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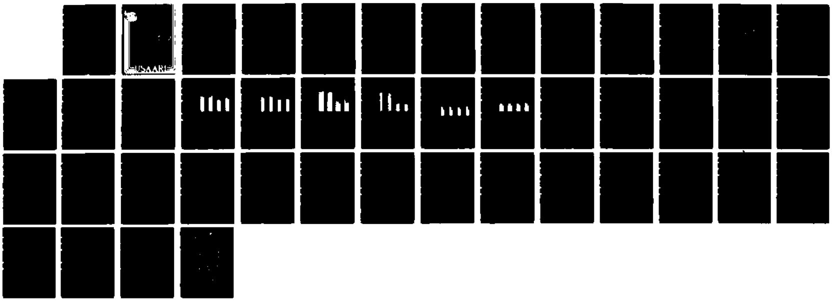

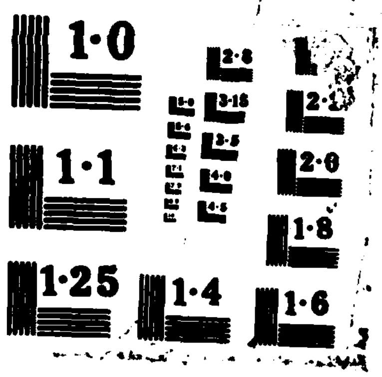
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USAARL Report No. 87- 14

Simultaneous Multiple Control Force Exertion Capabilities of Males and Females versus Helicopter Control Force Design Limits

By
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Biodynamics Research Division

September 1987

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20. ABSTRACT

Military standards and design guidelines do not consider the potential for degradation in the magnitude of force which can be applied by a crewmember or operator as the result of having to perform more than one control input at the same time. In assessing helicopter-control-referenced strength capabilities as a part of an overall program to update medical standards for US Army flying duty, 130 subjects performed maximal voluntary exertions on each of the three primary helicopter controls (cyclic, collective, and pedals). These exertions were undertaken both as separate inputs to single controls and as simultaneously executed inputs to all three controls. The findings revealed substantial and significant force degradation occurred during simultaneously executed exertions (relative to the magnitudes of single control exertions). Cyclic inputs were affected least. The degree of force degradation associated with collective and pedal inputs varied with the particular combinations of direction-of-exertion employed. The resulting "patterns" for force degradation were similar for the collective and pedal with the extent of degradation being larger for the pedal inputs (typically 40-50 percent) than for collective inputs (typically 20-35 percent). Substantial proportions of the subjects (approximately 50 percent of the males and more than 90 percent of the females) were unable to consistently attain design-guide force levels (MIL-H-8501A, 1961) on all three controls during all of the 16 simultaneously executed exertions. There exists a need to consider simultaneously executed force inputs in relevant design guides and standards and the probability of an aviator being confronted with those input requirements.

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Introduction

Overview

This report is one of a series of reports pertaining to a large-scale reexamination of the anthropometric requirements for classes 1, 1A, and 2 flying duty for US Army aviators. These criteria appear in Army Regulation (AR) 40-501, Medical Services Standards of Fitness (Department of the Army 1960), Chapter 4. At present, there are no minimum strength criteria in AR 40-501. The US Army Aeromedical Research Laboratory (USAARL) response (USAARL letter to US Army Medical Research and Development Command (USAMRDC), May 1980) which conveyed the results of the initial anthropometric cockpit compatibility evaluation undertaken by the first author also cited the need for concern regarding minimum physical strength criteria. This concern derived from the following: (a) the provisionally-adopted anthropometric criteria permitted smaller males (1st-2d percentile males versus 5th percentile, previously) and more and smaller females (those in the 20-35th percentile and above versus the 50th percentile and above, previously) to enter the program; (b) size generally is correlated positively with strength; and (c) the upper body strength of females is approximately one-half to two-thirds that of males of comparable stature. In terms of concern for pilots' lives, aircraft costs, and training-related costs, the issue arises as to whether or not newer, smaller entrants into the program physically are capable of handling the aircraft during emergency hydraulic failure conditions. The research reported here describes the findings of a substantial evaluation of gender- and stature-related factors related to helicopter-control-referenced force exertion capabilities of individuals performing maximal exertions on all three of the principal controls simultaneously.

Previous research findings

Research previously reported by the present authors addressed the issue of helicopter-referenced force exertion capabilities of males and females when such exertions were executed on one control at a time (Schopper and Mastroianni 1985). In consonance with other research findings (*e.g.*, Laubach 1976), the forces associated with male exertions exceeded those of female subjects. A comparison of those data with the maximum control force design limits cited in the military specification pertaining to helicopter flying qualities, MIL-H-8501A (Department of Defense 1961), yielded the conclusion that very few of the anticipated population of motivated male or female applicants to the Army's flight school would fail to meet or exceed the design limits. Any that might fail to achieve these levels of force likely would be confined to females performing downward-directed exertions on the collective.

The findings of Schopper and Mastroianni (1985) also were compared to other research undertaken to assess the magnitudes of the forces required during the actual, in-flight execution of simulated emergency "hydraulics-off" approaches and landings (Schopper, Wells, and Kaylor 1985). This comparison showed all male and female force-exertion capabilities demonstrated exceeded actual recorded "in-flight" force demands associated with the right-hand-operated cyclic control and the pedals. Unfortunately, the distribution of collective-related in-flight forces recorded during these simulated emergency conditions overlapped considerably with the distribution of comparable force exertion capabilities of Army females and, to a lesser extent, small males in the Army tested.

It could be that the human body may function as if available physical resources were constrained or operated under a fixed limit at any given moment. If this were the case, then the addition of a requirement to meet additional, simultaneously imposed demands would result in force degradation. Alternatively, it may be that the forces exerted on any given control during an attempt to meet simultaneously imposed demands may be more sensitive to the mechanical advantage or disadvantage which results from being able to use other points of contact (the other controls) to obtain additional leverage. These possibilities are not mutually exclusive. They may coexist; e.g., simultaneously executed force inputs may all suffer some degree of degradation, with the extent of degradation being related to the degree to which a particular combination afforded (or denied) the opportunity to gain additional mechanical leverage.

Method

Subjects

One hundred thirty subjects, 67 males and 63 females, participated in the study. These subjects comprised eight groups determined by specified preselected ranges of stature (Table 1). Six groups represented males and females of comparable stature in the following three ranges: 159-163 cm; 164-167 cm; and 174-177 cm. With the exception of a cell size of 9 in the group of tallest women, the number of subjects in each group ranged from 15-20. As reflected in the preponderance of small individuals, the emphasis was upon the assessment of strength capabilities of personnel whose stature was just above and just below 162.7 cm (64 in), the stature which, prior to 1980, had been the traditional lower limit for entrance into the US Army aviator flight training program.

Two additional groups for which comparably-sized individuals of both sexes were not available also were included in the study: females less than 159 cm (62.5 inches) and males greater than 183 cm (72.0 inches).

