Motion Performance of Pressure-suited Subjects Under Zero and Lunar Gravity Conditions

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The motions of unsuited and pressure-suited subjects were studied as they performed lunging, egressing and landing tasks during the weightless and lunar gravity maneuvers of a large cabin aircraft. Performance data are presented for various combinations of clothing, gravity and body position conditions. Time and contact data are presented for the egress motion as it is influenced by changes in the exit diameter. Motions of suited subjects generally required 30 per cent more time than corresponding motions of unsuited subjects under both gravity levels. Most motions required 35 per cent more time during zero-G than during lunar-G. No significant differences in egress time were found for four body-position configurations. Five inches of exit clearance improved egress time by 6 per cent. Accuracy of motion rather than time of motion appeared to be a more sensitive measure of operator performance for the egress task.

HAMMER[1] DESCRIBES the motion behavior of the the free-floating, shirt-sleeved operator. In the present paper the description of motion behavior has been extended to include inflated full-pressure suit and lunar gravity conditions. The motion behavior of pressure-suited subjects while lunging, egressing and landing under both zero and lunar gravity conditions are described. A quantitative analysis of the subject's motions and of factors that influence them is presented.

METHOD

Lunging, egressing and landing tasks were structured by having the subjects travel the route shown in Figure 1: depart seat No. 1, egress through an adjustable iris and arrive at and position themselves in seat No. 2 in a zero-G aircraft.

Apparatus—A aluminum iris (Figure 2) was mounted in the aft cabin area of the C-131B aircraft. The iris could be adjusted with a hand lever from 18 to 40 inches in diameter by ½-inch increments. The extensive experimental design and the limited availability of aircraft time precluded the use of more than one shape.

To isolate and define problems the following objective and subjective records were taken: (A) 16-mm. movies were taken of all trials with camera 1 (see Figure 2) covering the egress and landing area, camera 2 the landing area and camera 3 the lunging and ingress area. The films were used to analyze maneuvering techniques, handhold usage, body contacts and to double check the sequence of condition presentations.

(B) Three 1/100-second electric timers were used to record time from seat 1 (see Figure 1) to the iris (T-1, lunge time), through the iris (T-2, egress time) and from the iris to seat 2 (T-3, landing time). The lunging-

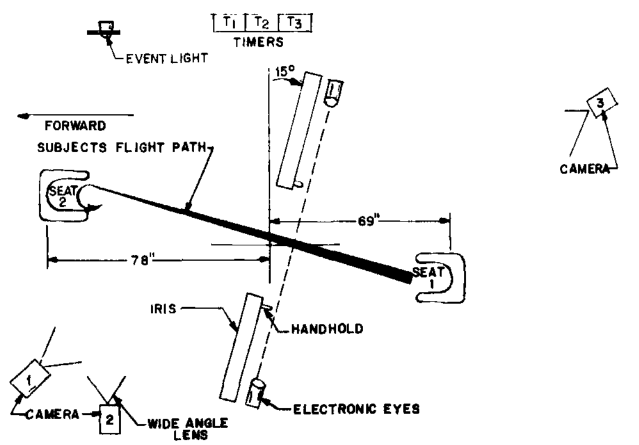

Fig. 1. Test area in zero-G aircraft.

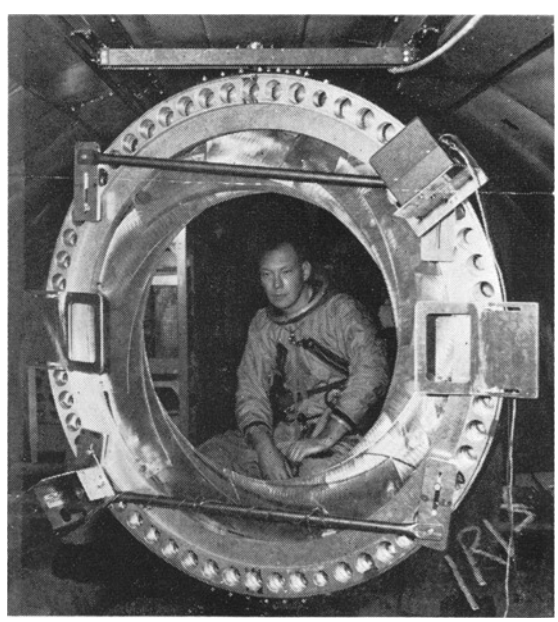

Fig. 2. Adjustable iris, fixed handholds and photo cells.

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time period included the tasks of departure (reaction time), standing, walking, grasping and pulling. The landing-time period included tasks of soaring, grasping, holding, turning and sitting. Lunge time was the time interval between the hand release of a pressure switch in seat 1 and the body's interruption of the photo cell beam at the iris. Egress time was the duration of interruption of the photo cell beam (see Figure 1). Landing time was the interval from egress to body contact on a pressure switch mounted in seat 2.

Ten subjects were used to minimize motion sickness probabilities and apprehension over inflight problems. Only subjects with zero-G experience and complete familiarity with the wearing of the full-pressure suit were selected. For the unsuited trials the subjects wore regulation summer flying suits and a soft safety helmet. For the pressure-suited trials they wore the A/P-22S-2 full pressure suit which was designed for an operational inflation level of 3½ psi. (This pressure level is now being considered for future space requirements, with a safety factor of inflating to 5 psi in case of abnormal occurrences, such as bends, etc.) In our tests a pressure level of 2½ psi was maintained by a press-to-test feature (Figure 3). A relief valve allowed an inflation pressure of 2½ psi and a dump valve for any added pressure which was supplied.

