AMRL-TR-64-126

AD 613597

A COMPARISON OF THREE FULL-PRESSURE SUITS IN TERMS OF CONTROL ACTIVATION TIME

EARL D. SHARP

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700 - March 1965 - 448-31-717

A COMPARISON OF THREE FULL-PRESSURE SUITS IN TERMS OF CONTROL ACTIVATION TIME

EARL D. SHARP

FOREWORD

This study was initiated by the Maintenance Design Branch, Human Engineering Division, Behavioral Sciences Laboratory of the Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio.

The full-pressure suits compared in this evaluation were supplied by the National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas. The data reduction was accomplished by the University of Dayton, making use of NASA funds as provided in NASA Purchase Request Number T-23630-G. The data collection was accomplished under Project No. 7184, "Human Performance in Advanced Systems," Task No. 718402, "Criteria for the Design and Arrangement of Controls and Control Systems." Research was initiated November 1963 and completed February 1964.

This technical report has been reviewed and is approved.

WALTER F. GRETHER, PhD
Technical Director
Behavioral Sciences Laboratory

ABSTRACT

Three pressure suits, both pressurized and unpressurized, were compared on the basis of times taken by two subjects to initiate action and to reach to and operate controls located in various positions in a simulated workspace. The suits compared were the Apollo Phase B, the Gemini G2C-1, and the Apollo 1960 State-of-the-Art. The controls used were knobs, toggle switches, and pushbuttons. The work area investigated was semicircular, extending left and right 78°, 34 to 49 inches above the floor, at a distance of approximately 2 feet. Average times for each combination of suit, suit condition (pressurized or unpressurized), control type, control location, and hand used are presented. No suit appeared to be unequivocally superior. Total time to initiate action and to reach to and operate toggle switches and pushbuttons was typically, although not universally, shorter when wearing the Apollo 1960 State-of-the-Art suit. Total time to initiate action and to reach to and operate knobs was typically, although not universally, shorter when wearing the Gemini G2C-1 suit; however, not all locations could be reached when wearing this suit.

Figure 1. Aerospace Medical Workplace Evaluator Showing Control Arrangement

SECTION I

INTRODUCTION

The general restrictive effects of pressure suits on human mobility are widely recognized, and considerable effort is being expended by NASA and the military services to develop less restrictive pressure garments. As a part of this continuing effort, it has been necessary to devise means of assessing suit mobility characteristics, both for purposes of comparatively evaluating different suit configurations as well as for defining for system designers the range and speed of motions that can be accomplished by people wearing these various configurations. In the evaluation to be reported here, measurements were made of the time required for each of two subjects (alternately wearing the Apollo Phase B suit, the Gemini G2C-1 suit, and the Apollo 1960 State-of-the-Art suit) to activate controls located in various positions in a simulated workspace.

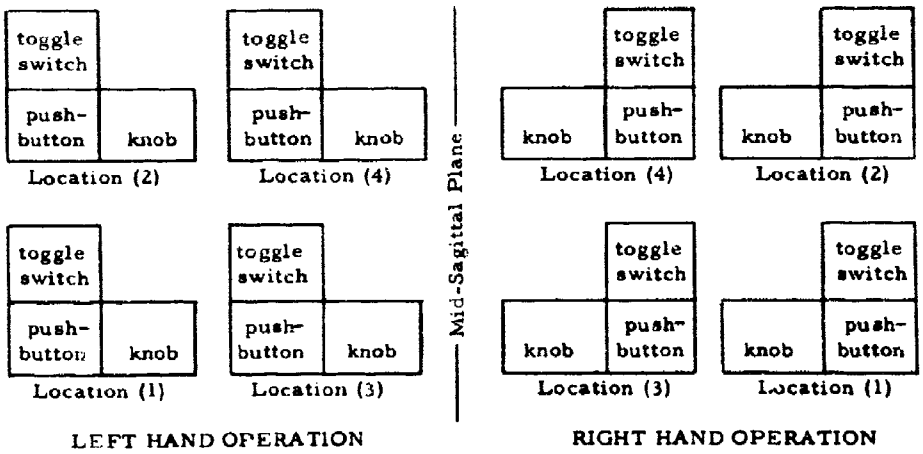
SECTION II

APPARATUS

The Aerospace Medical Research Laboratories workplace evaluator in the configuration shown in figure 1 was used for this study. The controls were arranged in eight groups of three, each group consisting of a knob, a toggle switch, and a pushbutton control (table I). Red stimulus lights above each control indicated which control was to be operated. In the case

TABLE I

SCHEMATIC OF CONTROL LAYOUT AND CONTROL NUMBERS



of the knobs, two stimulus lights were associated with each control, and the required operation was to position the knob within a narrow preset null region. The first stimulus light presented indicated the direction the knob was to be turned to reach a predetermined null region. The light was extinguished when the null region was entered. If the knob was turned past the null region, the opposite stimulus light was illuminated, indicating that the null region had been passed and that the direction of movement had to be reversed to again reach the null position. Correct operation was accomplished when the knob was positioned within the null region and both lights were extinguished. In the case of the toggle switches and pushbuttons, activation of the control extinguished the single stimulus light associated with each of these controls. The toggle switches were spring loaded to the center position and switch activation was accomplished by moving the toggle either up or down.