Table 1

Stature, mass, and gender-appropriate, stature-related percentile equivalents for groups of male and female subjects

Gender	Stature (cm)	Percentile equivalent	Number of subjects
Female	≤158.9	<28	18
Male	159.0-162.9	2-5	20
Female	159.0-162.9	29-52	19
Male	163.0-166.9	5-12	19
Female	163.0-166.9	52-73	19
Male	174.0-176.9	49-67	19
Female	174.0-176.9	94-98	10
Male	<183.0	>93	16

Procedure

Subjects, in pairs, came to the laboratory for the entire day. Following an initial briefing regarding the purpose of the study and a description of the tasks to be performed, they were assigned randomly by the toss of a coin to perform initially either a series of maximal voluntary single-control isometric exertions on helicopter controls (Schopper and Mastroianni 1985) or a series of maximal voluntary simultaneous multiple control (SMC) isometric exertions. During both series, subjects also performed several additional reference exertions (e.g., hand grip) and dynamic force-loaded arm and leg tracking tasks.

Subsequent to the completion of whichever series was assigned first, the other series was completed following a 90-minute lunch break. Those exertions reported here address the 16 SMC exertions performed by each subject.

Each exertion consisted of a 4-second maximal voluntary exertion executed simultaneously in specified directions upon each of the three helicopter controls. The subject's right hand was employed to input forces to the handle of the cyclic, a vertically oriented control located between and just above the subject's thighs. Inputs were performed in forward, rearward, left, and right directions. Upward- and downward-directed inputs were made by the left hand to the collective control. This control is pointed forward and upward at approximately 40 degrees from the floor in a plane parallel to the midsaggital plane of the subject. The cylindrical handle is located just to the left of the middle of the subject's left thigh. The third "control" is a set of foot pedals, one for the left foot and one for the right.

Interexertion intervals (IEIs) of 2 minutes were employed. The timing of the exertions, the designation of the helicopter control to be used, and the direction-of-exertion to be applied to each control were accomplished by using a programmed electronic timer in conjunction with a slide projector and a color-coded series of lights.

Seven seconds prior to the required onset of the exertion, the slide projector displayed a 1 m by 1 m image of the helicopter controls upon a screen located directly in front of the subject approximately 2.5 m away. Depicted on it (Figure 1) were all controls: cyclic, collective, left, and right pedals. Each was shown in the same location on each trial. Immediately adjacent to the designated control, an arrow and a label were shown to indicate the direction in which the exertions were to be performed.

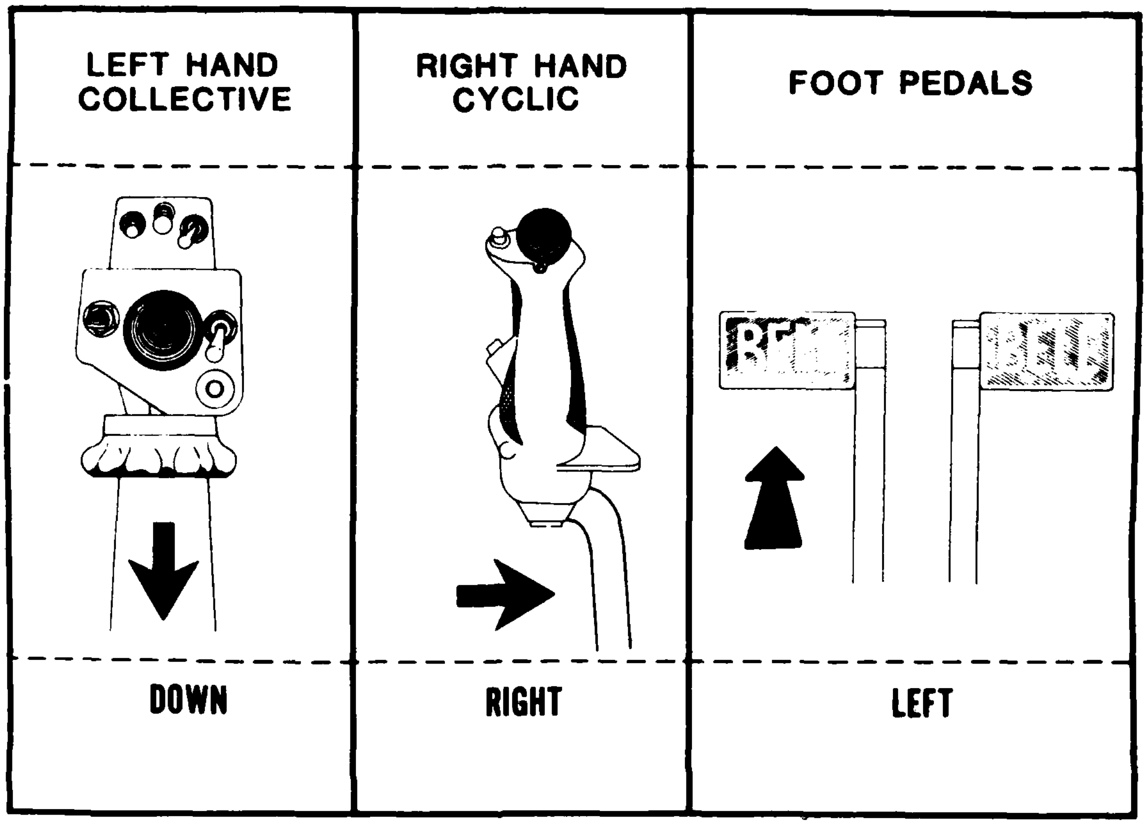

Figure 1. Sample exertion-identifying instructional display.

A 14-channel tape recorder started 4 seconds before the subjects were cued to begin their exertions. It remained on for 4 seconds after the completion of the exertion. The force-related output analog voltages from strain gages applied to the controls were recorded during this interval. The tapes also contained voltage-encoded subject/group identification information and voice-input session identification information.

The cueing of the exertions was indicated to the subjects through the use of a series of color-coded lights located slightly to the right of the forward field-of-view (FOV), approximately 1.5 m from the subject. Five seconds prior to the onset of the exertion, an amber lamp was lighted. The subjects were informed this meant they should position their hands and feet on the proper controls at this time in preparation for the required exertions. The amber lamp was extinguished 2 seconds prior to the time the exertion was to begin, and a green lamp lighted and remained on for the succeeding 8 seconds.

The subjects were instructed when the green lamp appeared they were to initiate their exertions in a prompt, linear fashion such that it was at a maximum within 2 seconds of the onset of the green lamp. Two seconds after the onset of the green lamp, a red lamp was lighted and remained on for the next 4 seconds. During this time, the subjects were instructed to hold his or her exertions at their maximum levels. When the red lamp extinguished, the subjects were to relax their exertions. Two seconds later, the green lamp was extinguished and the subjects released the control.

The series of 16 SMC exertions involved all combinations of directional inputs to the controls. All subjects performed cyclic exertions in all four directions (0, 90, 180, and 270 degrees) with the cyclic at the center of its range of motion (i.e., center position). Exertions in both up and down directions were performed on the collective at the center position. Exertions on each pedal were performed at their center positions. The sequence in which the exertions were performed was designed to maximize the amount of rest possible between any two successive exertions in the same direction by the same limb. On a random basis, one of the two subjects appearing for each session performed the fixed sequence in one direction; the other performed it in the reverse direction.