A portable air supply inflation unit (Figure 3) was worn by the subjects to free them from aircraft-connected lines or hose and allow them to maneuver and soar freely. The air supply unit provided a four-minute supply of air for breathing and for inflating the suit. A shut-off switch on the air bottles conserved the air supply between parabolas. Figure 3 shows the integration of the high pressure bottles and the A/P-22S-2 full pressure suit.

EXPERIMENTAL DESIGN

Each subject was given 48 trials during two flights. Three subjects were rerun to study learning and fatigue effects. The experimental variables were selected after a prior pilot-study involving three of the subjects.

The experiment was a fixed factorial design with four treatments (gravity, clothing, iris clearance and body position for approach to iris) and 13 orders of presentation. Subjects and presentation-order were compounded. The following treatment levels were presented in a partially counterbalanced order.

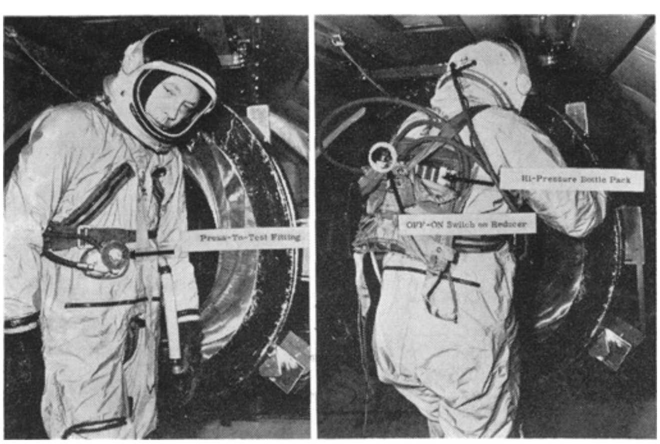

Fig. 3. Portable air supply inflation unit.

Iris Clearance
- —"shoulder width" plus *one* inch
- —"shoulder width" plus *five* inches
- —"shoulder width" plus *ten* inches

Body Position for Approach to Iris
- —head-first, side handholds
- —head-first, bottom handholds
- —feet first, side handholds
- —feet-first, top handholds

Gravity Conditions
- —Zero gravity (0-G ± .05)
- —Lunar gravity (.17G ± .025)

Clothing
- —Unsuited (Coverall)
- —Inflated Pressure Suit

The unsuited "shoulder width" of all subjects was measured directly. Two inches were added to this dimension to obtain "shoulder width" for the suited condition. Iris diameters were equated by adjusting the iris for each trial to each subject's "shoulder width" plus clearance. Clothing levels were only partially counterbalanced because of the subject's inability to rapidly don a pressure suit between trials.

Film from cameras #1, #2 and #3 were projected in slow motion for two film editors who independently tallied handhold usage and all discernable touches (contacts) the subjects made with the iris. A third editor resolved disagreement about contact occurrences. Data cards were punched for subjects x trials with the following coded bits of information:

- Test Date
- Trial No. (1-24)
- Subject (1-13)
- Clothing (coverall or pressure suit)
- Gravity (zero-G or lunar-G)
- Iris diameter (+1, +5 or +10″)
- Position-handhold (1, 2, 3 or 4)
- Hangup (subject's progress has stopped)
- Body contacts (including head, shoulder, arm, hand, back, butt, hip, upper leg, stomach, knee, calf, shin, ankle, heel, sole or toe, also left, right or both for limbs)

No attempt was made to separate purposeful from inadvertent contacts. The subjects were instructed to use the handholds and not the iris as the primary source of propulsion. Time scores were separately recorded and permitted a comparison of main effects and first order interactions. An analysis of contact scores permitted time-accuracy comparisons.

RESULTS

Statistical means for the subjects' clothing, gravity, iris clearance and position handhold were plotted for the following figures:

Total Time—These figures represent time scores required for the entire mission of launching, egress and

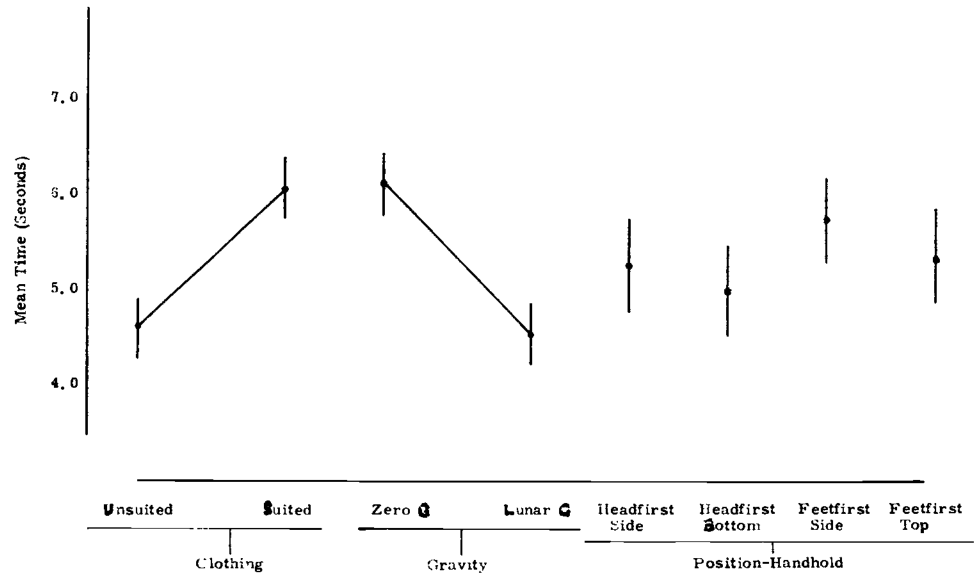

Fig. 4. All motions—time plot of clothing, gravity and position-handhold conditions. Dot represents mean and vertical bar indicates where the mean will fall 95 per cent of the time.

landing and do not represent any single motion.

