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A TECHNIQUE TO INVESTIGATE SPACE MAINTENANCE TASKS

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FOREWORD

This study was conducted jointly by the Aerospace Medical Research Laboratories and the George C. Marshall Space Flight Center, National Aeronautics and Space Administration. The work is documented under Air Force Project 7184, "Human Performance in Advanced Systems;" Task 718405, "Design Criteria for Crew Stations in Advanced Systems." This study was funded in part by NASA PR No. T-18811-G.

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Special thanks are due Mr. P. Woodbury of Brown Engineering Company for his dedicated work in developing the performance task sequence and for his contributions in design of tools for space maintenance.

The authors wish also to thank Lieutenant E. H. Sasaki and Master Sergeant C. W. Sears, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, for their assistance.

This technical report has been reviewed and is approved.

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ABSTRACT

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A series of preliminary studies was performed to determine if a high-fidelity ground-based simulation of zero gravity is necessary to obtain valid information about zero-G maintenance performance. Removal and replacement of a prestart solenoid valve on a rocket engine was selected as the basic maintenance task to be studied. Time scores for laboratory performance of the task were compared with scores obtained from subjects operating on the task during periods of transient weightlessness in a KC-135 aircraft. Modified hand tools, a tool box, and a worker tethering system were developed for use in the experiment. Major conclusions were (1) the factor contributing most to performance decrement in space maintenance was space suit pressurization level; (2) in this study, the effect of weightlessness on performance was less than the effect of suit pressure level, and, in this instance, it would not have been necessary to introduce zero-G conditions to conduct a meaningful study of space maintenance performance.

Author

INTRODUCTION

This report presents the results of a series of preliminary studies directed toward understanding performance problems of space-suited workers in maintaining space vehicles under weightless conditions.

The data reported pertain only to the full-pressure suit designed by the International Latex Company (1960) and designated the "State-of-the-Art" suit by National Aeronautics and Space Administration (NASA). The gloves used throughout these studies were supplied by the Crew Systems Branch of the Manned Spacecraft Center, NASA. The suit and gloves were designed for seated application at control/display consoles. Since the equipment was not designed for our operations, it would be unfair to comment on its adequacy for the performance of space maintenance tasks. Whether special suits or gloves will prove necessary for space maintenance remains for others to determine.

Our goal, initially, was to determine if a high-fidelity ground-based simulation of zero-gravity was necessary to obtain valid information on zero-gravity maintenance performance of pressure-suited subjects. Incidental to the overall goal, other problems presented themselves and were dealt with. These were

- a. What performance effects on the selected tasks were attributable to pressure suit mobility restrictions?
- b. Were serious measurable performance restrictions imposed by the zero-gravity environment?
- c. Can a method be devised to quantitatively evaluate psychomotor performance of space-suited workers?

PROCEDURES

A basic maintenance task was selected which might be representative of the type of task required of a space-suited worker during the course of a prolonged space mission. This task consisted of removing and replacing a prestart solenoid valve on a Model RL-10 rocket engine. The engine was mounted within a plywood mockup of the KC-135 zero-G aircraft (figure 1). Figure 2 shows a closeup of the prestart solenoid valve.

Initial performance data were obtained in the KC-135 mockup at Marshall Space Flight Center (MSFC), Huntsville, Alabama, and were gained mainly from the training of subjects in task performance sequence. Partial simulation of aircraft flight maneuvers was made possible by using a lever and spring scale device to impose 2-G loads on the subject. The lever was attached to a line which was connected to a hook between the subject's legs. Dry air, conditioned to 10 C at a flow of 9.5-11.5 cfm was provided for conditioning and pressurization. This combination of temperature and flow proved adequate to maintain a tolerable suit environment. Three subjects were trained and tested in the mockup. One of these subjects was also tested in the KC-135 zero-G aircraft with two other subjects at Wright-Patterson Air Force Base, Ohio.