The eight groups of controls used in this experiment were arranged in a semicircle around the subject so that if lines were drawn through the center of each control box perpendicular to the control surface, they would intersect at a focal point 44½ inches above the floor, directly above the Seat Reference Point. [1] Table II describes the spatial location of each control in terms of the straight-line distances from the focal point, the angle to the right or left of the sagittal plane, and the height above the floor.

The subject began each control operation with his hand on a starting switch strapped to his left thigh if he was to operate controls to the left of mid-sagittal plane, and strapped to his right thigh if he was to operate controls located to the right of his mid-sagittal plane. When a stimulus light appeared, the subject released the starting switch and activated the appropriate control. When a control activation was completed, the subject returned his hand to the starting switch and waited for the next stimulus light.

Performance time was recorded on decade counters and punched onto IBM cards using an IBM model 523 gang summary punch. This summary punch was triggered by the experimenter when the subject completed a correct control activation and returned his hand to the starting switch. Punching of time scores and resetting of the equipment and counters was automatically controlled by relays and cams contained in the summary punch.

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1 The Seat Reference Point, located 15 inches above the floor, is the midpoint of the line formed by the intersection of the back and the seat of the chair.

TABLE II

MEASUREMENTS DESCRIBING THE SPATIAL LOCATION OF EACH CONTROL

Controls to the Left of the Mid-Sagittal Plane					Controls to the Right of the Mid-Sagittal Plane				
Location	Control Type	Focal* Distance	Height (Inches)	Sagittal** Angle (Degree)	Location	Control Type	Focal* Distance	Height (Inches)	Sagittal** Angle (Degree)
1	Knob	28	34	70	1	Knob	28	34	70
	Toggle Switch	26 5/8	37 1/4	26		Toggle Switch	26 5/8	37 1/4	78
	Push-Button	27 7/8	33 1/2	78		Push-Button	27 7/8	33 1/2	78
2	Knob	25	45 3/4	70	2	Knob	25	45 3/4	70
	Toggle Switch	23 3/4	49	26		Toggle Switch	23 3/4	49	78
	Push-Button	25	45 3/8	78		Push-Button	25	45 3/8	78
3	Knob	27	34	17	3	Knob	27	34	17
	Toggle Switch	25 5/8	37 1/4	26		Toggle Switch	25 5/8	37 1/4	26
	Push-Button	26 7/8	33 1/2	26		Push-Button	26 7/8	33 1/2	26
4	Knob	23 7/8	45 3/4	17	4	Knob	23 7/8	45 3/4	17
	Toggle Switch	22 5/8	49	26		Toggle Switch	22 5/8	49	26
	Push-Button	23 3/4	45 3/8	26		Push-Button	23 3/4	45 3/8	26

* The focal point is located 44 1/2 inches above the floor and directly above the seat reference point.

** Measured in degrees to the right or left of the sagittal plane.

Performance time for all controls consisted of the time elapsed from the initial presentation of the stimulus light until final correct activation of the control had been completed. The following components of performance time were measured.

For the Knob:

1. Reaction Time - The time elasped from the initial presentation of the light until the subject released the starting switch.

2. Reach Time - The time elapsed from the release of the starting switch until the subject touched the control.

3. Manipulation Time - The time elapsed from the touching of the control until the null region was first entered.

4. Adjustment Time - The time taken to reposition the knob within the null region in the event that the null region was passed.

For the Toggle Switch and Pushbutton:

1. Reaction Time - The same as for the knob.

2. Operation Time - The time elapsed from the release of the starting switch until the light was extinguished.

SECTION III

SUBJECTS AND PROCEDURE

Two subjects were used, one a civilian civil service employee and the other a USAF MSgt. The subjects were selected on the basis of their similarity in height and weight so that each subject could wear any of the three suits. Practice sessions were provided for task familiarization.

For the data sessions, the subjects wore the full-pressure suit. Cycles I and IV (table III) were run with the suit uninflated and ventilated and Cycles II and III were run with the suit pressurized to 3.5 pounds per square inch. Two cycles were completed within a session, and each subject performed two sessions in each suit. The entire procedure was repeated, using the same subjects with the second and third suits.