No feedback was provided the subjects regarding their efforts. Polite restatement of their task (to perform maximal exertions) routinely was rendered approximately midway through the series; however, there was no effort to continuously exhort maximal performance from the subjects.

In consonance with the variation in the selection of actual in-the-aircraft seat adjustments noted among experienced aviators during another portion of this research program (Cote and Schopper 1985), subjects selected their own seat position relative to the controls with the controls positioned at the centers of their respective ranges of movement. The lap belt was fastened snugly. The shoulder harness was in place, but unlocked to allow freedom of forward bending movement. The unlocked harness is consistent with current aircrew instruction.

All controls were instrumented with strain gages. Output voltages were recorded on a 14-channel FM tape recorder. The strain gages were calibrated before each pair of subjects was run. This was accomplished by hanging lead weights of known value to a steel cable and pulley assembly which was attached to the control to be calibrated. The calibration sequence was 0 N, 135 N (30 lbs.), 270 N (60 lbs.), and 405 N (90 lbs.). A 30-second recording of the output of the strain gages was made at each of these weights.

For each exertion, analog data from the data tapes were sampled at 10 Hz and digitized. Mean values were computed from the 40 data points resulting from the 4-second maximal exertion period for each exertion.

Results

The mean magnitudes of the simultaneously executed multiple control exertions are provided in Table 2.* Among the pedal data, the differences in the magnitudes of the inputs between the left and right pedals were small. The pedal forces associated with simultaneous rearward inputs to the cyclic were larger than those associated with inputs in other directions on the cyclic. Pedal inputs performed while simultaneously pulling on the collective generally were larger than those performed while pushing on the collective. Examples of these patterns are shown in Figure 2 (for males) and Figure 3 (for females) whose stature is in the 163-167 cm range.

The collective-related findings provided in Table 2 evidence little consistency regarding the influence of the direction of simultaneously executed pedal or cyclic control inputs. What is readily apparent is the large effect of the direction of the exertion on the collective itself. Downward-directed force inputs are all substantially smaller than those in the upward direction. This general pattern is evidenced clearly for both male and female exertions. Male exertions, however, were considerably larger than those of females. Figures 4 and 5 display the overall effect of direction-of-exertion for collective inputs by males and females, respectively, whose stature is in the 163-167 cm range.

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* The data reported in Table 2 reflect one less male and one less female than are reported elsewhere in the report. This is because recording equipment failures resulted in the loss of single-control exertion data for these two subjects. Because the data in Table 2 will subsequently be cited in the comparison of SMC data with corresponding single control data, it was necessary to assure that the data were from the same subjects.

Table 2

Mean magnitudes of simultaneously executed multiple control exertions as a function of subjects' gender

Simultaneous exertion combinations directions of control inputs			Pedal		Collective		Cyclic fore-aft		Cyclic left-right	
Pedal	Collective	Cyclic	Male	Female	Male	Female	Male	Female	Male	Female
Left	Up	Forward	765.8	528.6**	575.2	394.3	307.3*	190.4	--	--
		Rearward	968.8	679.8***†	551.7	390.2	357.6	254.4	--	--
		Left	772.0	510.7	532.5*	378.9***	--	--	179.7	90.8
		Right	744.2	531.7*	555.6	405.8	--	--	125.0	73.9
	Down	Forward	546.7	351.9	238.9	92.2	253.0	164.1	--	--
		Rearward	700.6	449.7	282.9	135.6	337.1	253.0*	--	--
		Left	580.7	351.9	220.2	102.3	--	--	172.5	87.0
		Right	546.6	355.9	210.1	97.7	--	--	122.9	75.1
Right	Up	Forward	739.3	462.8	525.4**	380.0***	290.0***	187.5	--	--
		Rearward	944.0*	624.5†	543.8	371.5***	343.1	250.8*	--	--
		Left	725.8	485.3	480.8	366.4***	--	--	169.8	94.2
		Right	789.0	482.0	553.5	368.5***	--	--	119.4	68.7
	Down	Forward	602.0	383.6	250.9	112.5	258.3	166.8	--	--
		Rearward	791.7	522.7	314.1	146.5	348.3	255.3	--	--
		Left	624.1	395.7	222.1	107.8	--	--	169.4	92.8
		Right	635.3	396.3	215.4	103.1	--	--	119.1	699.7

Notes: Values are in newtons.

1. Significance levels: unless otherwise indicated, all values were significantly less than their corresponding single control referent values at $p < .001$ based on paired t-tests analyses. Other levels of significance are indicated by the following: an underscore denotes $p > .05$, * denotes $.01 < p < .05$, ** denotes $.005 < p \leq .01$, *** denotes $.001 < p < .005$.
2. The use of † denotes that the table value exceeds the single control referent value.
3. Number of males = 66; number of females = 62.
4. Male single control referents (N): pedal left: 948.7; pedal right: 1032.8; collective up: 578.0; collective down: 417.9; cyclic forward: 338.7; cyclic rearward: 367.1; cyclic left: 207.8; cyclic right: 144.1.
5. Female single control referents (N): pedal left: 592.8; pedal right: 622.3; collective up: 412.2, collective down: 199.0; cyclic forward: 225.0; cyclic rearward: 270.4; cyclic left: 124.0; cyclic right: 91.5.

