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PRELIMINARY INVESTIGATIONS OF SPACE MAINTENANCE

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ABSTRACT

The ability of man in a space-suit to do a space-maintenance task was investigated. Task-performance was done by human subjects under various restrictions of pressure and acceleration in ground experiments and in parabolic aircraft flights.

From correlation of the data gained, it was learned that zero-gravity need not be simulated under these experimental conditions to determine performance-limitations; the limiting factor was found to be the pressurization level of the space-suit.

The results form a method of predicting the effect of pressure-suited, reduced-gravity conditions on tasks done under earth-gravity.

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PROPULSION AND VEHICLE ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

ACKNOWLEDGEMENT

The authors are grateful to the many people who assisted in the production of this report.

The staff of the Marshall Space Flight Center's Future Projects Office directed the effort and gave many valuable suggestions.

Mr. P. Woodbury of Brown Engineering Company developed the performance-task sequence and helped much in tool-design for space-maintenance.

Lieutenant E. H. Sasaki and Sergeant Sears, USAF, served well and faithfully as our subjects.

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SUMMARY

Preliminary study of space-maintenance problems was done in cooperation with the United States Air Force. This report recounts experiments in simulation of a basic, space-maintenance task under earth-gravity and zero-gravity conditions.

These experiments were done with space-suited human subjects under "shirtsleeve," "shirtsleeve-equivalent," "vented," and full-pressure conditions. The task was removal and replacement of a prestart solenoid valve on an RL-10 rocket engine. It was necessary to enlarge the tool handles for operations with pressurized gloves. In the zero-g situation a body-tethering system was used; tool-loss was no problem. Subjects followed a prescribed sequence of operations in their performances. Supplemental experimenting was done with the Purdue Pegboard.

Results of this work indicate no need to simulate zero-gravity in such studies. The key cause of performance-decrement is the pressurization level of the space-suit. The synthesized results in FIG 8 - 13 form a method for comparing performances of psychomotor-tasks.

author

INTRODUCTION

In this report are the results of preliminary study in the problems of space-maintenance. This study was directed by the Future Projects Office of the George C. Marshall Space Flight Center. Part of the work was done at Wright-Patterson Air Force Base; the other part was done at the George C. Marshall Space Flight Center.

A method of comparing performances of psychomotor tasks grew out of this effort. The initial goal for this study was to learn if conditions of zero-gravity were necessary to get valid data on the performance of space-maintenance tasks by human workers in space-suits. Task experiments were executed in ground-facilities and in flying aircraft. The subjects who did the experimental task wore a full-pressure space-suit. This was a best-state-of-the-art suit developed by the International Latex Company. Gloves worn by the subjects came from the Crew Systems Branch of the Manned Spacecraft Center. Both suit and gloves were designed for seated-operations at control/display consoles; so, it is inappropriate to evaluate adequacy or inadequacy of the garments for space-maintenance work. (This study did not explore the question of special space-garments for space-maintenance jobs.

The time-limitations inherent in experimenting with an aircraft flying Keplerian trajectories, and the necessity of correlating the ground-based results with the flight-results, forced selection of a task that was at once typical of space-maintenance and that could be done within the time-frame. This task was removal and replacement of a pre-start solenoid valve on a RL-10 rocket engine. Subjects were connected to their work-area, in the zero-g situation, by a body-tethering system.

A nearly linear progression was established from the experiments. This progression shows that the most significant cause of attrition in performance is the level of pressure in the space-suit. In the ground-based trials, the subjects worked under various suit-restrictions, from "shirtsleeve" to full-pressure. Motion-picture records were made of nearly all the trials.

Corroborative data emerged from trials on the Purdue Pegboard. The near-linear trend was evident in these data also.

GOALS

The 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?

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 pre-start solenoid valve on a Pratt and Whitney Aircraft Company, model RL-10 rocket engine.

PROCEDURES

Figure 1 shows this engine mounted within a plywood mockup of the KC-135. The KC-135, a military version of the Boeing 707, was used for zero-g flights.

Figure 2 shows a side view of the zero-g or Keplerian trajectory flown by the KC-135 aircraft. Two-g conditions were experienced for approximately 20 seconds. 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.

Figure 3 is a close-up of Figure 1 and shows the pre-start solenoid valve. In order to remove and replace the valve, the following task-sequence was followed.

TASK PERFORMANCE SEQUENCE

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.