TABLE III

COUNTERBALANCING SEQUENCE FOR SUITED CONDITIONS

Session	1				2			
Cycles	I		II		III		IV	
Pressurization (U or P)*	U		P		P		U	
Hand Condition Left (L) or Right (R)	R	L	L	R	R	L	L	R

* Unpressurized (U) or Pressurized (P)

The subject was required to respond to each control to the right of the mid-sagittal plane in a predetermined random sequence. He was then given a 2-minute rest, and again required to activate these controls, this time in a different predetermined random sequence. This procedure was repeated until each control to the right of the subject was operated five times (replications) in each location. The starting switch was then shifted to the left thigh and the same procedure followed for the left hand operation of the controls located to the left of the subject's mid-sagittal plane to complete one cycle consisting of 120 separate operations (2 hands x 3 controls x 4 locations x 5 replications).

SECTION IV

RESULTS

The results of this evaluation are summarized in table IV and figures 2, 3, and 4.

The most dramatic difference among the suits is evident at control locations 4 and 2. Neither subject could reach any controls in the number 4 location while wearing the pressurized Gemini suit, and only one of the subjects could reach the toggle-switch control located at number 2 location while wearing the pressurized Gemini suit; whereas both subjects could reach and activate all controls while wearing either the pressurized Apollo Phase B or the Apollo 1960 State-of-the-Art suits.

TABLE IV

APOLLO - PHASE-B

			Left Hand								Right Hand							
			Location								Location							
			1		2		3		4		1		2		3		4	
			$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
UNPRESSURIZED	Knob	Reaction Time	.48	.08	.44	.11	.48	.06	.56	.21	.42	.04	.45	.11	.50	.09	.46	.06
		Reach Time	.65	.10	.72	.25	.58	.12	.66	.11	.61	.10	.64	.10	.62	.13	.69	.14
		Manipulation + Adjustment	2.15	.73	2.12	.92	1.81	.61	2.39	.86	1.79	.52	1.83	.68	2.08	.85	2.16	.80
		Performance	3.27	.76	3.28	.93	2.87	.65	3.61	.84	2.83	.57	2.92	.67	3.20	.88	3.30	.84
	Toggle Switch	Reaction Time	.59	.13	.57	.10	.64	.12	.67	.14	.56	.09	.57	.09	.60	.09	.63	.10
		Operation Time	.93	.14	.99	.14	.72	.11	1.09	.32	1.00	.20	.98	.30	.79	.20	1.00	.19
		Performance	1.52	.24	1.56	.18	1.35	.15	1.75	.37	1.56	.19	1.55	.27	1.39	.19	1.63	.16
	Push-Button	Reaction Time	.58	.09	.61	.09	.66	.10	.60	.10	.58	.09	.59	.09	.60	.09	.60	.10
		Operation Time	.96	.15	1.03	.24	.74	.12	.99	.24	.94	.16	.90	.13	.79	.16	.99	.16
		Performance	1.54	16	1.64	.27	1.40	.19	1.59	.24	1.54	.20	1.49	.15	1.39	.17	1.59	.17
PRESSURIZED	Knob	Reaction Time	.50	.13	.50	.07	.49	.04	.49	.06	.46	.06	.48	.06	.50	.14	.49	.10
		Reach Time	1.14	.43	1.15	.26	.73	.25	1.29	.17	1.03	.23	1.04	.22	.74	.25	1.04	.18
		Manipulation + Adjustment	4.97	3.03	3.27	1.01	3.61	1.80	4.05	1.72	4.03	2.78	3.18	2.11	3.28	1.52	2.91	1.47
		Performance	6.61	2.79	4.92	1.05	4.83	1.80	5.83	1.77	5.52	2.85	4.70	2.23	4.52	1.46	4.43	1.49
	Toggle Switch	Reaction Time	.55	.09	.62	.13	.68	.09	.70	.16	.59	.10	.63	.11	.64	.12	.62	.10
		Operation Time	1.61	.25	2.08	.78	.97	.12	1.84	.67	1.36	.32	1.48	.25	.93	.18	1.51	.59
		Performance	2.16	.27	2.70	.80	1.65	.15	2.54	.64	1.95	.32	2.10	.25	1.56	.24	2.13	.63
	Push-Button	Reaction Time	.62	.10	.63	.09	.65	.10	.66	.11	.63	.16	.61	.13	.63	.10	.62	.12
		Operation Time	2.27	.71	2.01	.67	1.11	.29	1.45	.22	1.53	.38	1.51	.32	1.09	.29	1.22	.18
		Performance	2.89	.73	2.64	.66	1.76	.25	2.11	.23	2.16	.48	2.13	.32	1.73	.29	1.84	.22
Percent Increase in Performance Time, Unpressurized to Pressurized Condition		Knob	102		50		68		61		95		61		41		34	
		Toggle Switch	42		73		22		45		25		35		12		31	
		Pushbutton	88		61		26		33		40		43		24		16	

TABLE IV(continued)