Suited motions required 32 per cent more time than unsuited motions. Motions performed during zero gravity required 35 per cent more time than equivalent motions performed during lunar gravity.

The headfirst-bottom handhold-position technique for iris passage was the quickest method and the feetfirst-side technique was the slowest method. The latter required 15 per cent more time than the former. It appeared to be easier to tuck the arms under the body rather than to the side of the torso, the latter technique frequently causing underarm hangups.

Figure 5 indicates that approximately 30 per cent more time was required under O-G than under lunar gravity when unsuited and 40 per cent more time when suited. In approximate terms, A SUITED SUBJECT PERFORMED AS WELL AT LUNAR G AS AN UNSUITED SUBJECT AT ZERO G. Apparently the mobility restrictions of the suit were offset by the poor body control during the zero-gravity condition. For all maneuvers under all G conditions the suited condition was inferior to the unsuited condition.

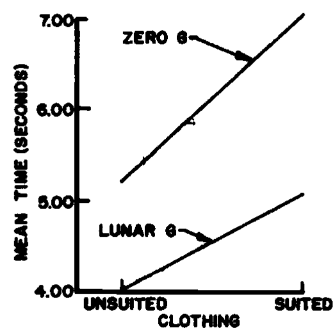

Fig. 5. All motions—time plot of two clothing conditions for two gravity conditions.

Egress techniques appear virtually equivalent under the lunar gravity condition. However, under zero-G the side handhold appears to be definitely inferior to

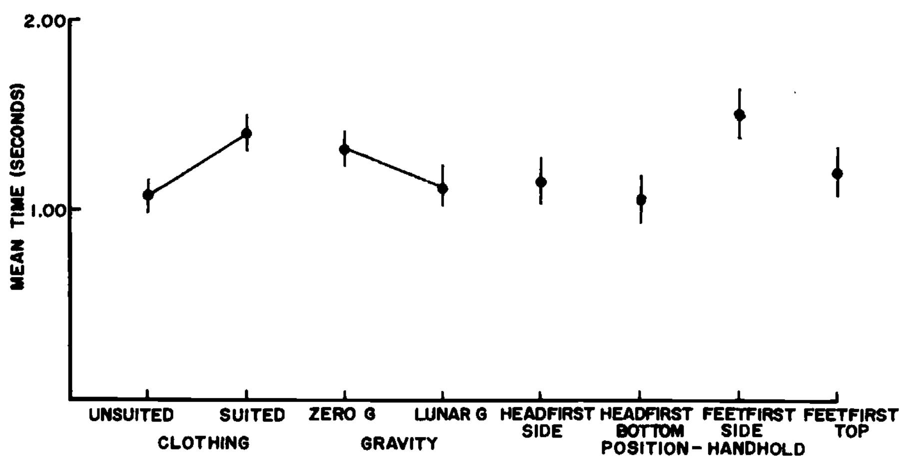

Fig. 6. Lunge time—time plot of clothing, gravity and position-handhold conditions. Dot represents mean and vertical bar indicates where the mean will fall 95 per cent of the time.

other techniques. The effect of this egress technique appears in the lunging and landing tasks and is exaggerated in the suited condition. It was difficult for a suited subject to raise his arms sideways, over his head.

Lunge Task—The approach to the iris consisted of a set of smooth motions. Rather than standing up, walking, leaning and jumping, most subjects used a single, seat-launched lunge motion. Under lunar and zero gravity conditions their feet normally left the floor before their hands left the armrest (the right hand release started the first timer). This takeoff posture was particularly evident when they used a feet-first egress technique. In this case a hand-launched rather than a foot-launched thrust was clearly evident. Frequently subjects did not change from their sitting posture until well through the iris for foot-first approaches.

Reference Figure 6 suited motions required 32 per cent more time than unsuited motions and motions during zero gravity required 17 per cent more time than during lunar gravity. The cause of the latter appeared to be the poorer body control shown by the subjects after they had grasped the handholds.

The headfirst-bottom technique was the quickest and feetfirst-side technique the slowest, with the latter requiring 42 per cent more time than the former. The latter required a body rotation while using side handholds (biomechanically an awkward motion). The former technique often required handholds only to guide the momentum attained during the initial seat-launched lunge. Several subjects sailed headfirst through the larger clearances without touching the bottom or side handholds.

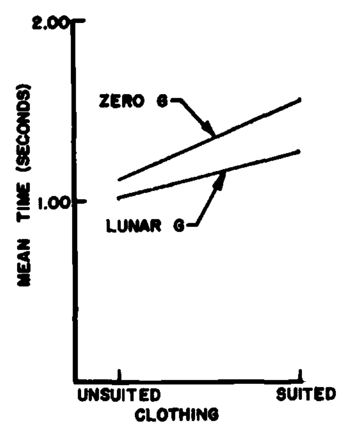

Fig. 7. Lunge motion—time plot of two clothing conditions for two gravity conditions.

Figure 7 indicates that lunging at zero-gravity required from 11 per cent (unsuited) to 22 per cent (suited) more time than did lunging under lunar gravity conditions.

Figures 8 and 9 again reveal the awkwardness of the feetfirst-side handhold technique which is particularly detrimental under zero-gravity and suited conditions. Use of the feetfirst-side technique required 21 per cent more time under unsuited conditions and 64 per cent more time under suited conditions than the quickest technique (Figure 9). The pressure suit appeared to amplify a difficulty that also existed for the unsuited subject.