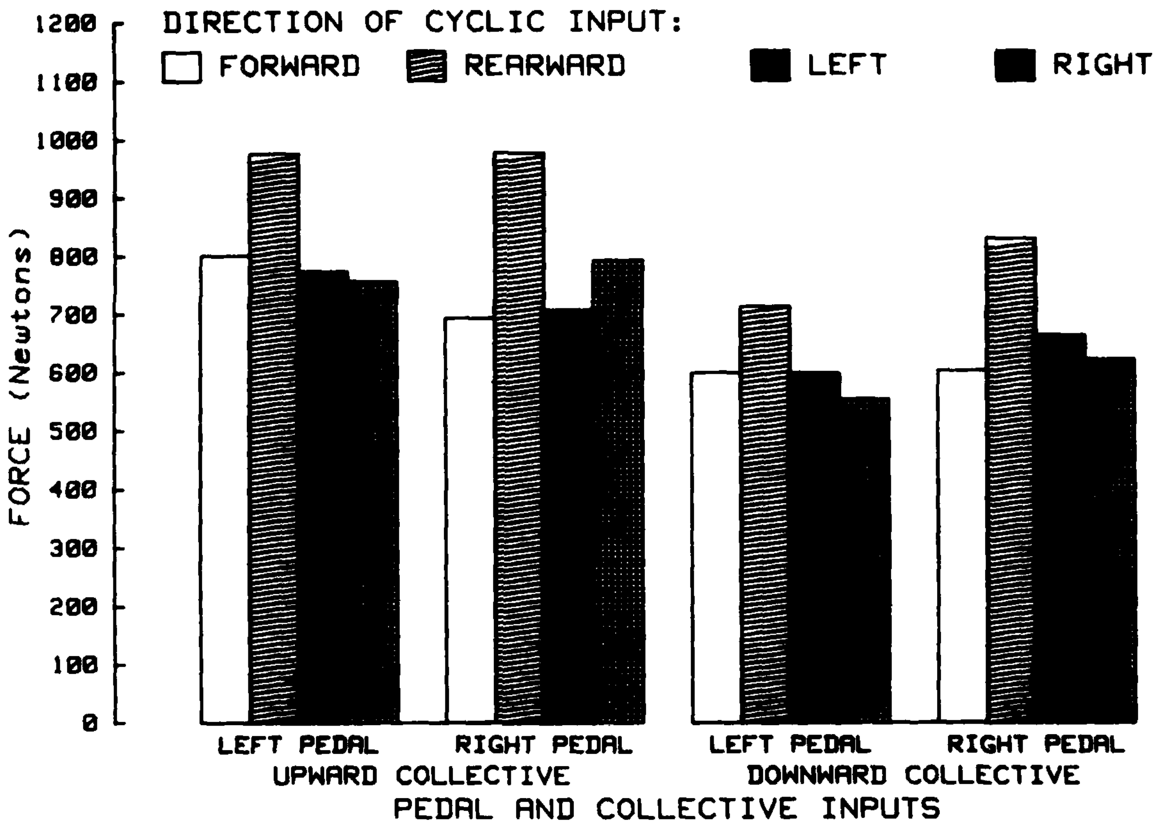

Figure 2. Mean magnitudes of left and right male pedal force exertions as a function of the simultaneously executed directional inputs to the collective and cyclic controls.

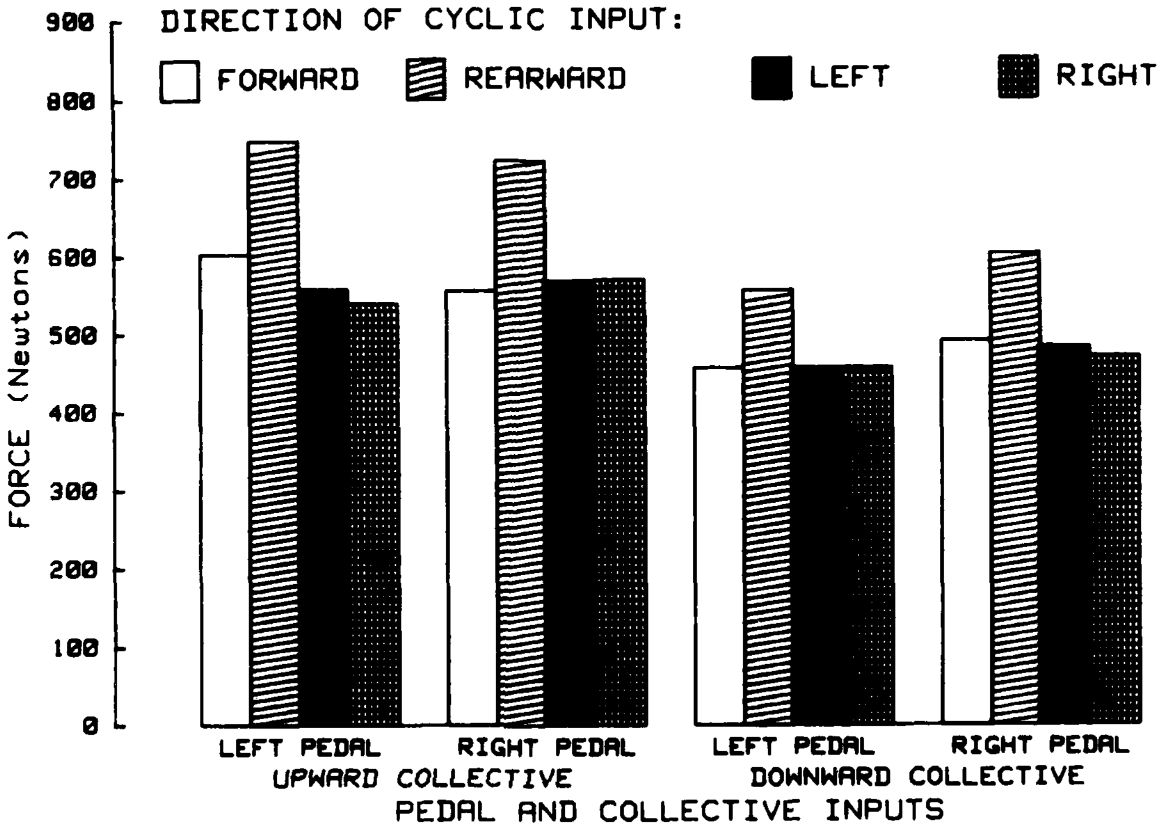

Figure 3. Mean magnitudes of female left and right pedal force exertions as a function of simultaneously executed directional inputs to the collective and cyclic controls.

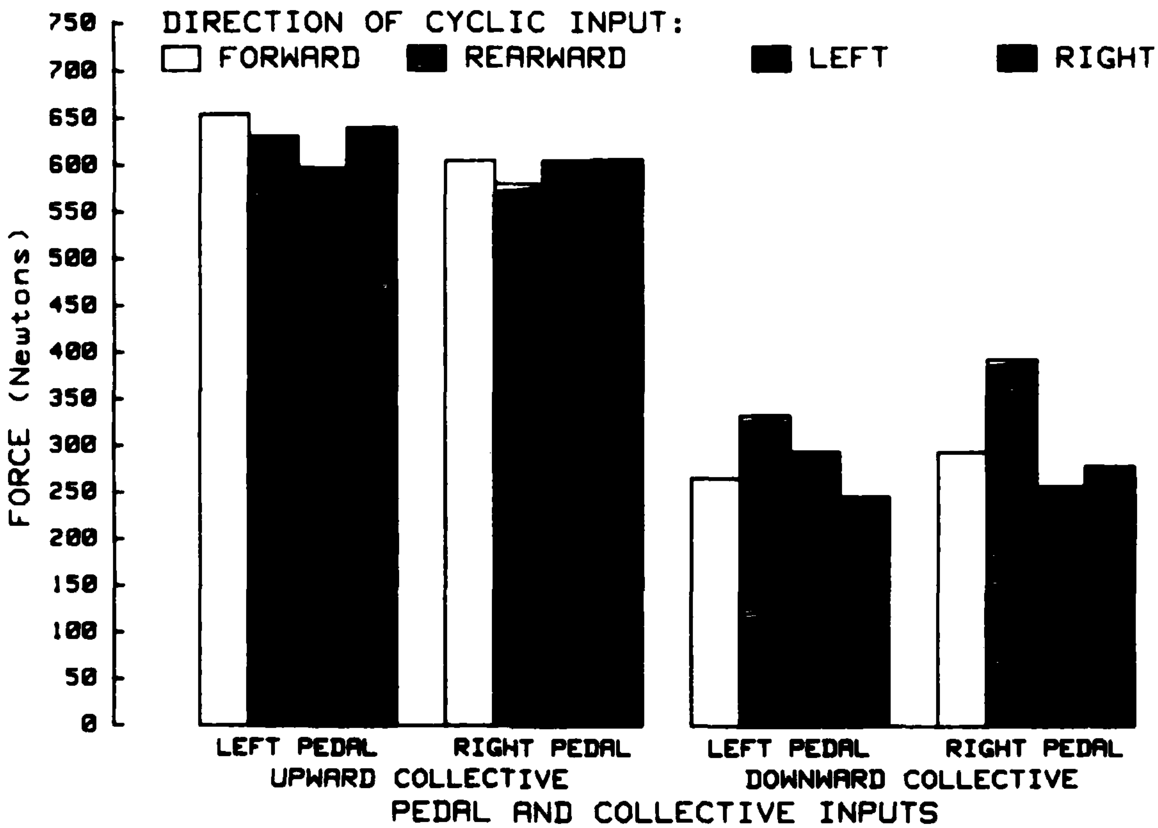

Figure 4. Mean magnitudes of male upward- and downward-directed collective force exertions as a function of simultaneously executed inputs to the pedals and cyclic controls.