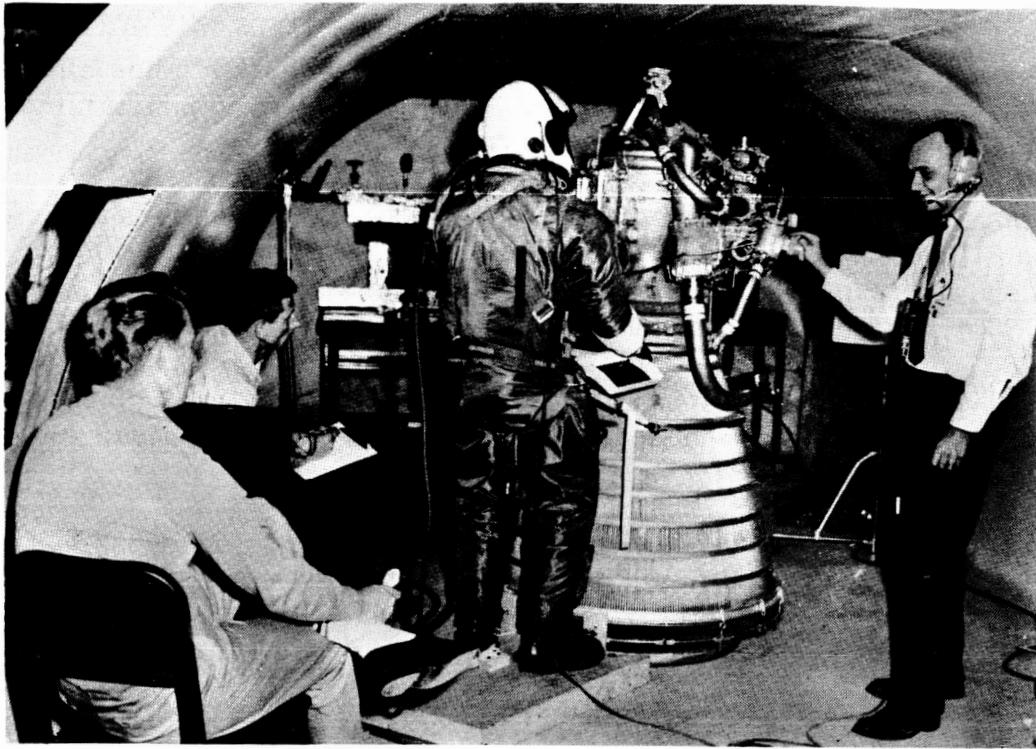


Figure 1. RL-10 Engine Installed in Mockup.

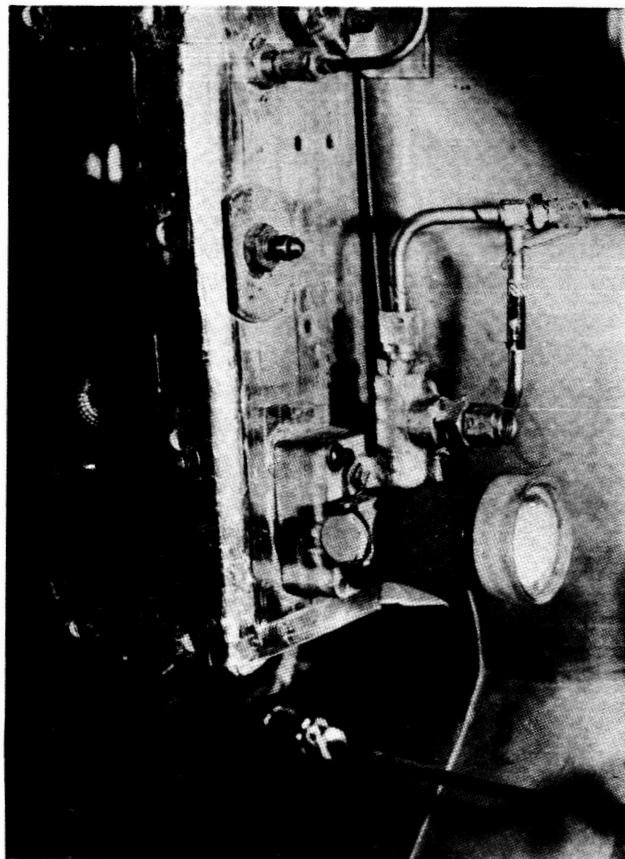


Figure 2. Prestart Solenoid Valve.

Another condition in these experiments was the selection and use of a body tethering system.* Two waist straps and two toe hooks effectively connected the subject to the work area and served quite well in preventing the translation of rotational torques to a subject under weightless conditions (figure 3).