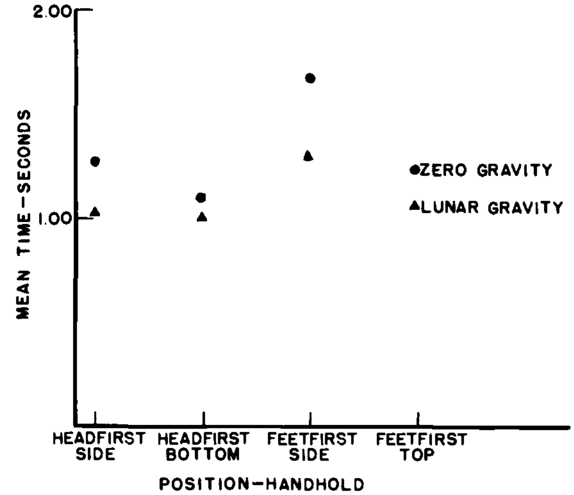

Fig. 8. Lunge motion—time plot of four position-handhold conditions for two gravity conditions.

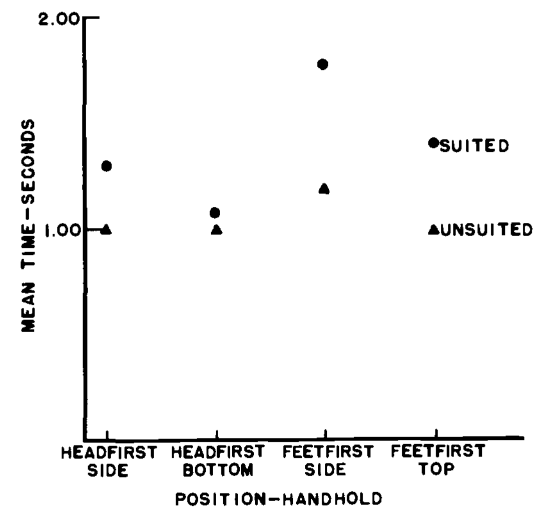

Fig. 9. Lunge time—time plot of four position-handhold conditions for two clothing conditions.

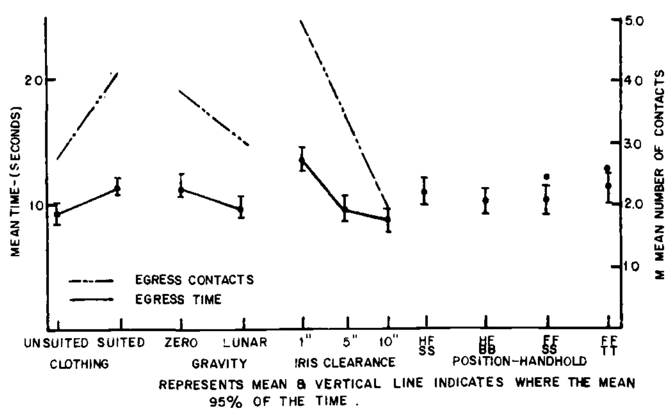

Fig. 10. Egress motion—time plot of clothing, gravity, iris clearance and position-handhold conditions.

Egress Motions—Figure 10 suggests that suited motions required 34 per cent more time than unsuited motions. Zero gravity required 19 per cent more time than lunar gravity. Since egress times were less for lunar gravity than zero gravity and one could assume that egress time would be considerably longer at earth gravity, THERE IS PROBABLY A G LEVEL BETWEEN ZERO AND ONE FOR WHICH EGRESS TIME WILL BE MINIMUM. This suggests that there is an optimum G level for other motions. If so it would provide another criterion for selecting an artificial gravity level for rotating space stations.

Egress time was inversely related to iris clearance. One-inch iris clearance required 55 per cent more time for egress than ten inches and five inches required 11 per cent more time than ten inches. The curve appears to approach an asymptote between five and 10 inches of clearance. The only aborted trials (a subject stuck in the iris, unable to move) occurred with a one-inch iris clearance.

Particularly significant was the finding that most of the position-handhold techniques were similar in time but dissimilar in manner of contacts.

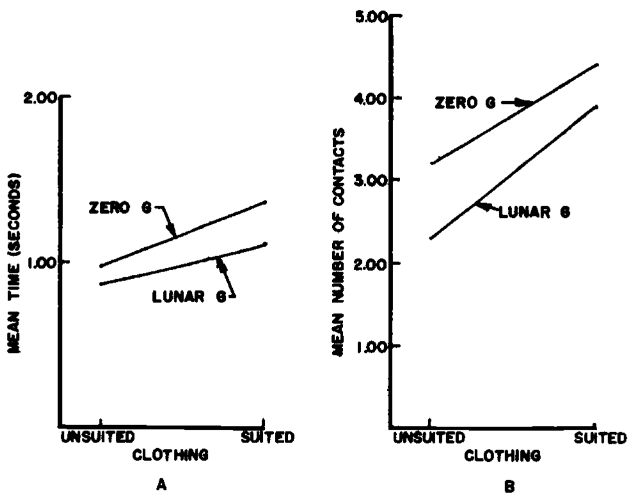

Fig. 11. Egress motion—a time (A) and contact (B) plot of two clothing conditions for two gravity conditions.

Figure 11 indicates that there is a greater percentage increase in contacts than in time under suited conditions.

Figures 12 and 13 suggest that the largest time improvement appears to be within the one-to-five-inch clearance range whereas contacts appear to decrease linearly within the one-to-ten-inch clearance range.