These procedures were established after observing the preferred performance mode of workers in shirtsleeves and in the pressure-suit during preliminary performance-trials in Huntsville. Subjects were required to adhere rigidly to the operational sequence. A frame-by-frame analysis of motion-picture films of task-performances indicated that learning this sequence was not easy. It was necessary, in later tests, to require to perform the sequence as many as thirty-one times to assure that it was being followed rigidly. This procedure was followed because the 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 the subjects.

Another condition in these experiments was the selection and use of a body-tethering system, (Ref. FIG 4). Two waist-straps and two toe-hooks connected the subject to the work area. This system was developed at Wright-Patterson Air Force Base, and served quite well in preventing the translation of torques to a subject under weightless conditions.

Due to use of pressurized gloves, it was necessary to modify tools which would be used in the task-performance. Figure 5 shows the tools ultimately provided. Modification was by increasing the diameter of the tool handles. This ensured that the tools could be grasped positively and held by hands encumbered by pressurized gloves. Wherever possible, handles were made at least 1.5-inch outside diameter. Some of the tools shown in this figure had been prepared for a much more extensive testing-program than could be undertaken. The white object behind and above the tools is a tool-box designed to hold tools in a zero-gravity environment. This box, 15 inches long, 10 inches wide and 4 inches thick was designed by Captain Mueller and is lined with an adherent material, known as "Velcro." This material, in the figure, can be seen as a black substance lining the interior of the fiberglass box. Velcro was also affixed to those tools which were used. Safety wires, used to retain nuts, were removed from the engine to avoid puncturing the suit or gloves.

The tool box was positioned on the front of the subject using a system of spring coils and hooks, (Ref. FIG 6). The box served effectively as a tool receptacle. On occasion, however, the box slipped out of its correct position, preventing the subject, under pressurized conditions, from seeing that portion of the box closest to his body. The Velcro material required deliverate acts for removing and replacing tools. This added a control to the time required for task-performance. Although no analysis was performed, it is believed that the time required for tool-removal and replacement was essentially the same for all subjects.

Initial performance-data were obtained in the KC-135 partial mock-up provided in Huntsville and consisted mainly of training subjects in task-performance sequence. Partial simulation of aircraft-flight maneuvers was made by a lever and spring-scale device to impose 2-g loads on the subject, (Ref. FIG 7). The lever was attached to a line which was connected to a hook between the subject's legs. Dry air, at 50 degrees Fahrenheit flowing between 9.5 and 11.5 cubic feet per minute, was provided for conditioning and pressurization. This combination of temperature and flow was adequate for a tolerable suit-environment. Three subjects were trained and tested in the mockup. One of these subjects was tested also in zero-g flight. Two other subjects were used at Wright-Patterson Air Force Base.

RESULTS AND DISCUSSION

Figure 8 shows the data obtained from the subject who was trained and tested in the mockup. 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, subject-learning had not been completed under any of the test-conditions. Equipment-malfunctions may have caused the high time-scores on the two trials noted. Spurious measurements were made as indicated in trials, 5, 6, and 7 when times were quite different (when taken from a tape recorder and from film-frame counts). All subsequent data are based on film-frame counts. Analysis of motion picture films of task-performance showed that performance-sequence was modified from trial to trial and time-scores could not be compared justifiably. Similar difficulties were present in the data of the other two subjects tested in the mockup. The results obtained from all three subjects led to an increase in the number of trials of subsequent subjects for task-sequence learning. Also, the task was changed slightly and the experimental procedures were standardized for zero-g performance to allow more confidence to be placed 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 were inadvertently struck by the subject during task-performance or because they were too small to be held properly. The procedures 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 suited and pressurized.

Two subjects were tested extensively at Wright-Patterson Air Force Base. Figure 9 is data obtained from the first of these subjects. All of these data were obtained under shirtsleeve-conditions. Where ground-testing is indicated, it refers to the fact that 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 amounted to mockup-performance. To negate the effects of the 2-g maneuvers, a unique condition was imposed during flight testing. On the right side of the graph (Ref. FIG 9) are plotted times for task-performance under shirtsleeve-conditions for zero and one-g. The one-g trials were conducted as follows: The aircraft was required to roll 60 degrees 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, a control was provided for the effects of the 2-g experiences inevitably included in studies dealing with zero-g parabolic flight. When the task had been completed successfully under these conditions, zero-g parabolic flight was initiated. Zero-g and one-g flying alternated until 14 trials had been completed under each of the conditions.