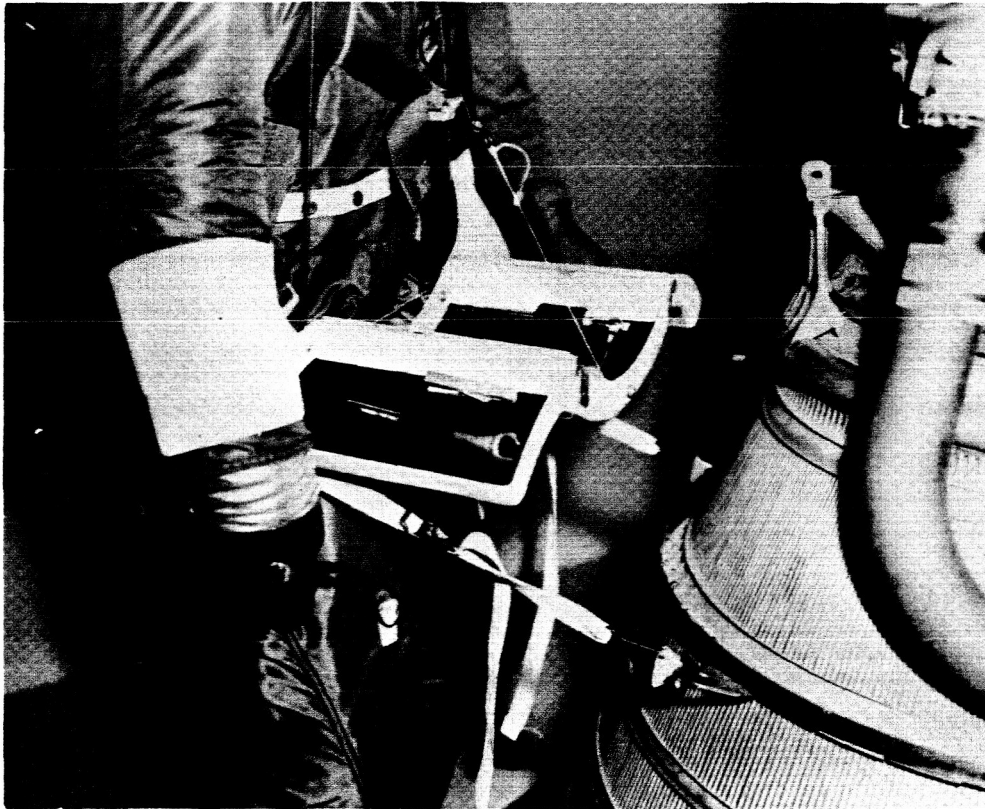


Figure 3. Subject Shown in Working Position.

The tools shown in figure 3 were modified for use with pressurized gloves. Modifications were no more radical than increasing the diameter of tool handles, and were required to ensure that the tools could be positively grasped and held by hands encumbered by inflated gloves. Wherever possible, handles were made at least 1.5 inches outside diameter. The fiberglass tool box is 15 inches long, 10 inches wide, and 4 inches thick, and is lined with Velcro[®] to hold tools in a zero-gravity environment. Velcro was also affixed to those tools which were used on our task. Safety wires, used to retain nuts, were removed from the engine to negate the possibility of puncturing the suit or gloves. The tool box was positioned on the front of the subject (figure 3) using a system of spring coils and hooks. The box served effectively as a tool receptacle. On occasion, however, it slipped out of its correct position thereby preventing the subject, under pressurized conditions, from seeing that portion of the box closest to his body. The Velcro material required deliberate acts for removing and replacing tools. This added a control to the time required for task performance. Although no analysis was performed, we believe the time required for tool removal and replacement was essentially the same for all subjects.

*This system and the fiberglass tool box were developed by Captain Mueller at Wright-Patterson Air Force Base, Ohio.

During ground-based tests, instructions given to the suited subject were identical to those he would have received during actual flight and followed, as closely as possible, actual flight condition sequencing. This sequence of operations was established after observing the preferred performance mode of workers in shirtsleeves and in the pressure suit during preliminary performance trials. Subjects were required to observe the sequence rigidly. In order to remove and replace the prestart solenoid valve, the subjects were instructed to follow the procedures listed below.

Begin on command. Tool box open and first tool in the preferred hand.

1. Loosen 9/16-inch "B" nut.
2. Remove "B" nut and cannon plug simultaneously.
3. Remove 12-point bolt with retainer clip.
4. Remove valve from box.
5. Replace valve in box.
6. Remove 12-point bolt from retainer and engage finger-tight.
7. Run down "B" nut and secure cannon plug simultaneously.
8. Attach crowsfoot to torque wrench and torque "B" nut to 140-160 inch-pounds.
9. Remove crowsfoot and attach adaptor, extension, and socket.
10. Torque 12-point bolt to 40-60 inch-pounds.
11. Remove attachments from torque wrench and hand torque wrench to test conductor.

A frame-by-frame analysis of motion picture films of task performances indicated that learning this sequence was not an easy task. In later tests it was necessary to require subjects to perform the sequence as many as 31 times to assure that it was being rigidly followed. This procedure was followed because our only performance measure during the course of these studies was time. It was imperative that minor changes in performance be kept to a minimum so as not to confound this measure with time differences attributable to slight changes in sequence. Analysis of the task according to the method of Barnes (ref 1) indicated that approximately 100 hand operations had to be learned sequentially by our subjects.

RESULTS AND DISCUSSION

Figure 4 shows the data obtained from the subject who was trained and tested in the mockup and later in the zero-G aircraft. These data have been confounded by many uncontrolled variables and are presented only as evidence of the difficulties of performing this type of research. Obviously, learning had not been completed under any of the test conditions. Equipment malfunctions may have caused the high time scores