The feetfirst techniques were the slowest techniques for lunging and landing and they yielded the smoothest egress, probably due to the subject's ability to see his legs in relationship to the iris and better position his lower torso. Several suited subjects reported that they did not know where their legs were, apparently due to poor kinesthetic feedback because of the lack of forces on the pressure receptors while suited under pressure and sailing over, rather than walking on, the floor. Accuracy of motion rather than time of motion may be a more sensitive measure of operator performance for the egress motion. However, the absolute number of contacts is too small to confirm this hypothesis.

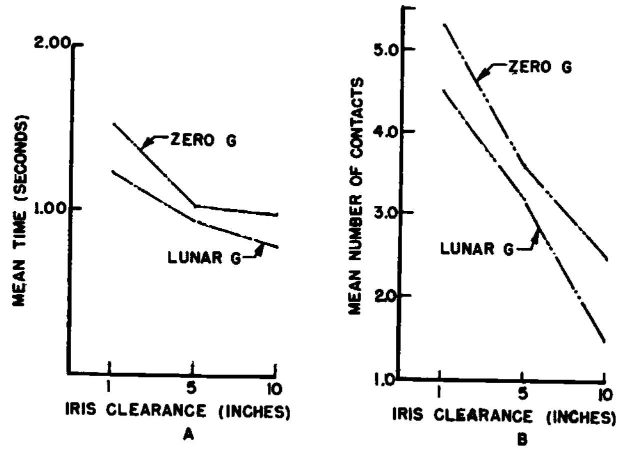

Fig. 12. Egress motion—a time (A) and contact (B) plot of three iris clearances for two gravity conditions.

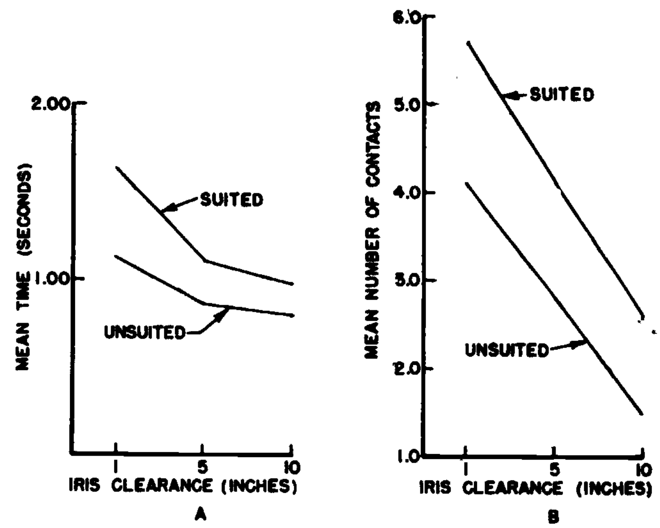

Fig. 13. Egress motion—a time (A) and contact (B) plot of three iris clearances for two clothing conditions.

Figure 14A indicates that the 1-5 inch clearance range yielded the largest time differences although techniques did not differ. Again, contact scores appear to differ over the 10-inch range and show a marked improvement for the feetfirst techniques. One could speculate that if the subjects had taken more time the magnitudes of the contact scores would probably decrease but the relative differences between techniques would probably be maintained.

Figures 15A and B suggest that the number of upper torso contacts was consistently higher for the suited and zero gravity conditions whereas the lower torso contacts appear to be random. One could suppose that the upper torso contacts were purposive and lower torso contacts were generally aimless and the result of flailing limbs. Fig. 15C indicates a progressive decrease in the number of contacts for the upper torso

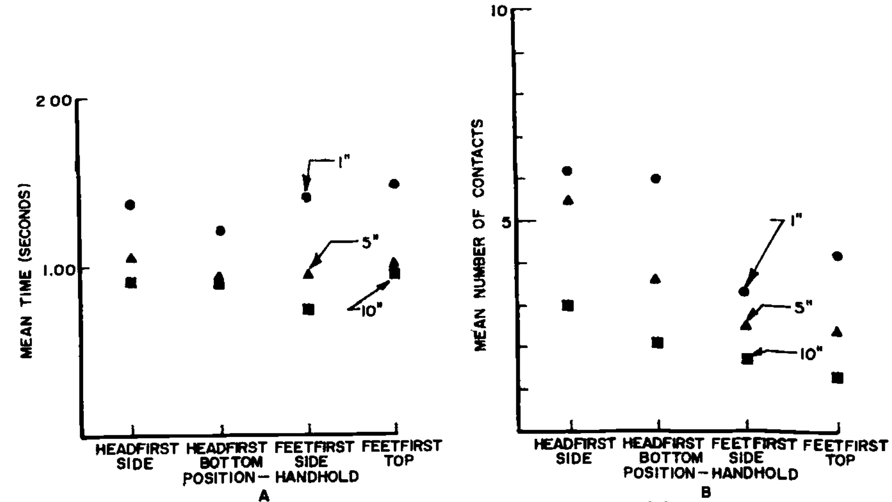

Fig. 14. Egress motion—a time (A) and contact (B) plot of four position-handhold conditions for three iris clearances.