It was felt that the imposition of the 2-g pullouts for zero-g testing might have introduced a variable, called fatigue, which was not present in ordinary level flight. Since the task-duration measure may have been sensitive to fatigue, an attempt was made to equalize its effects for both conditions. It is possible that 2-g experiences would have affected performance-times, had the subject been naive to parabolic flying, but the subject had had about 2 years of experience in zero-g flight.

Task-performance time began to level off after twenty-five ground-trials. Some of these trials were accomplished under an interrupted condition. The interrupted condition means that the task was performed during twenty-five-second work-intervals as opposed to permitting the subject to proceed from start to finish without interruption as was permitted on trials one through fifteen. Trials sixteen through twenty were conducted under the interrupted condition. Trials twenty-one through twenty-five were conducted without the imposition of parabolic interruptions. The apparent difference was not sufficient to consider it a serious limitation of performance under weightless conditions.

Results shown on the graph, FIG 9, also show that there was no reason to continue imposing interrupted work-periods because no serious differences in performance-times were evident.

Data obtained on the second subject tested at Wright-Patterson Air Force Base are presented in FIG 10. At this point, performance-time effects of pressure-suits were checked. The tasks were performed on the ground and no flight-conditions were imposed. Note that on this graph the ordinate begins at 80 seconds. The subject required longer to perform the task, under all conditions, than the previously discussed subject. Task-training proceeded for twenty trials. (Twenty trials actually occurred. A filmed record was unavailable for trial number three; so, an accurate performance-time is not plotted). Up to trial thirty, the points plotted must be considered training-trials only. It appears that by the end of the training-period the subject had reached--or was approaching--a lower limit to his performance-time on the task. All of these trials were performed continuously.

Trials twenty-one through thirty were performed in the same manner but the subject was required to wear the International Latex Pressure-Suit without gloves or helmet. This was called the shirt-sleeve-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 ten trials as was achieved in twenty trials under shirtsleeve-conditions alone: indicating significant transfer. The three lines on the right of the graph (FIG 10) represent performance-time per trial under the three suited conditions. The shirtsleeve-equivalent condition was repeated on trial thirty-one. On trial thirty-two, gloves and helmet were added to the suit but the suit was not pressurized. This was called the vented condition. Trial thirty-three required task-performance under full-suited conditions pressurized to 3.5 psi. Trial thirty-four repeated the condition of trial thirty-one, and so on. In all, twelve shirtsleeve-equivalent, twelve vented, and twelve pressurized task-performances were accomplished. One full week elapsed between trial one and trial sixty-six. The data plotted through trial thirty were obtained on the first day of testing and show the results of only the shirtsleeve and shirtsleeve-equivalent conditions.

Figure 11 shows the data obtained for this subject--and on the right of FIG 10, those data converted to percentage scores. Shirtsleeve-performance on trials fourteen through twenty was chosen as 100% per -

formance-time. Because performance-time was continually decreasing, during the training training trials, the 100% mean performance-time may be high, giving a built-in conservatism on baseline-comparisons. This graph shows that there was only 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 corroborate the opinions of others who are well aware of the mobility-restrictions of pressure-garments. It is also confounded, to a certain extent, by learning which took place under most conditions. However, it may be that 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, they point to the need for research: not so much into the effects of zero-g (as interesting as these might be), but into methods for increasing pressure-suited mobility. Also, it points out that much of the research into the development of cumbersome torqueless tools for the space-environment might more productively have been concerned with the modification of ordinary tools to be used by the pressure-suited worker on space-vehicle hardware. Of course, the use of these tools depends heavily upon the body-tethering systems employed in the weightless environment.

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

Figure 12 shows the results obtained from further tests on the subject reported on in Figures 10 and 11. These tests were conducted on the ground in the Aerospace Medical Research Laboratories (Wright-Patterson Air Force Base). Performance-changes under various pressure conditions while the subject sat and worked at a Purdue Pegboard are shown. The subject, in his shirtsleeve-performance on this task, fell at approximately the 50th percentile of his normative group. These data again show the almost-linear 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 task were taken only for two suit-conditions. Reach-time of response was recorded automatically.