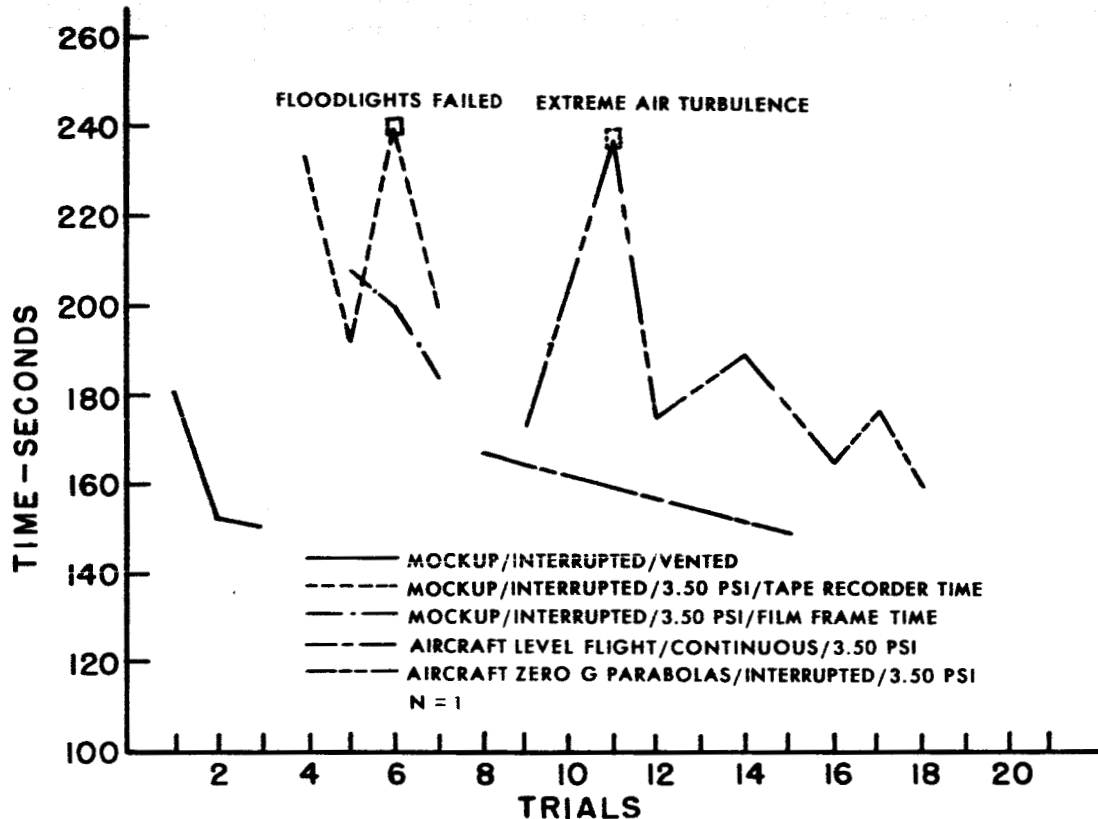


Figure 4. Performance Time Measurements of a Subject Typical of Those Tested and Trained in the KC-135 Mockup. This Subject Was Subsequently Tested Under Zero-G Conditions.

on the two trials noted. Spurious measurements were made as indicated in trials 5, 6, and 7 where times were quite different when taken from a tape recorder and by counting film frames. All subsequent data are based on film frame counts. Analysis of motion picture films of task performance showed that the performance sequence was modified from trial to trial and time scores could not justifiably be compared. Similar difficulties were present in the data of the other two subjects tested in the mockup. The results obtained from all three subjects led us to increase the number of trials required of subsequent subjects for task sequence learning.

The task was slightly changed and the experimental procedures were modified for zero-G performance to allow us to place more confidence in the time measure to be made. A bolt-retaining clip was included as one of the tools and the experimenter was instructed to retrieve and replace any tools or other objects which floated away from the subject during zero-G flight. The subject was required to retrieve any floating objects himself but, if an article floated beyond his reach, he was to continue task performance. On occasion, parts of tools did float away from the work area, either because they had been improperly placed in the tool box or because they were inadvertently struck by the subject during task performance or because they were too small to be properly held. The procedures maintained prevented these occurrences from affecting the time measure. Tool loss was not a problem peculiar to the weightless condition but occurred on the ground also whenever subjects performed the task while suited and pressurized.

Two subjects were tested extensively at Wright-Patterson Air Force Base. Figure 5 presents data obtained from the first of these subjects under shirtsleeve conditions. Where ground testing is indicated, the subject was tested with the rocket engine in position inside the KC-135 aircraft, while the airplane was stationary on the ground. Essentially, except for the imposition of 2-G forces, this was the same as the mockup performance. In order to negate the effects of the 2-G maneuvers necessary to achieve zero-G, a unique condition was imposed during flight testing. On the right side of figure 5 are plotted times for task performance under shirtsleeve conditions for zero- and 1-G. The 1-G trials were conducted as follows: The aircraft was required to roll 60° and execute a 2-G maneuver for approximately 20 seconds. When this was completed, the aircraft rolled back to its correct attitude and maintained straight and level flight for approximately 25 seconds. It would then repeat the roll and 2-G maneuver. Task performance was permitted only for the 25-second level flight period. In this manner, we hoped to control for the effects of the 2-G experiences inevitably included in studies dealing with zero-G parabolic flight. When the task had been successfully completed under these conditions, zero-G parabolic flight was initiated. Zero-G and 1-G flying alternated until 14 trials had been completed under each of the conditions.