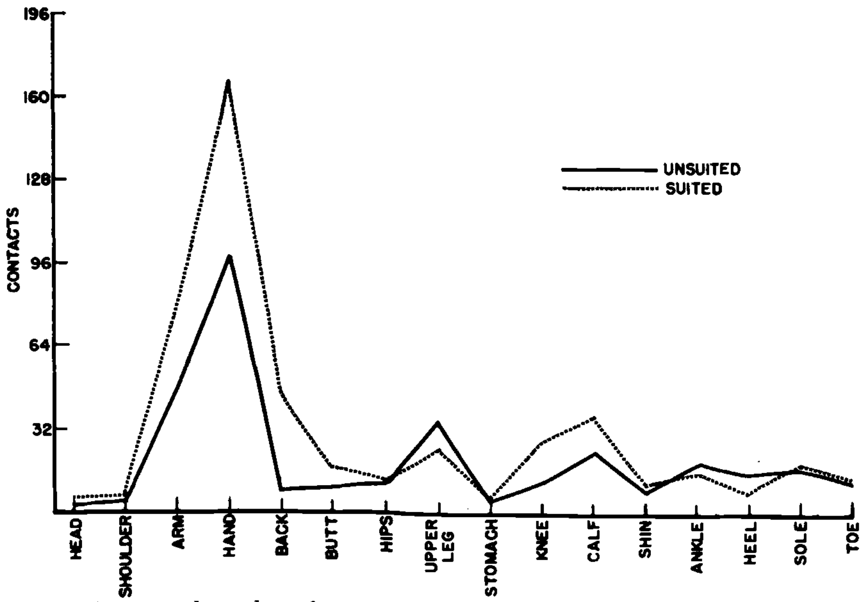

Fig. 15 A. Total number of contacts for each body segment for all conditions.

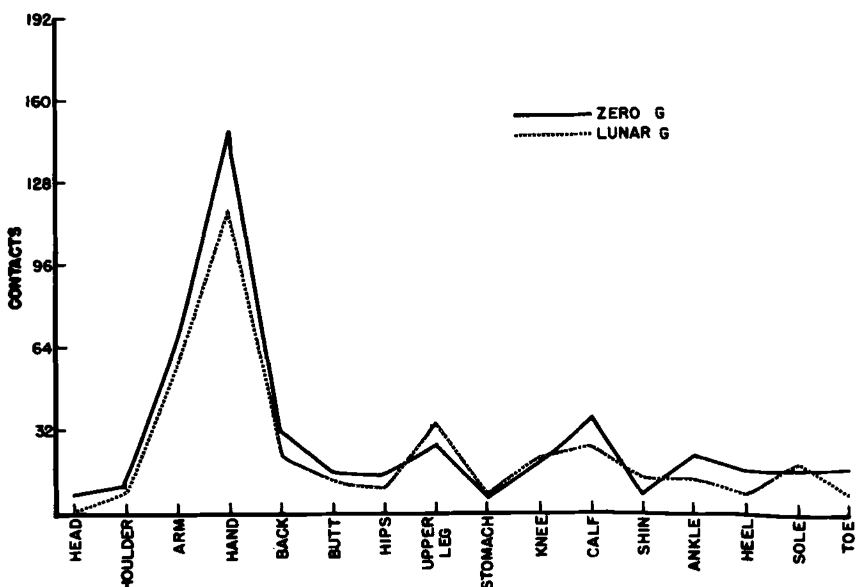

Fig. 15 B. Total number of contacts for each body segment for all conditions.

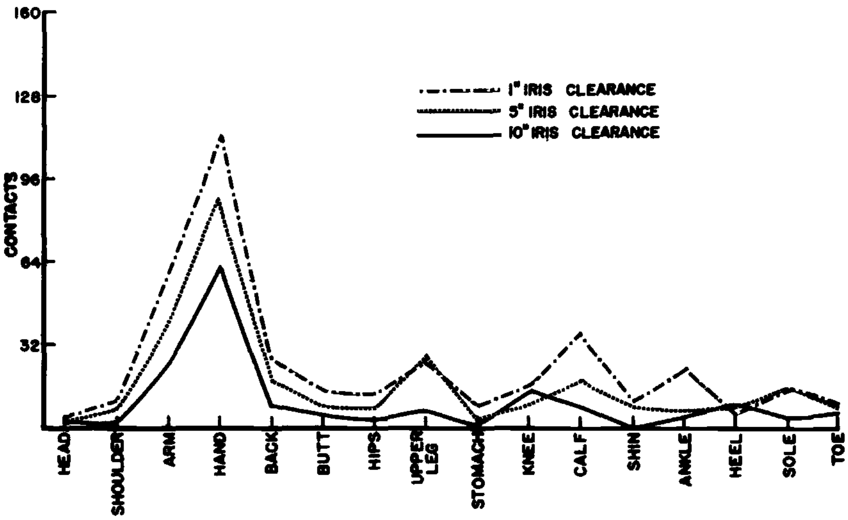

Fig. 15 C. Total number of contacts for each body segment for all conditions.

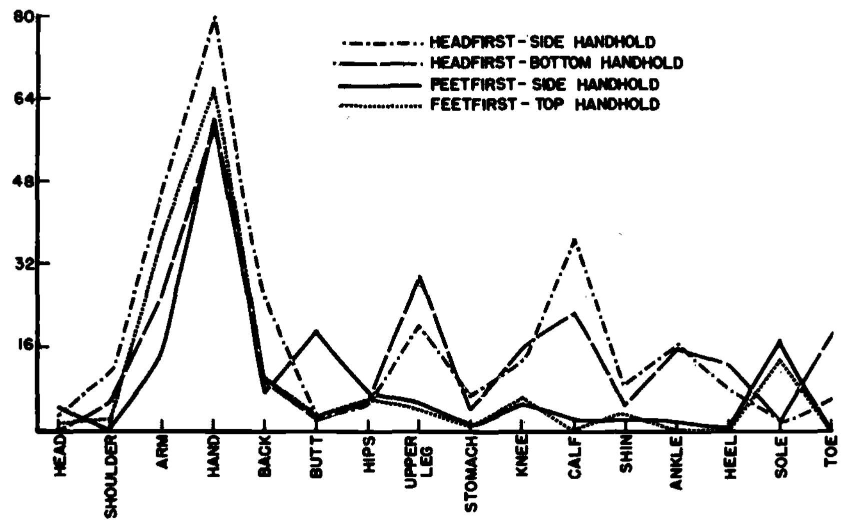

Fig. 15 D. Total number of contacts for each body segment for all conditions.

as iris clearance increases; however, lower torso contacts again appear to be random throughout the iris clearance range.