APOLLO - 1960 STATE-OF-THE-ART

			Left Hand								Right Hand							
			Location								Location							
			1		2		3		4		1		2		3		4	
			$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
UNPRESSURIZED	Knob	Reaction Time	.42	.05	.42	.05	.44	.05	.45	.05	.43	.04	.42	.06	.42	.03	.44	.06
		Reach Time	.52	.07	.53	.09	.48	.08	.56	.10	.53	.09	.56	.13	.51	.10	.63	.16
		Manipulation + Adjustment	2.17	.73	2.11	.74	2.40	.98	1.77	.57	1.97	.58	2.04	.78	2.17	.84	2.14	.96
		Performance	3.10	.73	3.06	.74	3.33	.99	2.77	.58	2.93	.56	3.03	.77	3.10	.81	3.21	.94
	Toggle Switch	Reaction Time	.56	.09	.55	.06	.53	.05	.55	.05	.58	.05	.54	.07	.56	.07	.55	.07
		Operation Time	.61	.07	.69	.11	.61	.25	.76	.20	.69	.27	.72	.14	.54	.14	.76	.17
		Performance	1.18	.13	1.24	.13	1.14	.26	1.30	.22	1.27	.30	1.26	.16	1.10	.16	1.31	.20
	Push-Button	Reaction Time	.54	.05	.53	.06	.58	.07	.54	.06	.55	.06	.52	.07	.56	.06	.53	.06
		Operation Time	.69	.07	.73	.10	.63	.11	.73	.18	.72	.19	.75	.21	.60	.15	.69	.17
		Performance	1.23	.11	1.25	.12	1.21	.13	1.27	.21	1.27	.20	1.27	.25	1.17	.14	1.22	.19
PRESSURIZED	Knob	Reaction Time	.48	.04	.49	.11	.52	.05	.54	.11	.50	.05	.51	.15	.49	.05	.52	.07
		Reach Time	.75	.19	.94	.16	.65	.15	.90	.32	.96	.13	1.00	.24	.63	.15	.79	.22
		Manipulation + Adjustment	3.82	1.63	3.27	1.73	2.92	.98	3.57	1.56	3.25	1.72	4.07	1.68	3.59	1.81	2.88	1.21
		Performance	5.05	1.57	4.69	1.70	4.09	1.03	5.01	1.53	4.72	1.72	5.58	1.69	4.71	1.87	4.20	1.22
	Toggle Switch	Reaction Time	.62	.06	.64	.07	.63	.04	.62	.08	.61	.07	.64	.15	.62	.04	.64	.04
		Operation Time	1.12	.21	1.39	.11	.70	.12	1.42	.43	1.36	.33	2.03	.39	.77	.13	1.53	.35
		Performance	1.73	.24	2.03	.15	1.33	.14	2.04	.47	1.97	.35	2.67	.45	1.39	.15	2.16	.35
	Push-Button	Reaction Time	.59	.07	.60	.07	.65	.07	.63	.06	.62	.06	.61	.05	.63	.07	.62	.05
		Operation Time	1.24	.33	1.31	.50	.71	.23	1.00	.27	1.17	.20	1.27	.46	.73	.16	.91	.24
		Performance	1.84	.35	1.90	.51	1.37	.22	1.63	.30	1.79	.22	1.88	.46	1.35	.20	1.53	.26
Percent Increase in Performance Time, Unpressurized to Pressurized Condition		Knob	63		53		23		81		61		84		52		31	
		Toggle Switch	47		64		16		57		55		112		26		65	
		Pushbutton	50		52		13		28		41		48		15		25	

TABLE IV (continued)

GEMINI - G2C-1

			Left Hand								Right Hand							
			Location								Location							
			1		2		3		4		1		2		3		4	
			$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
UNPRESSURIZED	Knob	Reaction Time	.41	.06	.44	.06	.44	.06			.44	.05	.43	.06	.46	.06		
		Reach Time	.54	.09	.64	.14	.51	.09			.57	.11	.63	.11	.59	.10		
		Manipulation + Adjustment	1.92	.88	1.87	.68	1.77	.51			1.68	.59	1.66	.63	1.72	.36		
		Performance	2.36	.95	2.95	.76	2.71	.57			2.69	.65	2.73	.69	2.77	.38		
	Toggle Switch	Reaction Time	.56	.09	.56	.12	.57	.09			.59	.09	.56	.11	.55	.11		
		Operation Time	.73	.16	.84	.09	.66	.11			.76	.20	.73	.16	.68	.13		
		Performance	1.29	.19	1.40	.15	1.23	.14			1.35	.21	1.30	.22	1.23	.19		
	Push-Button	Reaction Time	.54	.11	.55	.10	.57	.11			.59	.08	.56	.13	.60	.14		
		Operation Time	.86	.17	.82	.17	.69	.17			.75	.12	.81	.16	.75	.22		
		Performance	1.40	.24	1.38	.19	1.26	.21			1.33	.18	1.37	.23	1.35	.23		
PRESSURIZED	Knob	Reaction Time	.46	.05	.52	.07	.50	.08			.51	.10	.52	.13	.54	.17		
		Reach Time	.76	.21	.96	.15	.91	.26			.66	.20	.77	.14	.85	.21		
		Manipulation + Adjustment	4.15	2.08	3.88	2.11	3.59	2.29			2.85	1.22	3.36	1.38	3.99	2.18		
		Performance	5.37	2.28	5.37	2.15	5.01	2.28			4.02	1.24	4.65	1.45	5.38	2.21		
	Toggle Switch	Reaction Time	.64	.10	.61	.13	.64	.10			.64	.14	.62	.11	.63	.11		
		Operation Time	1.05	.21	2.80	.59	1.34	.29			1.06	.35	2.90	.59	1.48	.60		
		Performance	1.68	.22	3.40	.59	1.97	.32			1.70	.35	3.52	.64	2.12	.60		
	Push-Button	Reaction Time	.64	.09	.69	.17	.64	.14			.61	.19	.61	.11	.65	.11		
		Operation Time	1.20	.40	1.40	.24	1.04	.18			1.08	.31	1.25	.27	1.05	.28		
		Performance	1.84	.43	2.09	.28	1.69	.18			1.70	.33	1.86	.28	1.70	.30		
Percent Increase in Performance Time, Unpressurized to Pressurized Condition		Knob	88		82		85				49		70		94			
		Toggle Switch	30		143		60				26		171		72			
		Pushbutton	31		51		34				28		36		26			

