, a counter-clockwise rotation is positive.

TABLE 8

ARMREST ANGLE OUTBOARD
(degrees)

	N	MIN	5%	Q1	MEAN	Q3	95%	MAX
NONPILOT PERSONNEL								
ALL	70	-17.3	-8.2	-2.5	-1.8	5.4	14.4	18.5
ALL MALE	52	-13.3	-7.9	-1.6	2.7	6.7	15.6	18.5
ALL MALE RIGHT-HANDED	46	-13.1	-8.7	-1.3	3.0	6.9	16.4	18.5
ALL MALE LEFT-HANDED	6	-4.5	-4.5	-3.9	0.6	5.0	7.1	7.1
ALL FEMALE	18	-17.3	-17.3	-4.4	-0.8	3.4	9.4	9.4
ALL FEMALE RIGHT-HANDED	16	-17.3	-17.3	-4.2	-0.4	3.9	9.4	9.4
ALL FEMALE LEFT-HANDED	2	-4.4	-4.4	-4.4	-3.6	-2.7	-2.7	-2.7
ALL RIGHT-HANDED	62	-17.3	-9.2	-2.2	2.1	5.7	14.6	18.5
ALL LEFT-HANDED	8	-4.5	-4.5	-4.2	-0.4	3.7	7.1	7.1
PILOT PERSONNEL								
ALL NOT WEARING CB GEAR	7	-5.1	-5.1	-0.4	0.7	2.6	4.5	4.5
ALL WHILE WEARING CB GEAR	7	-8.6	-8.6	-3.3	1.3	6.7	14.9	14.9

When viewed from the top a clockwise rotation is positive.

TABLE 9

HAND ATTACK ANGLE
(degrees)

	N	MIN	5%	Q1	MEAN	Q3	95%	MAX
NONPILOT PERSONNEL								
ALL	70	-10.5	-5.7	7.6	14.7	22.6	30.5	37.1
ALL MALE	52	-10.5	-7.7	6.5	14.5	23.9	30.8	37.1
ALL MALE RIGHT-HANDED	46	-10.5	-7.9	6.0	14.4	23.7	31.1	37.1
ALL MALE LEFT-HANDED	6	5.9	5.9	7.3	15.0	25.1	28.3	28.3
ALL FEMALE	18	2.2	2.2	12.0	15.1	19.7	27.2	27.2
ALL FEMALE RIGHT-HANDED	16	2.2	2.2	11.2	14.9	19.1	27.2	27.2
ALL FEMALE LEFT-HANDED	2	14.1	14.1	14.1	17.5	20.9	20.9	20.9
ALL RIGHT-HANDED	62	-10.5	-7.0	7.2	14.5	22.6	30.5	37.1
ALL LEFT-HANDED	8	5.9	5.9	8.4	15.7	23.3	28.3	28.3

When viewed from the top a counterclockwise rotation is positive.

DISCUSSION

In general, there are noticeable differences between the means of left- versus right-handed and male versus female personnel.

Controller Rotation (Table 2 and Figure 7)

The rotation data were obtained from the camera located over the subject's head. Cosine corrections were applied to adjust for both the forward and inward cant angles of the controller.

The range of adjustment required by pilot personnel with and without MOPP was within the range required by nonpilot personnel. An adjustment from about 16 degrees clockwise to 32 degrees counterclockwise rotation satisfied 90 percent of the males and females in our sample. Within this range, pilots tended to select a comfort position which was more orthogonal to the airframe axes because they were perhaps influenced by the current grip design and the need to operate switches on the control head itself. The difference between the mean rotational angle selected by males and females was significantly different at the 0.05 level with a t of 1.73 and a df of 68. The difference between left- and right-handed nonpilot personnel was not significant.

The most comfortable position for the hand when grasping the controller was to position the hand with 10 degrees more rotation than the rotation of the grip itself. This is depicted in Figure 8. The difference was greater for left-handed personnel than right-handed personnel while female personnel selected 15 degrees as the most comfortable position.

Fore/Aft Controller Angle (Table 3 and Figure 5)

The range selected by nonpilot males was not sufficient to include the range selected by pilot personnel. No physical differences were noted during data collection other than the flight clothing worn by the aviators. Therefore, the required range should be from 12 degrees rearward cant to 28 degrees forward cant. Within this range, there was a shift in means of almost 7 degrees between left- and right-handed male personnel. The effect of wearing MOPP narrowed the range of comfort selected by personnel without MOPP rather than to significantly shift it. The difference between male right and male left means was statistically significant at the 0.05 level with a t of 1.90 and a df of 50. The difference between the male and female means was also significant at the 0.05 level with a t of 2.43 and a df of 68.

Left/Right Controller Angle (Table 4 and Figure 4)

The range selected by pilots was from 7 degrees outboard to 26 degrees inboard. The range selected by nonpilots was from 0 degrees outboard to 39 degrees inboard. The mean position of 5.2 degrees selected by pilot personnel was not significantly different than the mean position of 15.7 degrees selected by nonpilot male personnel. The 9.5-degree shift toward a more upright position was tested at the 5-percent level using a two-tailed test.

Controller Position (Tables 5 and 6)

The controller position was based on a selected point centrally located within the grip. When personnel grasped the controller, this point remained relatively stable when compared to the angle of the controller within the hand. The range of adjustment was from 38 to 53 centimeters forward and 31 to 38 centimeters above the seat reference point as selected by nonpilot male personnel. The position selected by pilots was between 39 to 48 centimeters forward and 29 to 34 centimeters above the seat reference point.

Armrest Angle (Tables 7 and 8 and Figure 5)

Both the upward and outboard armrest angles selected as being comfortable tended not to follow the upward and outboard angles of the subject's forearm. Personnel seemed to want the armrest adjusted so that the muscular portion of the forearm was the only area in contact with the armrest. The perception of comfort seemed to be influenced by the need to have some flexibility in upper body movement which was observed as subjects shifted their upper torsos and shoulders while selecting a comfortable position. Normally, if one rests one's forearm along the arm of a chair when seated and attempts to shift the body, the arm of the chair restricts the motion of the body. Even though a fully supported forearm is better for control input, it is not always the most comfortable.

CONCLUSIONS

The data suggest that the classical approach of providing a side-arm controller which is orthogonal to the axes of the helicopter is not the most comfortable position. The controller must be significantly angled forward and inboard with a counterclockwise rotation. We realize that controller design has an impact on how a pilot selects a position of comfort and should be looked into with more detail. Of equal importance is that, even though the controller is comfortable to hold, the position may not allow the pilot to control the helicopter without noticeable cross coupling. The concern is, for example, if a control input to pitch forward were made by initiating a motion along the axis of the helicopter, a roll to the left would also occur.

An orthogonal position of the controller to the axes of the helicopter was within the range of comfort selected by the subjects.

MOPP gear did not expand or shift the comfort range selected by the subjects.

Studies are being planned to investigate the effects of controller attitude on simulator flight performance. In addition, the effects of operating switches on the control head will be examined with reference to flight performance.

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