Future studies should attempt to isolate purposeful from inadvertent contacts so that a contact measure truly reflects either accurate or inaccurate flight paths but not both categories. For example, the soles-of-the-feet contacts for feetfirst approaches could probably be considered as deliberate contacts.

We expected more differences between gravity levels when the subjects' feet left the floor for the egress task. It was supposed that the subjects would tend to scrape through the iris during lunar G because of the small but existent downward attraction of gravity. Fig. 15B, however, indicates that the lunar G condition yields fewer contacts than zero G. The difference is probably due to the more accurate body control of the subject during the lunar G approach task.

Figure 16 indicates that suited landing motions required 31 per cent more time than unsuited motions. Motions during zero gravity required 50 per cent more time than during lunar gravity. This extremely large time difference suggests the relative helplessness of the flailing subject attempting to reach a surface during the zero-G condition.

Figure 17 indicates zero gravity required 45 per cent more time than lunar gravity in the unsuited condition and 54 per cent more time in the suited condition.

The wide spread between means in Figure 18 suggests that arriving headfirst enhances body control under suited conditions. Frequently subjects overshot or missed the seat and found it difficult to turn around and align with the seat when arriving feetfirst. Subjects often found themselves hovering over the seat during zero gravity and awkward pushing motions were made on cabin surfaces when the subjects could not grasp the seat. With small iris openings it was difficult to see around one's legs to the landing area.

Handhold Preferences—An analysis of film from camera #3 (subjects ingressing through the iris) revealed hand position preferences for each of the three fixed handholds (top, sides and bottom). When the top bar was used for ingress all subjects gripped the bar in a

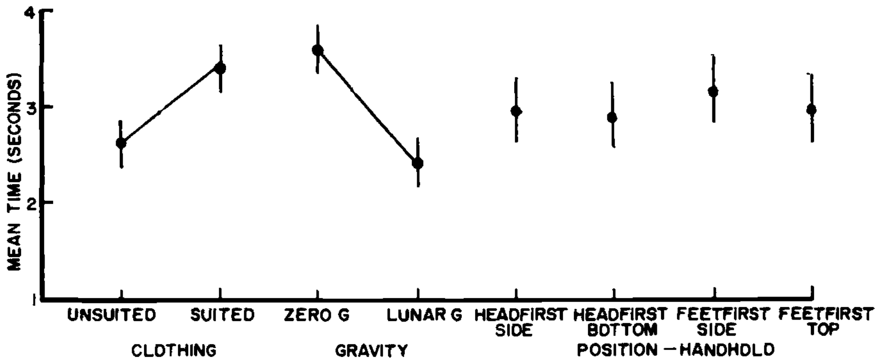

Fig. 16. Landing motion—time plot of clothing, gravity and position-handhold conditions. Dot represents mean and vertical bar indicates where the mean will fall 95 per cent of the time.

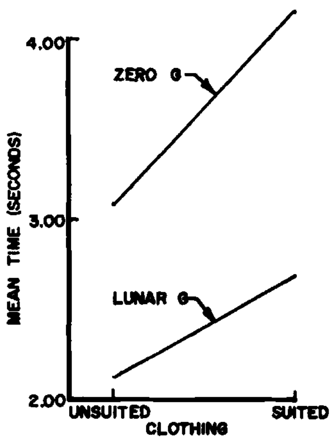

Fig. 17. Landing motion—time plot for two clothing conditions for two gravity conditions.

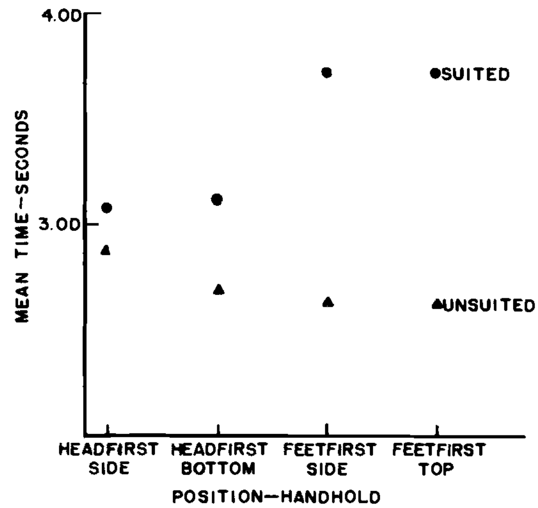

Fig. 18. Landing motion—time plot of four position-handhold conditions for two clothing conditions.

palm down attitude (pronated). When the side handholds were used 90 per cent of all trials were accomplished with the palms facing medially. For the bottom handhold 90 per cent of all egress trials were accomplished with the palm-down hand-position (pronated). There were no significant differences in handhold preference between suited and unsuited conditions.