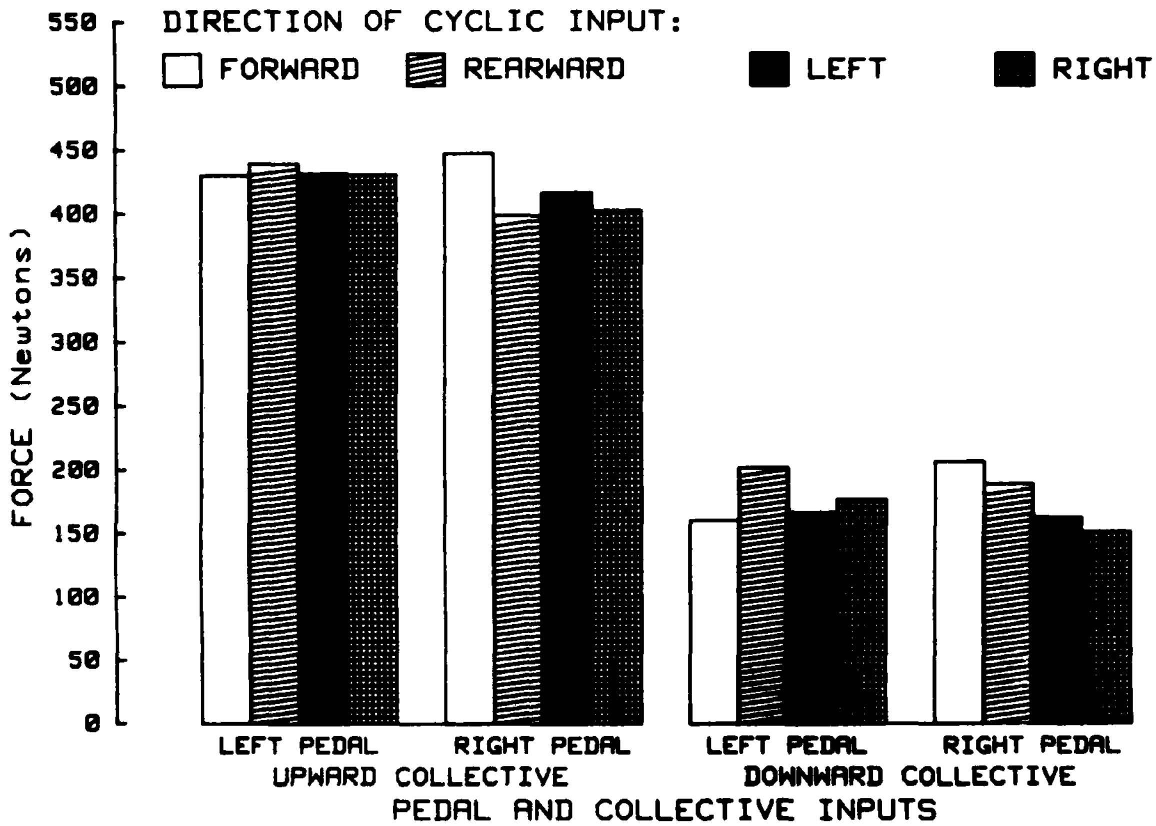

Figure 5. Mean magnitudes of female upward- and downward-directed collective force exertions as a function of simultaneously executed inputs to the pedals and cyclic controls.

The findings cited in Table 2 for cyclic-related data evidence a wide range of values. They range from 68 N to 75 N for right-directed exertions by females through values in the 337 N to 357 N range for rearward-directed exertions by males. As was the case with pedal and collective exertions, male cyclic exertions, regardless of direction, were larger than those of females. Of note are the magnitudes of the cyclic exertions which largely were independent of the simultaneously performed exertions on either the collective or pedals. However, for both males and females, a consistent pattern of force magnitudes is evident; i.e., regardless of other ongoing pedal and collective exertions, the rank order (from highest to lowest) of the mean magnitudes of cyclic exertions was rearward, forward, left, and right. Longitudinal cyclic inputs were considerably larger than were lateral cyclic inputs. Figure 6 for males and Figure 7 for females show the effects of stature 163-167 cm.