NOTE: The portions inclosed by double lines include only one subject. The other subject could not reach this particular location.

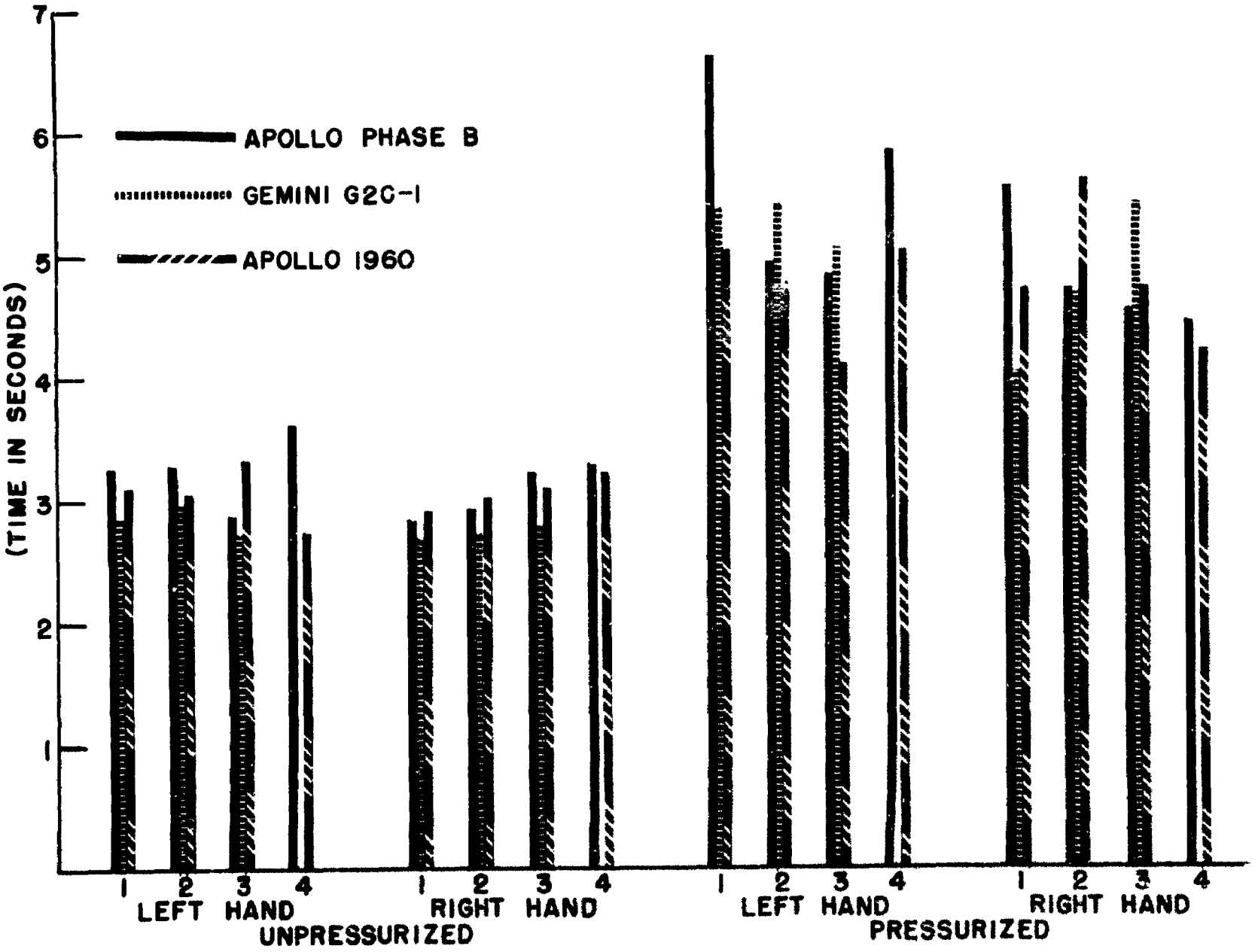

Figure 2. Comparison of Performance Time for Knobs

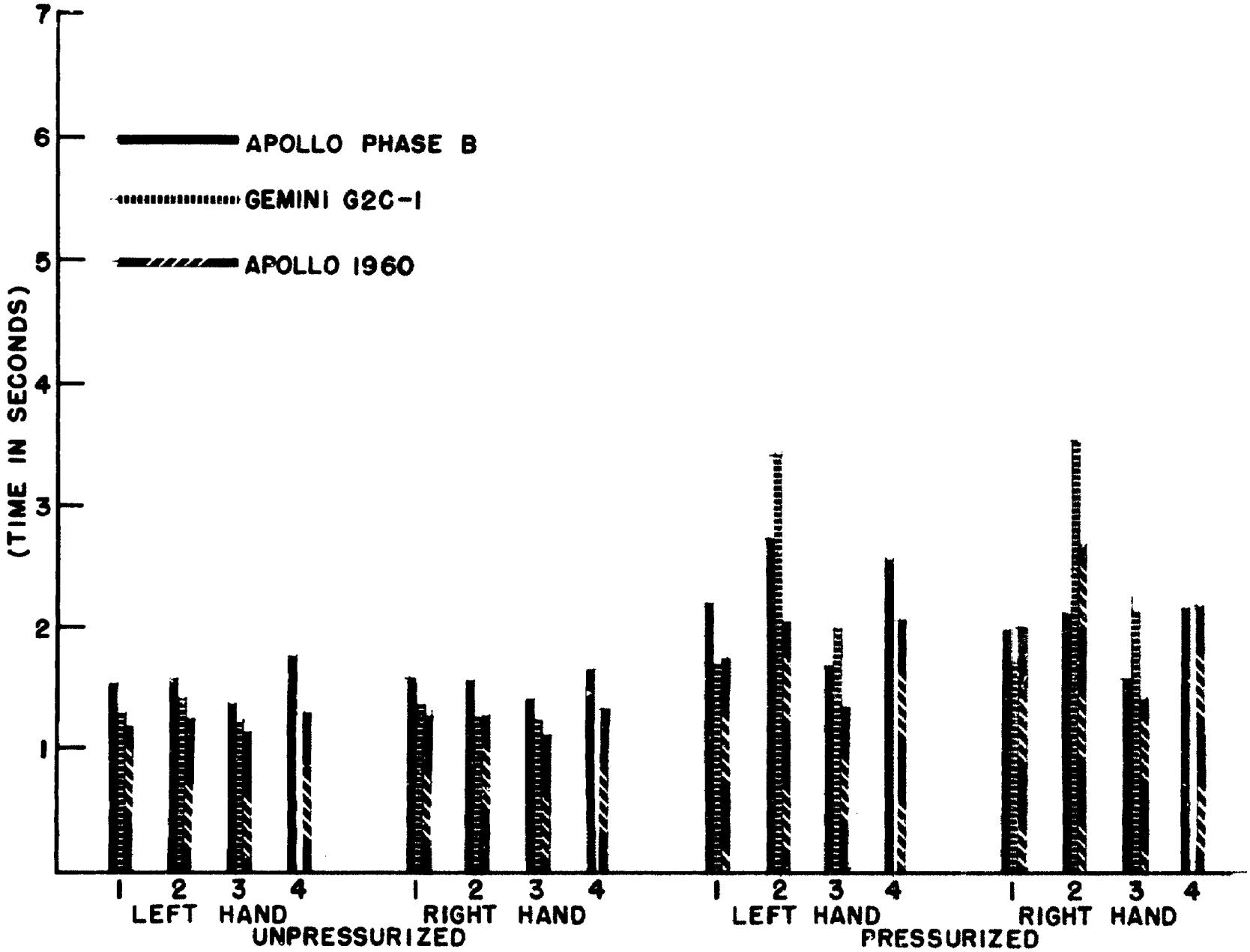

Figure 3. Comparison of Performance Time for Toggle Switches

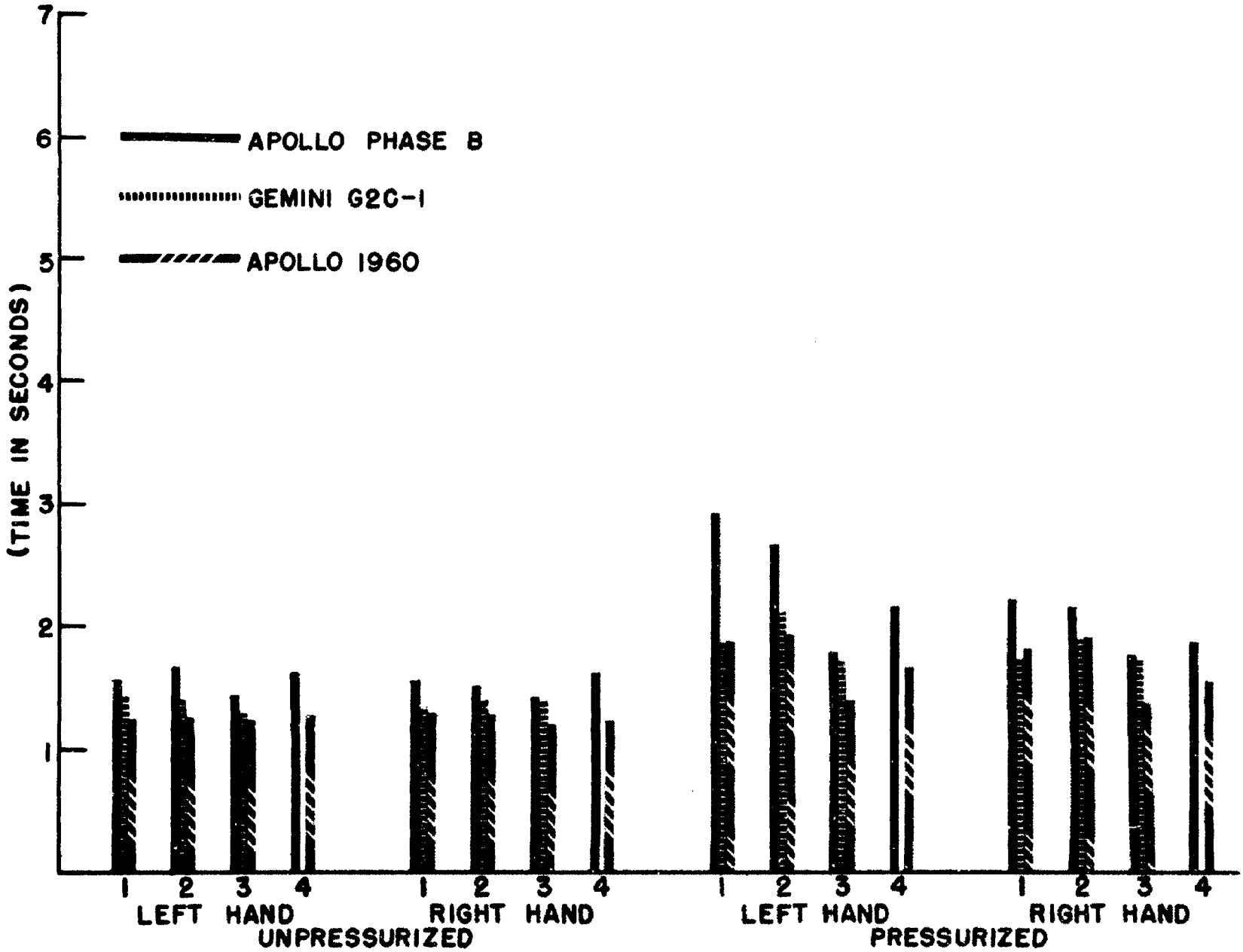

Figure 4. Comparison of Performance Time for Pushbuttons

As can be seen in figures 2, 3, and 4, the time required for subjects wearing the unpressurized Apollo 1960 State-of-the-Art suit to respond to the toggle switches and pushbuttons was consistently shorter at all locations than comparable times recorded when the Gemini G2C-1 or Apollo Phase B suits were worn. For knob operations while wearing the Gemini G2C-1 suit, performance time is consistently shorter than for the other two suits for those locations that could be reached. However, in the pressurized condition, the time required to activate all controls for subjects wearing the Apollo 1960 State-of-the-Art suit was consistently shorter with left-handed operation than for comparable operation wearing the other two suits. For right-handed operation, however, the effects of control location and suit configuration interact in such a manner that the performance times are no longer consistently superior for any of the three suits.

Further information relative to the restrictive effects of the three suits may be gleaned from a review of the component time scores in table IV. Note that the reaction time component was virtually constant over all conditions and contributed little to overall performance variability. The other components of performance time (eg, reach time and manipulation-plus-adjustment time for the knobs and operation time for the toggle switches and pushbuttons) did vary widely as a function of pressure condition, there being a general and substantial increase in these performance time components in the pressurized condition.