We had felt that the imposition of the 2-G pullouts for zero-G testing might have introduced a variable, which we will call fatigue, that is not present in ordinary level flight and, since our measure may have been sensitive to fatigue, we attempted to equalize its effects for both conditions. Performance changes might have occurred if our subject had been naive to parabolic flying but the test subject used had had about 2 years of experience in zero-G flight. Task performance time began to level off after

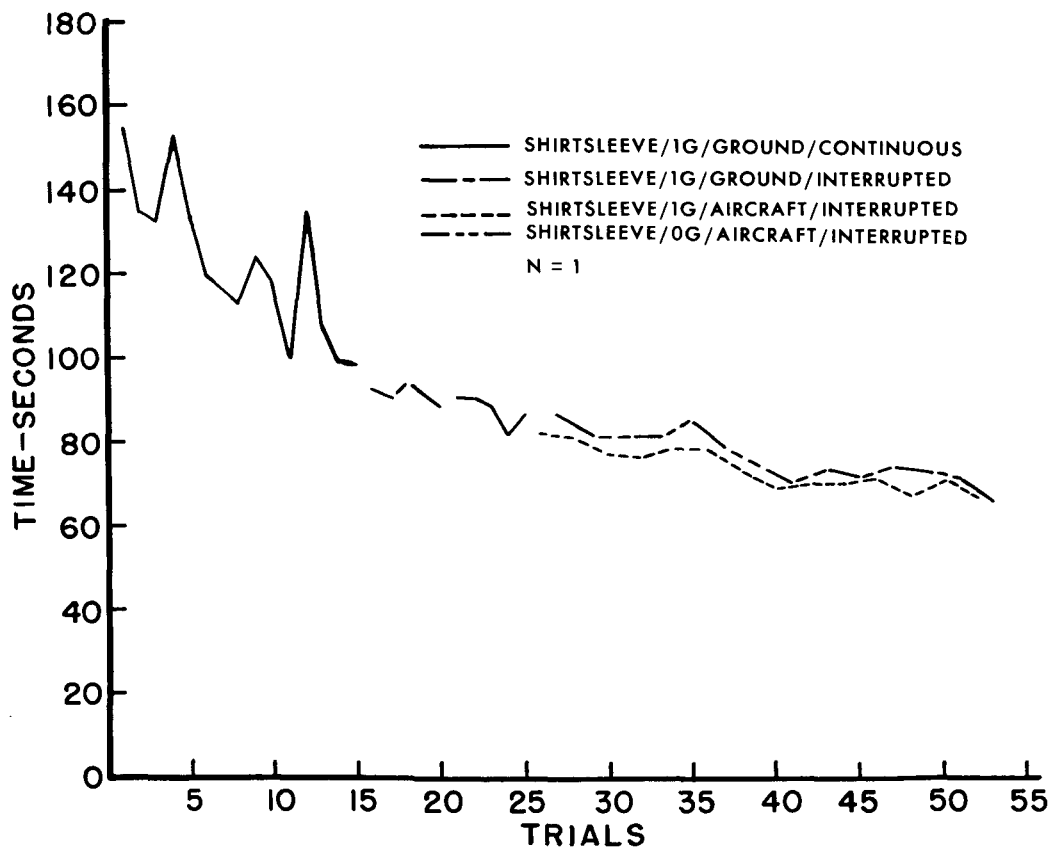


Figure 5. RL-10 Engine Task Performance Under Shirtsleeve Conditions (No Pressure Suit Used). Zero-G and 1-G Flying Conditions Imposed.

25 ground trials. Some of these trials were accomplished under an interrupted condition. The interrupted condition refers to the fact that the task was performed during 25-second work intervals as opposed to permitting the subject to proceed from start to finish without interruption as was permitted on trials 1 through 15. Trials 16 through 20 were conducted under the interrupted condition. Trials 21 through 25 were conducted without parabolic interruptions. The difference was not sufficient for us to consider it a serious limitation of performance under weightless conditions. Results shown on this graph also led us to conclude that there was no reason to continue imposing interrupted work periods because no serious differences in performance time were evident.

Data obtained on the second subject tested at Wright-Patterson Air Force Base are presented in figure 6. Up to this time, our interest concerned the effect of wearing the pressure suit on performance time. The tasks were performed on the ground and no flight conditions were imposed. Note that on this figure the ordinate begins at 80 seconds. This subject required longer to perform the task, under all conditions, than the previously discussed subject. Task training proceeded for 20 trials. Although 20 trials were actually performed, a filmed record was unavailable for trial number 3 and an accurate performance time could not be plotted. Up to trial 30, the points plotted were training trials. The subject, by the end of the training period, appeared to have reached or was approaching a lower limit to his performance time on the task. All of these trials were performed continuously.