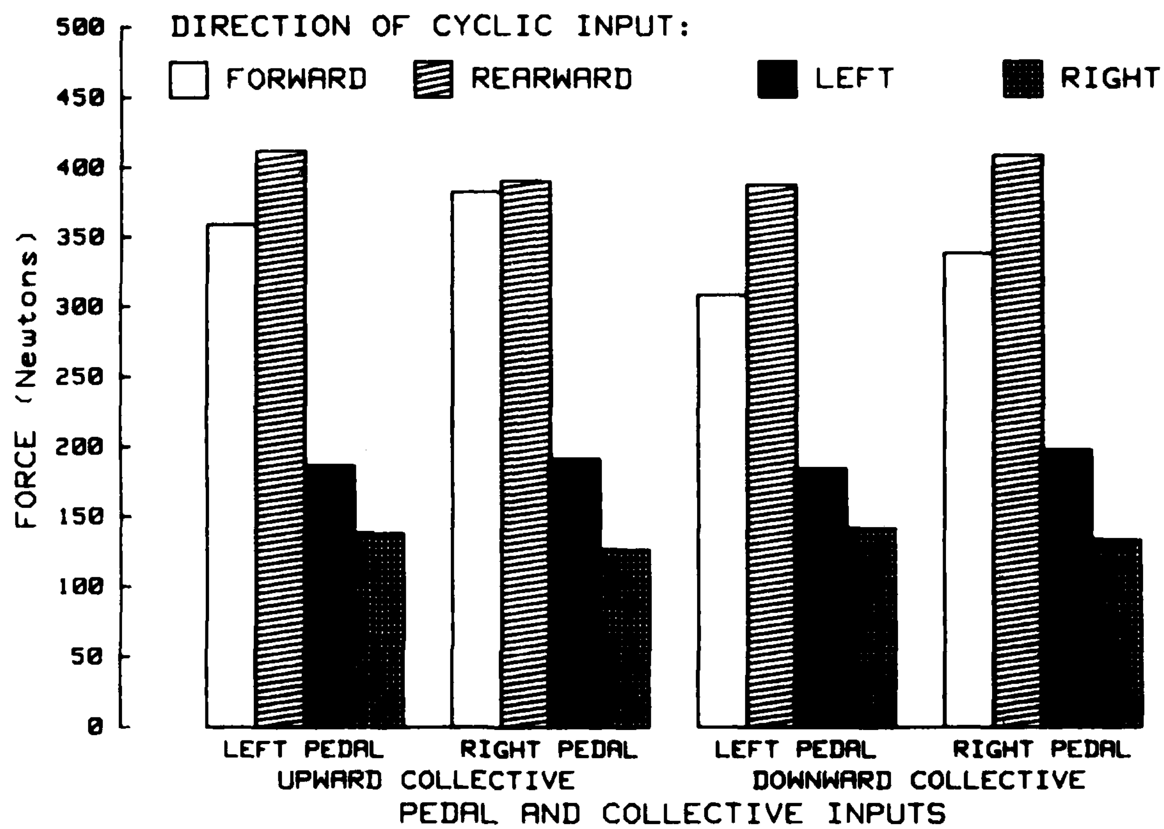

Figure 6. Mean magnitudes of male forward-, rearward-, left-, and right-directed cyclic force exertions as a function of simultaneously executed inputs to the pedals and collective controls.

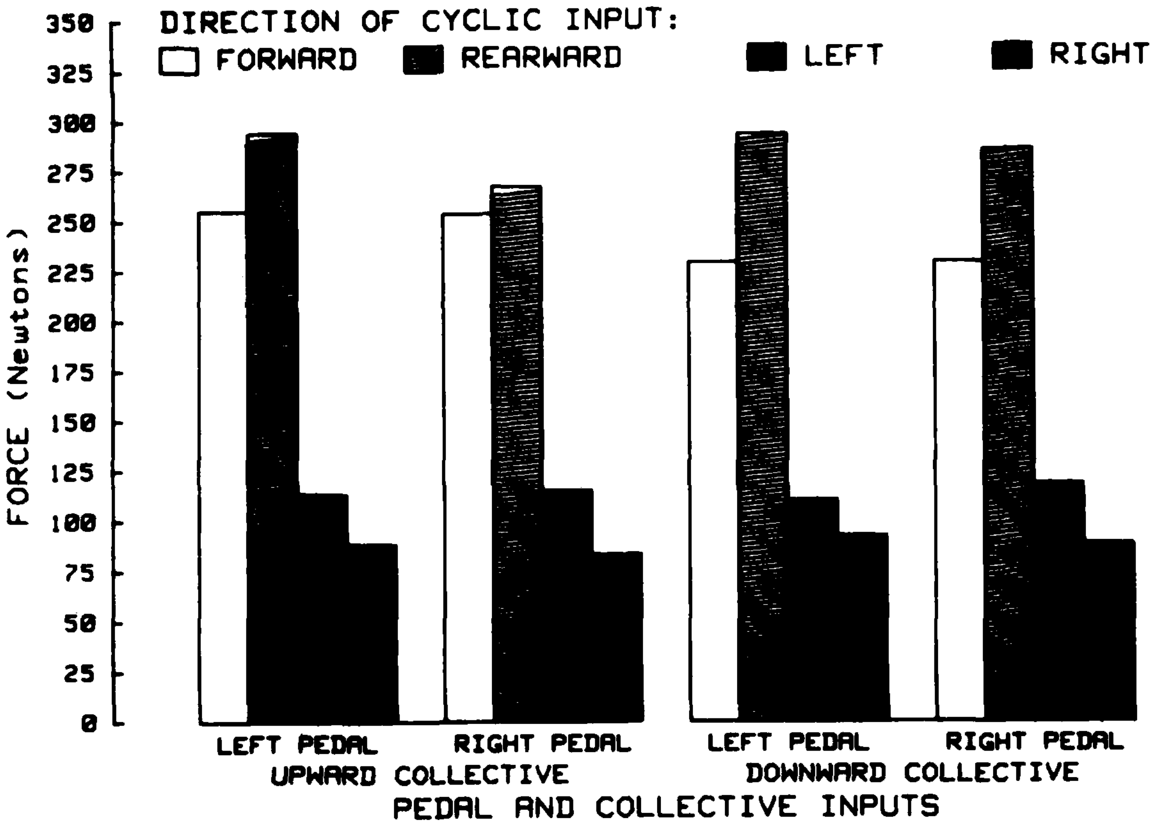

Figure 7. Mean magnitudes of female forward-, rearward-, left-, and right-directed cyclic force exertions as a function of simultaneously executed inputs to the pedals and collective controls.

Discussion

Two factors are worthy of mention regarding MIL-H-8501A (Department of Defense 1961). The first is that the duration of the force input associated with the control force design limits is not specified. The strength assessment procedures employed by Schopper and Mastroianni (1985) used a maximal input of 4-seconds duration. Accordingly, the comparison of capabilities with recorded in-flight force demands (Schopper, Wells, and Kaylor 1985) necessitated that a 4-second base be employed in reducing these data as well. Were other time bases employed, it is likely that the mean magnitudes of both the force exertion capabilities (Schopper and Mastroianni 1985) and the recorded in-flight force demands (Schopper, Wells, and Kaylor 1985) would have been lowered. Whether or not the magnitudes of the decreases would have been parallel is not known. As relates to the present study, it is noted that MIL-H-8501A (Department of Defense 1961) does not address the possibility or likelihood that multiple, simultaneously executed exertions may have to be performed. However, the question remains whether or not attempts to execute multiple maximal exertions simultaneously result in a change in the level of force applied to each control relative to that demonstrated when executing each exertion alone. There are no previously reported findings known to the authors which have addressed this issue.

The specification (MIL-H-8501A, Department of Defense, 1961) for the design limit associated with helicopter controls during in-flight disablement of the hydraulics assist mechanism is the following: longitudinal cyclic inputs, 112.5 N (25 lb); lateral cyclic inputs, 67.5 N (15 lb); collective inputs (up or down), 112.5 N (25 lb); pedal inputs (either pedal), 360.0 N (80 lb).

Comparisons of the control force design limit appropriate to each control with the mean magnitudes of the relevant force exertions by male and female subjects are provided in Table 3. In general, failure rates are lower among males than females, and failure rates are lower for the cyclic than they are for the other two controls. It is clear that, relative to their respective control force design limits, failures were most frequently encountered among the pedal exertion data. During the performance of the 16 SMC exertions, slightly more than one-half of the males performed at least one pedal input which failed to reach the 360 N design limit. Sixteen percent of the males failed to attain the pedal design-limit level during 25 percent or more of their exertions. One male failed to reach the referent level on every exertion.