The percentage increase in performance time incurred in going from the unpressurized to the pressurized condition gives a convenient summary of subject performance in the two suits for each type of control at each of the eight locations. Of most interest in this respect is the apparent lack of left hand - right hand symmetry in the Apollo Phase B suit. In the Apollo Phase B suit configuration used in this evaluation, over all controls there was a consistently greater decrement in performance in the pressurized as opposed to the unpressurized condition for the left hand. ie, the left-hand operations suffered more from the pressurized condition than did the right hand. The fact that this same relationship is not apparent in the Gemini G2C-1 or the Apollo 1960 State-of-the-Art suits suggested that some design factor in the Apollo Phase B suit rather than subject variables is responsible for the asymmetry.

Summary data showing mean performance, averaged across locations, for each of the three suits is contained in table V. In general, subject performance while wearing the Apollo 1960 State-of-the-Art pressure suit was superior to the performance obtained when either the Gemini G2C-1 suit or the Apollo Phase B suit were worn. This general finding applies to both the pressurized and unpressurized conditions, the only exception being that the Gemini G2C-1 suit was superior to the other suits in permitting faster operation of knob controls in the unpressurized condition.

TABLE V

PERFORMANCE TIMES, TAKEN FROM TABLE 4, AVERAGED OVER CONTROL LOCATIONS

		APOLLO PHASE "B"			GEMINI G2C-1			APOLLO STATE-OF-THE-ART		
		LH+	RH++	RH+LH/2	LH	RH	RH+LH/2	LH	RH	RH+LH/2
UNPRESSURIZED	Knob	3.26	3.06	3.16	2.84*	2.73*	2.78*	3.06	3.07	3.07
	Toggle Switch	1.54	1.53	1.54	1.31	1.29	1.30	1.21*	1.23*	1.22*
	Push-Button	1.54	1.50	1.52	1.35	1.35	1.35	1.24*	1.23*	1.24*
PRESSURIZED	Knob	5.55	4.79	5.17	5.25	4.68*	4.97	4.71*	4.80	4.76*
	Toggle Switch	2.26	1.93*	2.10	2.35	2.45	2.40	1.78*	2.05	1.91*
	Push-Button	2.35	1.96	2.16	1.87	1.75	1.81	1.68*	1.64*	1.66*

* Indicates lowest time score among the three suits for a given condition.

\+ Left hand.

++ Right hand.

Exercise extreme caution in attempting to generalize from these results since only two subjects were used in the experimental conditions. It is because of the small sample size that no inferential treatment of the results are warranted. The interpretation of the results presented in the previous paragraphs appeared permissible although between-subject variation was high and perhaps masked systematic effects of experimental treatments. However, practical limitations are imposed in obtaining a large sample, since it is very difficult to obtain subjects upon whom proper suit fits can be made with the limited sizes and numbers of suits available for evaluation. For this reason, mobility studies on pressure suits will often be limited to statistical interpretation at the descriptive level and limited in generalizability.

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DOCUMENT CONTROL DATA - R&D
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Aerospace Medical Research Laboratories, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio

2a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP
N/A

3. REPORT TITLE
A COMPARISON OF THREE FULL-PRESSURE SUITS IN TERMS OF CONTROL ACTIVATION TIME

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final report, November 1963 - February 1964

5. AUTHOR(S) (Last name, first name, initial)
Sharp, Earl D.

6. REPORT DATE
December 1964

7a. TOTAL NO. OF PAGES
14

7b. NO. OF REFS
None

8a. CONTRACT OR GRANT NO.

b. PROJECT NO 7184

c. Task No. 718402

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
AMRL-TR-64-126

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. AVAILABILITY/LIMITATION NOTICES
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Available, for sale to the public, from the Clearinghouse for Federal Scientific and Technical Information, CFSTI (formerly OTS), Sills Bldg, Springfield, Virginia 22151.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY
Aerospace Medical Research Laboratories, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson AFB, Ohio

13. ABSTRACT

Three pressure suits, both pressurized and unpressurized, were compared on the basis of times taken by two subjects to initiate action and to reach to and operate controls located in various positions in a simulated workspace. The suits compared were the Apollo Phase B, the Gemini G2C-1, and the Apollo 1960 State-of-the-Art. The controls used were knobs, toggle switches, and pushbuttons. The work area investigated was semicircular, extending left and right 78°, 34 to 49 inches above the floor, at a distance of approximately 2 feet. Average times for each combination of suit, suit condition (pressurized or unpressurized), control type, control location, and hand used are presented. No suit appeared to be unequivocally superior. Total time to initiate action and to reach to and operate toggle switches and pushbuttons was typically, although not universally, shorter when wearing the Apollo 1960 State-of-the-Art suit. Total time to initiate action and to reach to and operate knobs was typically, although not universally, shorter when wearing the Gemini G2C-1 suit; however, not all locations could be reached when wearing this suit.

DD FORM 1 JAN 64 1473
AF-WP-B-AUG 64 400

UNCLASSIFIED
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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Human engineering						
Anthropometry						
Anatomy						
Man						
Mobility, pressure suits						
Simulation						
Controls						
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