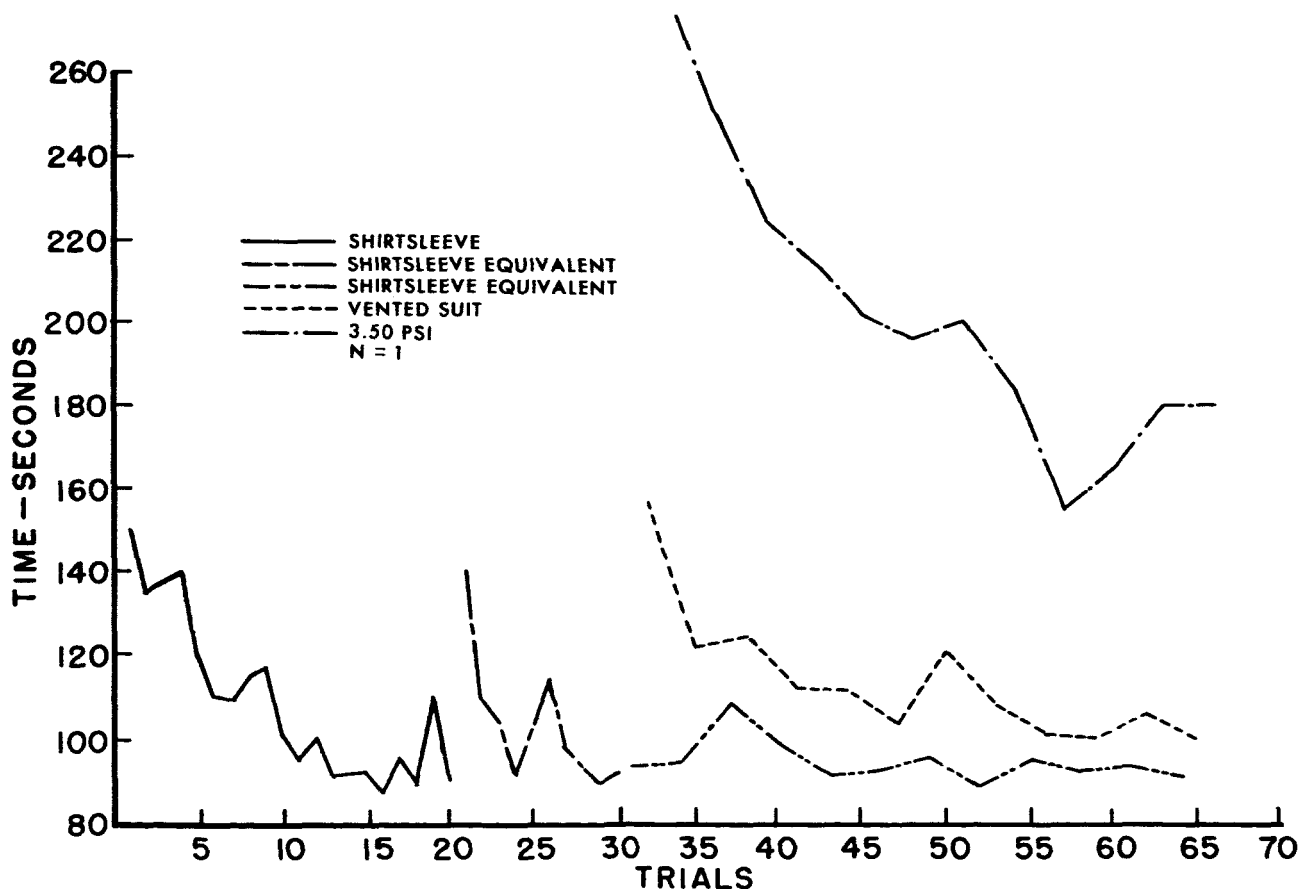


Figure 6. RL-10 Engine Task Performance Effects Upon Performance Time of Systematically Varied Suit Pressurization Level. No Flight Conditions Imposed.

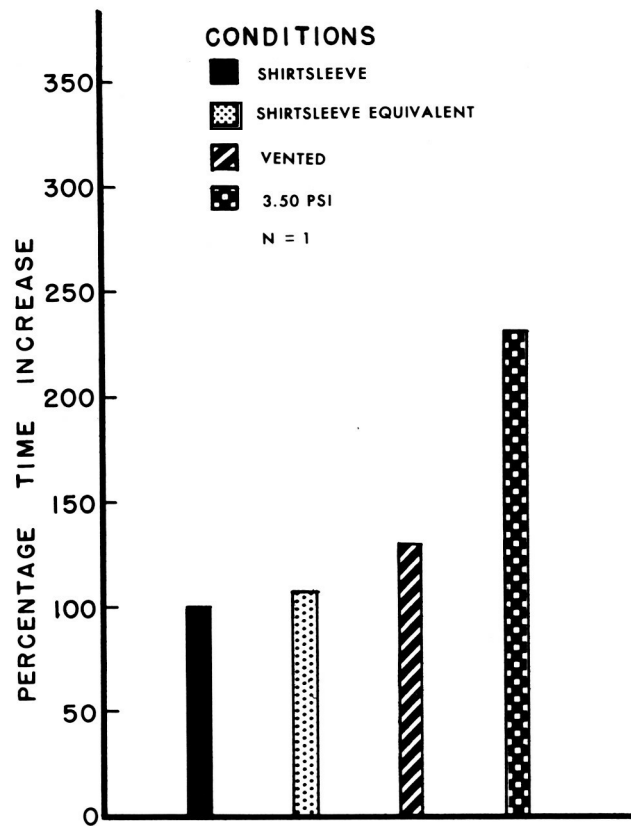


Figure 7. Effects Upon Performance Time of Various Suit Pressurization Levels. Data from Figure 6 Converted to Percentage Scores.