Table 3

Percentage of male and female control-specific exertions failing to meet control force design limits during the execution of 16 simultaneous multiple exertions

Control, directional: (limit)	Gender*	Number of failures per subject 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total subjects' >1 failure	Total number failures**
Pedal, left and right (360 N)	Males																		
	No.	8	10	3	2	2	2		1	2	1	1		1			1	34	143
	%	11.9	14.9	4.5	3.0	3.0	3.0		1.5	3.0	1.5	1.5		1.5			0.8	50.7	13.3
	Females																		
	No.	6	5	1	7	4	4	4	5	6	5	1		3	1		2	54	363
	%	9.5	7.9	1.6	11.1	6.3	6.3	6.3	7.9	9.5	7.9	1.6		4.8	1.6		1.5	85.7	36.0
Collective, up and down (112.5 N)	Males																		
	No.	12	2		9	2	4	2	1									32	108
	%	17.9	3.0		13.4	3.0	6.0	3.0	1.5									47.8	10.1
	Females																		
	No.	8	7	6	3	3	5	12	15									59	301
	%	12.7	11.1	9.5	4.8	4.8	7.9	19.0	23.8									93.7	29.9
Cyclic, forward and rearward (112.5 N)	Males																		
	No.	6	2	1														9	13
	%	9.0	3.0	1.5														13.4	2.4
	Females																		
	No.	13	12	1	2													28	48
	%	20.6	19.0	1.6	3.2													44.4	9.6
Cyclic, left and right (67.5 N)	Males																		
	No.	4	3															7	10
	%	6.0	4.5															10.4	1.8
	Females																		
	No.	8	9	10	3	3	1	5	1									40	139
	%	12.7	14.3	15.9	4.8	4.8	1.6	7.9	1.6									63.5	27.6

Notes:

* Number of male subjects = 67; number of female subjects = 63.

** The total number of pedal and collective exertions for males was 1,072 (i.e., 67 subjects times 16 exertions each); the total for females was 1,008 (63 times 16). The totals for longitudinal and lateral cyclic exertions were 536 and 504 for males and females, respectively.

The findings pertaining to pedal exertions by females were considerably worse. Overall, nearly 86 percent of the females performed one or more exertions below the design limit. The exertions of 28.6 percent of the females were below the pedal design limit for more than one-half of the 16 exertions they performed; 75 percent of the exertions by 6 of the 63 females were below design-limit levels. The last column of Table 3 provides the total number of exertions which failed to attain the design limit. To permit a male-female comparison, the column also includes the percentage-equivalent of this total based upon 1,072 exertions by males (i.e., 67 subjects times 16 exertions each) and 1,008 exertions by females (63 subjects times 16 exertions each). Thirty-six percent of the females' pedal exertions were lower than the design limit. The corresponding figure for males, 13.3 percent, was approximately one-third of that for females. These pedal-related percentages were, for both groups, higher than those evidenced on either of the other controls.

The findings for collective-related exertions generally were similar: 47.8 percent of the males and 94 percent of the females were unable to achieve collective design force limit levels during all of their exertions. Multiple occurrences of failures among their 16 exertions were evident particularly among females. Fully 43 percent of the females rendered collective inputs which were less than design-limit levels for 7 or more of their 16 SMC exertions. Far fewer males (4.5 percent) evidenced comparable failure rate. Nearly 30 percent of the males evidenced more than one exertion which was less than the design-limit exertion. The comparable figure for females is 81 percent.

The principal difference between these findings and those pertaining to pedal forces is the pattern evidenced in Table 3. Whereas failure rates were high for both controls, it is clear both males and females experienced more multiple pedal-related failures than they experienced multiple collective-related failures. All subjects attained design-limit levels for more than one-half of their collective-related exertions. However, more than one-half of the pedal inputs by fully one-third of the females and 18 percent of the males failed to attain the design limit level. The data in the last column of Table 3 supports this observation. The total number of design-limit-referenced failures among males was smaller for collective inputs (10.1 percent) than for pedal inputs (13.3 percent). For females, the difference was larger: 29.9 percent for the collectives vs 36.0 percent for the pedal inputs.

Cyclic-related failures were the smallest in number. Overall (reference the last column of Table 3), only 2.4 percent of the longitudinal and 1.8 percent of the lateral cyclic force exertions among males were smaller than their respective force design limits. The corresponding figures for female exertions were considerably higher, 9.6 and 27.6 percent. Considered from a subject-wise perspective (next-to-the-last column, Table 3), 13.4 percent of the males failed at least once to attain longitudinal design-limit forces during the eight SMC exertions involving longitudinal cyclic inputs. For lateral inputs by males, the corresponding value is 10.4 percent.

Relative to these values for males, the failure percentages for females were markedly higher--nearly three times higher for longitudinally-directed cyclic exertions (44.4 percent) and six times higher for laterally-directed cyclic exertions (63.5 percent).

The discussion to this point has focused on the overall failure rates associated with each control. Another question which can be addressed by the present research is the degree to which specific combinations of direction inputs affect the forces manifest. Table 4 provides design-limit-referenced failure rates for males and females as a function of each of the 16 combinations of exertions addressed in this research effort.

An examination of the pedal and collective data reveals a robust pattern associated with the direction of inputs to the collective. When the subjects pulled up on the collective, failure rates were substantially lower for both pedal- and collective-force inputs than they were during downward-directed exertions on the pedal. The mechanical advantage present during this oppositional combination of an upper body pull plus a lower-body push yielded greater applied forces on both controls than when subjects had to push upon both. When this combination was further augmented with an additional upper body rearward input to the cyclic (i.e., the combination of upward-directed collective and rearward-directed cyclic inputs coupled with pushes on either pedal), the failure rates were the lowest encountered for both male and female subjects (3 percent or less for males, less than 10 percent for females). No other clear patterns emerged among the pedal and collective data.

Among the cyclic data cited in Table 4, it is apparent rearward-directed design-limit-referenced failures occurred least frequently and were largely independent of the direction of inputs to the pedal and collective.

Table 4

Percentage of male and female failures to attain design-limit levels of force magnitude during simultaneous maximal multiple control exertions as a function of direction of input to each control and subject gender

Direction of control input			Control and subject gender							
			Pedal		Collective		Cyclic fore-aft		Cyclic left-right	
Pedal	Collective	Input	Male	Female	Male	Female	Male	Female	Male	Female
Left	Up	Forward	7.5	15.9	0	0	3.0	11.1	---	---
		Rearward	1.5	6.3	0	1.6	0	1.6	---	---
		Left	3.0	22.2	0	0	---	---	0	12.7
		Right	9.0	17.5	0	0	---	---	0	31.7
	Down	Forward	19.4	63.5	17.9	71.4	9.0	25.4	---	---
		Rearward	10.4	23.8	10.4	42.9	1.5	1.6	---	---
		Left	26.9	61.9	20.9	61.9	---	---	0	17.5
		Right	26.9	68.7	31.3	66.7	---	---	3.0	28.6
Right	Up	Forward	16.4	34.9	0	0	1.5	7.9	---	---
		Rearward	3.0	9.5	0	0	0	3.2	---	---
		Left	10.4	33.3	0	1.6	---	---	1.5	14.3
		Right	4.5	31.7	0	0	---	---	4.5	41.3
	Down	Forward	35.1	64.9	17.9	61.9	4.5	22.2	---	---
		Rearward	9.0	28.6	9.0	46.0	0	3.2	---	---
		Left	16.4	44.4	33.3	11.7	---	---	1.5	19.0
		Right	19.4	58.7	26.9	66.7	---	---	4.5	44.4
Single control referents			1.5	7.9	0	14.3	0	1.6	0	12.7

Note: Number of male subjects = 67; number of female subjects = 63.