SUMMARY

The motions of unsuited and pressure-suited subjects performing lunging, egressing and landing tasks under zero and lunar gravity conditions were studied. The subjects were timed and filmed during the trials and interviewed after each trial as they accomplished the motions during the weightless and lunar gravity maneuvers of a large cabin aircraft. Performance data are presented for various combinations of clothing, gravity and body position conditions. Time and contact data are presented for the egress motion as it is influenced by changes in exit area. Orientation problems and maneuvering techniques as influenced by area and volume restrictions are discussed.

Time Scores—A. Suited motions required approximately 30 per cent more time than unsuited motions for both gravity levels.

B. All motions required approximately 35 per cent more time during zero gravity than during lunar gravity. Zero gravity required approximately 30 per cent more than lunar gravity under unsuited conditions and 40 per cent more time under suited conditions.

C. The headfirst-bottom handhold body position proved to be the quickest approach, egress and landing technique. The feetfirst-side handhold position was the slowest. There was no appreciable difference between a headfirst-side handhold and a feetfirst-top handhold egress technique.

D. Egress time was inversely related to the exit clearance dimension. Five inches of exit clearance improved egress time by approximately 6 per cent.

E. Soaring, landing and sitting required 45 per cent more time for the suited subject and 54 per cent more time for the suited subject under zero-gravity conditions. Zero gravity tended to increase the total mobility of the subject compared to earth gravity but overcontrol and surface freedom retarded his task performance.

Contact Scores—Contact with the exit area was made twice as often in the suited condition as compared to the unsuited condition. The subjects contacted the iris twice as often with a one-inch clearance than with a ten-inch clearance. The subjects struck the edge of the iris most often when using the head-

first-side handhold technique and made fewer contacts when using the headfirst-bottom handhold technique. Subjects who egressed feetfirst made still fewer contacts using either top or side handholds. The feetfirst approach resulted in half as many contacts as the headfirst approach. The same order of exit method success held true for both suited and unsuited subjects.

Accuracy of motion with the environment rather than time of motion appeared to be a more sensitive measure of operator performance for the egress motion.

New Motions—No attempt was made to relate these soaring motions to earth gravity conditions because of the subject's inability to adequately perform these "surface-free motions" under one g conditions.

A. A one-G ingress motion would normally consist of standup, walk, grasp, pull and step motions. During low gravity conditions these fairly discrete motions were replaced with a smooth seat-launched lunge. The resulting floating of the subject allowed retention of the seated posture for a feetfirst approach.

B. A one-G egress task would require steps and climbing motions. These independent motions in a one-G environment were replaced by a continuous motion made possible by low gravity conditions, resulting in a saving of time and effort.

C. A one-G landing motion would probably require less time and would consist of walking, turning and sitting motions. The unaided soarer experienced flailing movements in attempts to return to the surface. Soaring motions during landings required 50 per cent more time during zero gravity than during lunar gravity which suggests the relative helplessness of a flailing suited-subject arriving at a surface. Arriving at a surface feetfirst without a handhold required 20 per cent more time than with the headfirst soar. Arriving at his seat the suited subject had noticeable difficulty in attaining and maintaining a seated posture. The suited operator required 33 per cent more time than the unsuited operator and zero gravity required 20 per cent more time than lunar gravity for the landing motions.

There is good reason to suspect that man will choose many new motions for performing other tasks in low gravity environments.

APPENDIX

The Lunar Gravity Maneuver

Mr. B. C. Dixon

Lear Siegler Service, Inc.

AF Contractor

The ever-changing requirements in space oriented research have necessitated the cabin aircraft used for Zero-G maneuvers to also simulate lunar gravity (.17 earth gravity). The maneuver for lunar gravity is accomplished in the same general manner as a Zero-G parabola. The following sketch illustrates the five phases of the lunar and zero gravity maneuvers as flown in a C-131B aircraft.

During Phase 1 the aircraft is maintained in level flight while preparing to enter the maneuver. At Phase 2 the aircraft is placed in a 12° dive and military thrust power applied until 250 knots indicated airspeed is attained. At this point, Phase 3, the aircraft is maintained at 2.5 normal acceleration in a climb until a 35° pitch up attitude is reached. Beginning Phase 4 the stick is pushed forward to push the nose of the airplane down. By controlling the pitch attitude of the aircraft the desired gravity level is maintained until a pitch down attitude of 35° is reached. Phase 4 is that portion of the maneuver in which lunar gravity and zero gravity maneuvers differ. During this phase the aircraft will float higher and longer during a lunar gravity maneuver than in a zero gravity maneuver. The selected gravity level (zero lunar) to be flown is displayed to the pilot on the horizontal bar of a Model 4055D attitude director indicator. By keeping the horizontal bar at center the selected gravity level is maintained throughout Phase 4 of the maneuver, which is approximately 15 seconds duration. Accuracy of ± .005G can be maintained for eight to 12 seconds with the remaining three to seven seconds ± .025G accuracy. Phase 5 is the pull-out phase during which the aircraft returns to level flight with a 2.5 normal acceleration pull up.

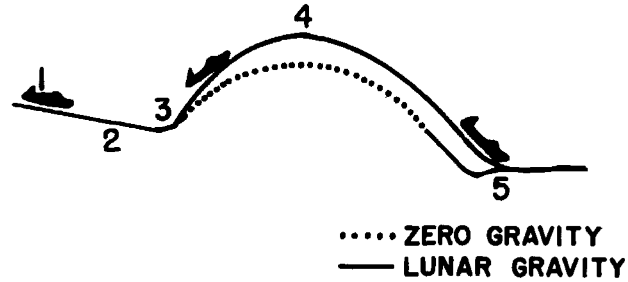

Fig. 19. Lunar and zero gravity maneuvers.

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