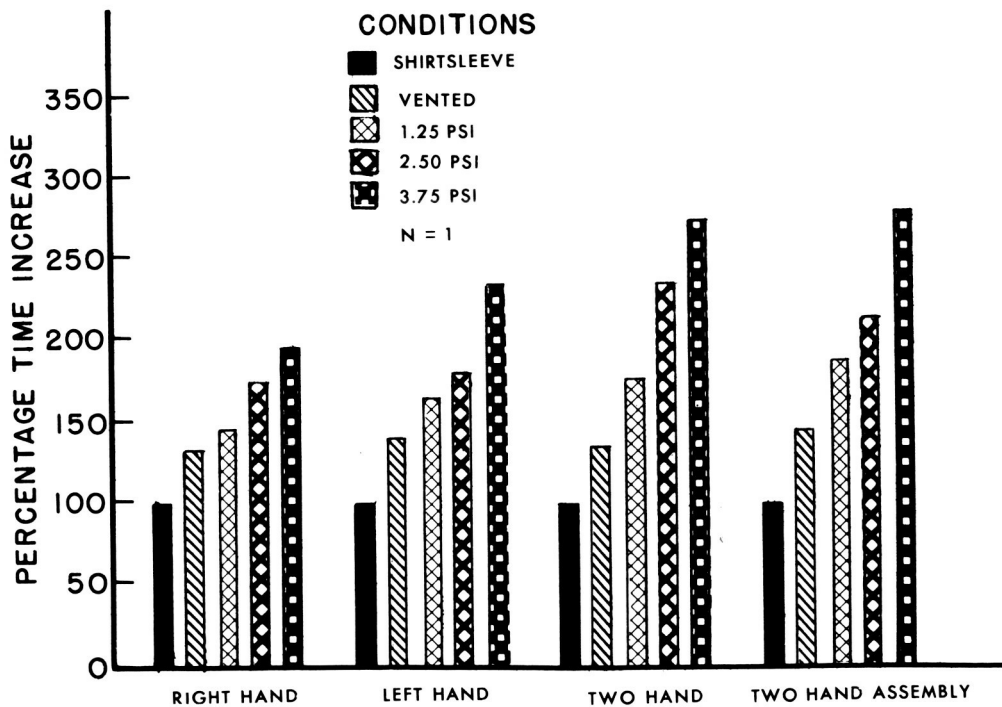


Figure 8. Purdue Pegboard Performance Data Under Four Suit Pressurization Levels. Data Converted to Percentage Scores. Mean Shirtsleeve Condition = 100%.

Trials 21 through 30 were performed in the same manner, but the subject was required to wear the pressure suit without gloves or helmet. This was called the shirtsleeve-equivalent condition. Apparently some relearning was necessary after the transition from the shirtsleeve to the shirtsleeve-equivalent condition. The same degree of proficiency was achieved under the shirtsleeve-equivalent condition after 10 trials as was achieved in 20 trials under shirtsleeve conditions alone. The three lines on the right (figure 6) represent performance time per trial under the three suited conditions. The shirtsleeve-equivalent condition was repeated on trial 31. On trial 32, gloves and helmet were added to the suit but the suit was not pressurized. This was called the vented condition. Trial 33 required task performance under full suited conditions pressurized to 3.5 psi. Trial 34 repeated the condition of trial 31 and so on. In all, 12 shirtsleeve-equivalent, 12 vented, and 12 pressurized task performances were accomplished. One full week elapsed between trial 1 and trial 66. The data plotted through trial 30 were obtained on the first day of testing and show the results of only the shirtsleeve and shirtsleeve-equivalent conditions.

Figure 7 shows the data obtained for this subject (also on the right of figure 9) converted to percentage scores. Shirtsleeve performance on trials 14 through 20 was chosen as 100% performance time. Because performance time was continually decreasing during the training trials, the 100% mean performance time may be high, giving us a built-in conservatism on comparisons. Figure 7 shows that there was an 8% increase in mean performance time under the shirtsleeve-equivalent condition, a 30% increase under the vented condition, and a 132% increase in mean task performance time under fully suited and pressurized conditions. These data, alone, are not startling, nor are they worth much alone except as they corroborate the opinions of others who are well aware of the mobility restrictions of pressure garments. They are also confounded, to a certain extent, by learning which took place under most conditions. However, to our knowledge, this is the first time such opinions have been given the respectability obtainable through quantification. Combined with previous data, which showed the small performance restrictions imposed by the weightless condition, the need for research into methods of increasing pressure-suit mobility seems more apparent than research into the effects of zero-G. Also, it points out that much of the research which has gone into the development of cumbersome torqueless tools for the space environment might more productively have been concerned with the integration of ordinary tools into the man-machine system. Of course, the integration of tools into the system depends heavily upon tethering systems for use in the weightless environment.

Further tests were performed to clarify the relationships between the RL-10 maintenance task and other psychomotor performance measures.

Figure 8 shows the results obtained from further tests with the same subject. These tests were conducted on the ground at the Aerospace Medical Research Laboratories and show the performance changes which took place under various pressure conditions while the subject sat and worked at a Purdue Pegboard. The results for this subject, performing under shirtsleeve conditions, fell at approximately the 50th percentile of his normative group. These data again show the increase in performance time with an increase in suit pressurization.

The same subject was tested under pressurized and unpressurized conditions while performing a reaction time experiment. The subject was required to remove his hand from a depressed button in response to a light stimulus and reach and depress other buttons within his reach envelope. Results on this performance were only taken for two suit conditions. Reach time of response was automatically recorded (figure 9).