Right-directed cyclic input failures to meet the design limit occurred most frequently. Failure rates among females for the four right-directed cyclic inputs ranged from 28.6 to 44.4 percent; the range for males was much lower, 0-4.5 percent. Right-directed failures occurred more frequently when paired with simultaneously executed right pedal inputs than when coupled with left pedal inputs. No other equally robust patterns were observed in the cyclic data.

Research previously reported (Schopper and Mastroianni 1985) provided the findings for single-control exertions, each performed separately by subjects from this same study. The lowermost row of data provided in Table 4 cites the single-control exertion failure rates for the same male and female subjects whose simultaneous multiple control exertion data are reported in the upper portion of the table.

In contrast to the failure rates evidenced for each control separately addressed, it is clear a requirement to perform multiple exertions simultaneously has escalated substantially failure rates on all three controls. The increase in the proportion of failures is markedly greater among females than it is among males. For the pedals, the average difference in failure rates between simultaneous- and singly-performed exertions is approximately 12 percent for males and 25 percent for females. For the collective, the corresponding differences are 10 percent and 16 percent. The differences were smaller for the longitudinal cyclic exertions (males - 2 percent, females - 8 percent) and the lateral cyclic exertions (males - 2 percent, females - 15 percent).

The findings presented in Table 5 are those pertaining to a subset of male and females cited in Table 4. The subset is comprised of the groups whose stature are just above and just below 162.6 cm (64 in), the stature used in AR 40-501 (Department of the Army 1960) until 1980 as the lower limit for those applying for flight training in the US Army. Because size and strength are, in general, positively correlated (<u>e.g</u>., McCormick 1976), this subgroup of subjects represent those in the present study who would have the greatest difficulty in meeting or surpassing any future strength standard. Hence, the data reported in Table 5 represent a sample of the target population of those who would be most likely to be "at risk."

The findings cited in Table 5 are consistent with expectations; <u>i.e</u>., because they reflect only the performance of smaller personnel, the failure rates are larger than those cited in Table 3. The subjects comprising these groups are equal in stature and are roughly equal in number. Therefore, chi-square analyses were undertaken. These results (which employed Yates correction factor) also are reflected in Table 5. With one exception, the failure rates evidenced for females were larger

Table 5

Percentage of design-limit-referenced failures among males and females of stature 159-167 cm during the execution of simultaneous multiple control exertions as a function of direction of input to each control

Direction of control input			Pedal (360 N)		Collective (112.5 N)		Cyclic fore-aft (112.5 N)		Cyclic left-right (67.5 N)	
Pedal	Collective	Cyclic	Male	Female	Male	Female	Male	Female	Male	Female
Left	Up	Forward	12.1	17.1	0	0	3.0	11.4	--	--
		Rearward	3.0	8.6	0	0	0	0	--	--
		Left	6.1	22.9	0	0	--	--	0	14.3
		Right	15.2	25.7	0	0	--	--	0	42.9+
	Down	Forward	36.4	62.9*	27.3	71.4+	15.2	28.6	--	--
		Rearward	21.2	20.0	18.2	48.6**	3.0	0	--	--
		Left	45.5	62.9	33.3	60.0**	--	--	0	22.9**
		Right	45.5	51.4	45.5	71.4**	--	--	0	37.1+
Right	Up	Forward	30.3	40.0	0	0	3.0	5.7	--	--
		Rearward	6.1	14.3	0	0	0	2.9	--	--
		Left	18.2	34.3	0	2.9	--	--	0	20.0**
		Right	9.1	31.4**	0	0	--	--	9.1	40.0***
	Down	Forward	48.5	65.7	36.4	62.9*	3.0	22.9**	--	--
		Rearward	18.2	25.7	15.2	54.3***	0	5.7	--	--
		Left	27.3	48.6	36.4	60.0*	--	--	3.0	25.7*
		Right	36.4	60.0*	48.5	77.1**	--	--	6.1	51.4+
Single control referents		3.0	8.6	0	11.4	0	0	0	11.4	

Note: Number of male subjects = 33; number of female subjects = 35

* - $.05 < p < .10$
** - $.01 < p < .05$
*** - $.001 < p < .01$
\+ - $.0001 \leq p < .0005$

than those for males. For approximately one-fourth of the chi-square analyses, these differences were statistically significant.

The same overall patterns of failures are evident in Table 5 as exist in Table 4. In most instances, the failure rates are larger in Table 4 than they were in Table 5, particularly for males. Whereas the largest percentage of pedal failures among the entire sample of males in Table 4 was 35 percent, that for right pedal exertions undertaken while simultaneously making downward-directed inputs to the collective and forward inputs to the cyclic, the corresponding value for those in stature 159-167 cm was nearly 50 percent (48.5 percent). The same percentage of failures among the shorter group of males was evidenced for the collective control during a right pedal, downward collective, right cyclic SMC exertion. This represented an increase of nearly 80 percent over the 26.9 percent failure rate cited for the corresponding exertion in Table 4. The extent of increase in percentage failures, between Table 4 and Table 5 values among male cyclic exertions was considerably less.

Conclusions

The findings of the present research support the following conclusions:

a. Relative to the helicopter-control-referenced force exertion capabilities of individuals performing separate maximal voluntary exertions on single controls, the requirement to execute such exertions on all three controls simultaneously resulted in substantial and significant levels of force degradation.

b. Among the pedal forces, the greatest degree of force degradation (typically 20-35 percent) was evidenced during pedal inputs undertaken with simultaneously executed downward-directed pushes on the collective. The magnitude of this degradation was mitigated to some extent when the simultaneous cyclic input was a rearward pull. Simultaneously executed upward-directed pulls on the collective and rearward pulls on the cyclic permitted individuals to attain the same levels of force inputs to the pedals as were evidenced during single-control exertions.

c. Among collective inputs, the same general pattern of force degradation was present as existed among the pedal force data. Relatively little degradation was evidenced during upward-directed pulls on the collective; however, downward-directed collective inputs were degraded markedly (typically 40-50 percent) as a consequence of executing them while simultaneously performing inputs to the pedals and cyclic.

d. In general, the extent of force degradation as a consequence of simultaneous force exertion requirements was the least for cyclic inputs. Lateral cyclic inputs tended to be degraded more than longitudinal inputs. Rearward pulls on the cyclic were little affected by simultaneous inputs to the other controls.

e. The simultaneous, multiple-control forces applied by substantial proportions of the subjects failed to meet the control force design limits cited in the military standard (MIL-H-8501A, 1961). The proportion of exertions failing to reach design-limit values were highest for pedal and downward-directed collective exertions. In general, failures were higher among smaller individuals than larger individuals and higher among females than males. Less than 50 percent of the males and 10 percent of the females evidenced design-level-or-higher force inputs on all controls throughout all 16 of the simultaneous, multiple control exertions performed.

f. There exists a need to consider simultaneously executed force inputs in relevant design guides and standards and the probability of an aviator being confronted with those input requirements.

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