These results, converted to a percentage basis, combined with results of the Purdue Pegboard performance converted to a percentage basis, plotted along with RL-10 performance data on the same subject show the relationship between suit pressurization and performance degradation. This follows from our intuitive impressions of the complexity of these three tasks. It is, perhaps, also a beginning to systematizing our methods of suit performance evaluation without the use of expensive and complex tasks, such as the removal and replacement of a solenoid valve.

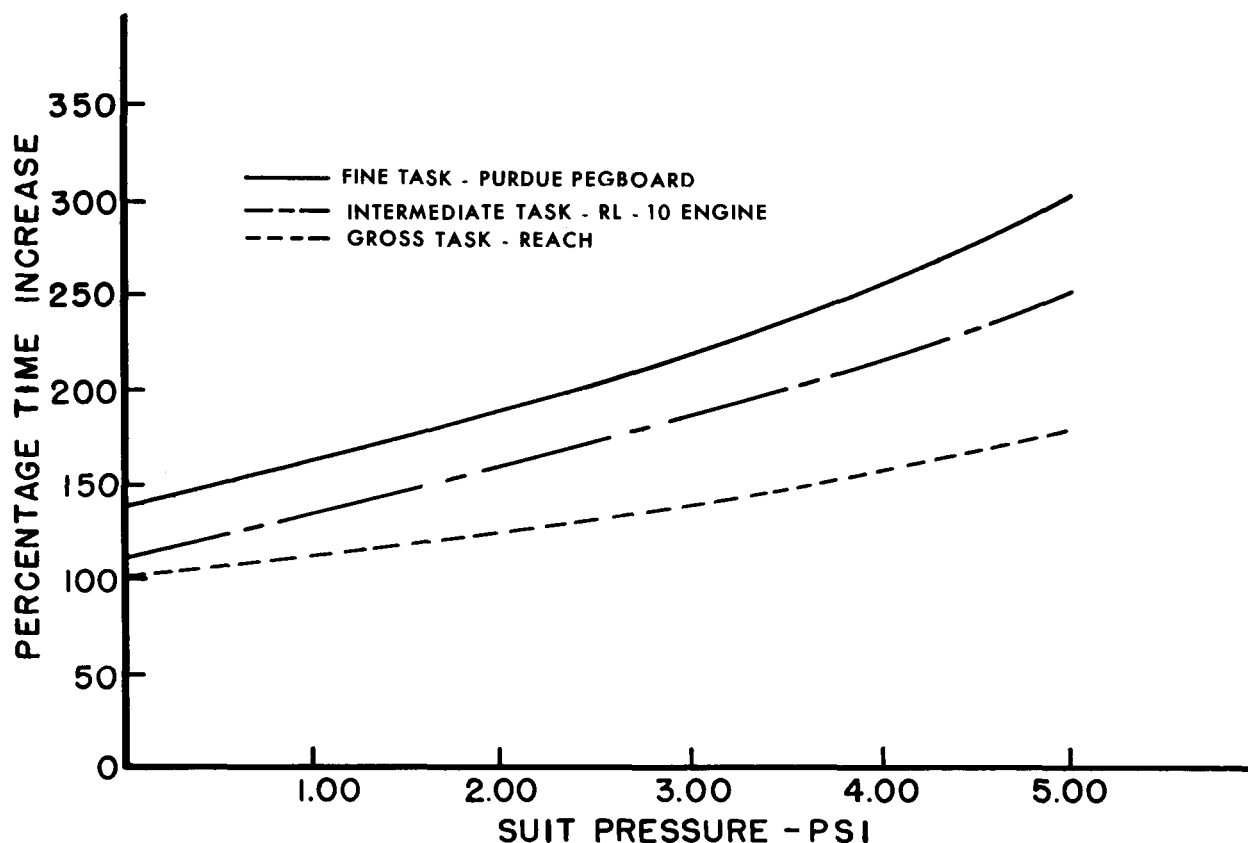


Figure 9. Comparison of Performance Time Percentage Increases for One Subject Under Various Suit Pressures for Three Psychomotor Tasks.

CONCLUSIONS

The greatest contributing factor to performance decrement in space maintenance activity is space suit pressurization level. This holds true apparently under both gravitational conditions involved in this study. Performance decrement here is defined as an increase in time required to accomplish a given psychomotor task.

In this study, the effect of weightlessness on performance was less than the effect of suit pressure level, and, in this instance, it would not have been necessary to introduce zero-G conditions to conduct a meaningful study of space maintenance performance. In future studies, however, the relative effects of various constraints on performance should be similarly determined since it is not yet possible to predict accurately the magnitudes of those constraints.

No data are available from this study on the effects upon performance of prolonged weightlessness. Conceivably, such an environment could introduce other effects and constraints on human performance. Hopefully, such questions can be dealt with on projects which permit continuous long-term exposure of personnel to orbital flights.

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1. Barnes, R. M., Motion and Time Study, J. Wiley and Sons, Inc., 4th Edition, pp 40-44, New York, N.Y., 1958.

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