These results, converted to a percentage basis, and combined with results ot the Purdue-Pegboard-performance similarly converted, then plotted with RL-10 performance-data on the same subject, show the relationship between suit-pressurization and performance-degradation, (Ref. FIG 13). This agrees with intuitive impressions of the complexity of the three tasks. It is perhaps, also a beginning to a systematic method of suit-performance evaluation without the use of expensive and complex tasks such as the removal and replacement of a solenoid valve. It is evident that simple extrapolation from pegboard-performance may be a valid predictor of performance-time on more complex tasks. More data will be necessary before this can be accepted as valid.

CONCLUSIONS

Assuming appropriate training under one-g conditions and the use of a body-tethering system similar to the one described, it is unnecessary to simulate zero-gravity conditions to study space-maintenance performance of the type described.

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 is defined as an increase in time required to accomplish a given psychomotor-task.

A method has been found to be a basis for future research, comparing performance on three psychomotor-tasks, relating percentage-increase in performance-time to pressure-suit pressurization. This may be a way to conserve funds and time in evaluating pressure-suit mobility quantitatively.

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

REFERENCES

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

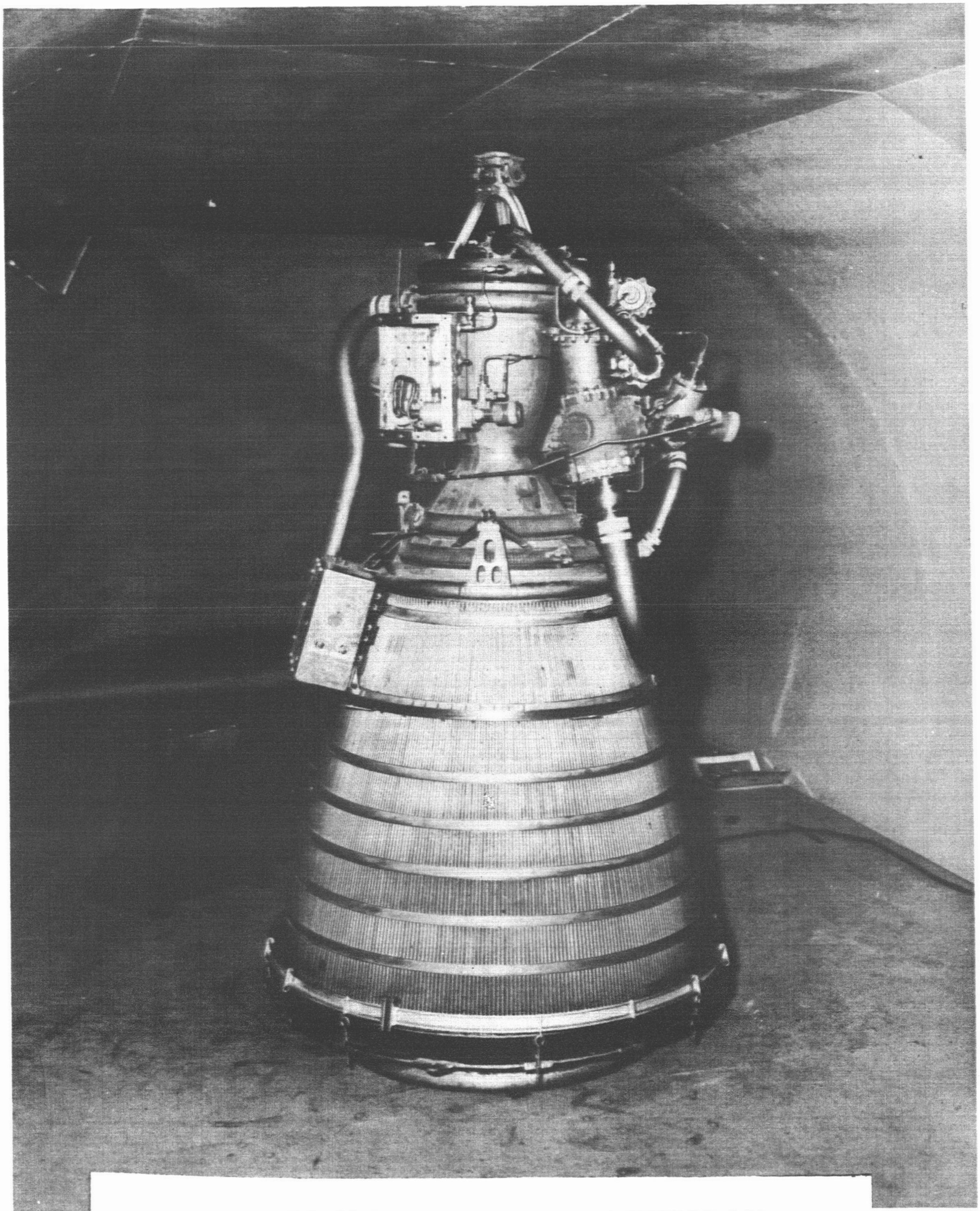

FIGURE 1. RL-10 ENGINE WITHIN PLYWOOD MOCKUP

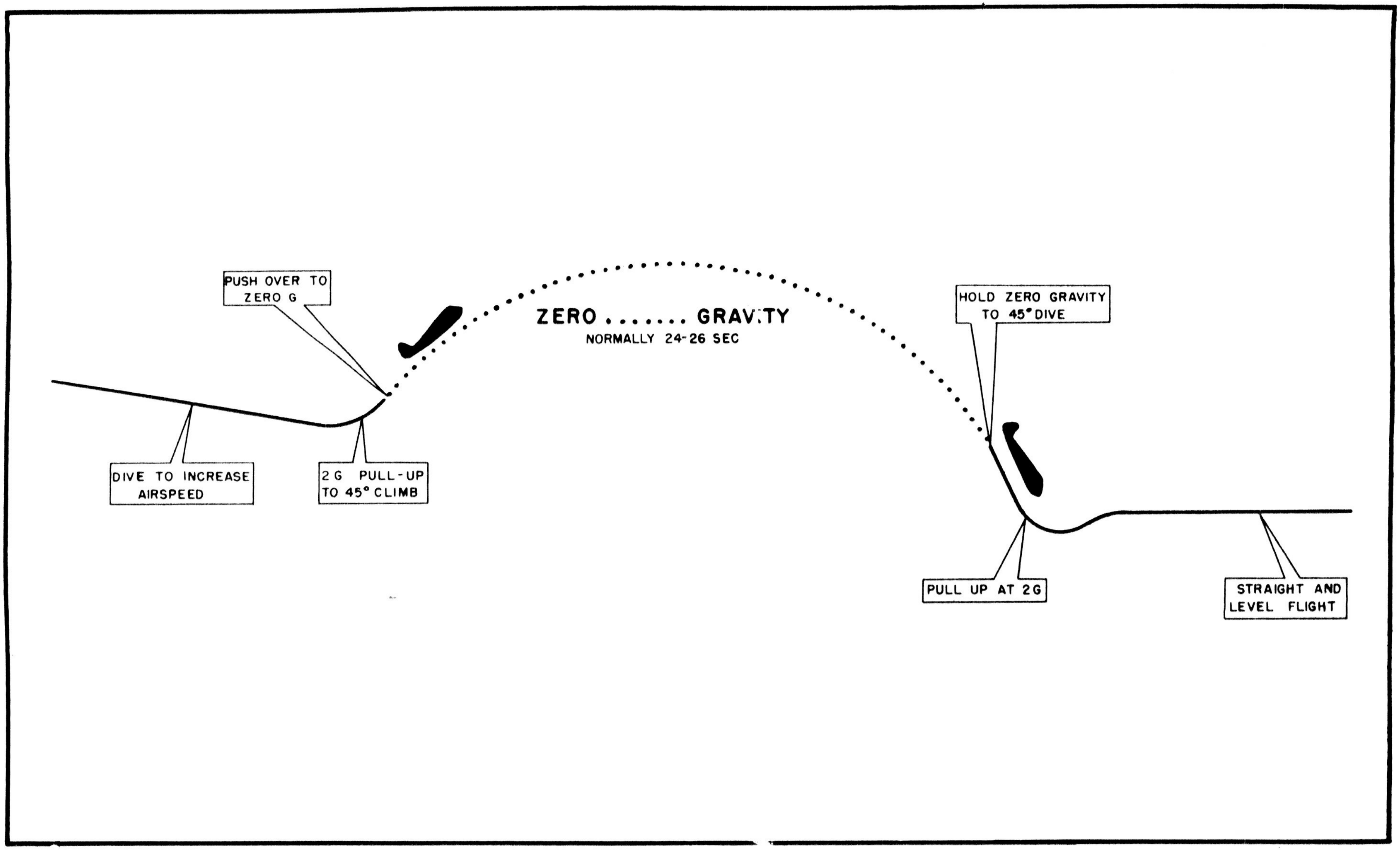

FIGURE 2. TYPICAL ZERO-G FLIGHT TRAJECTORY

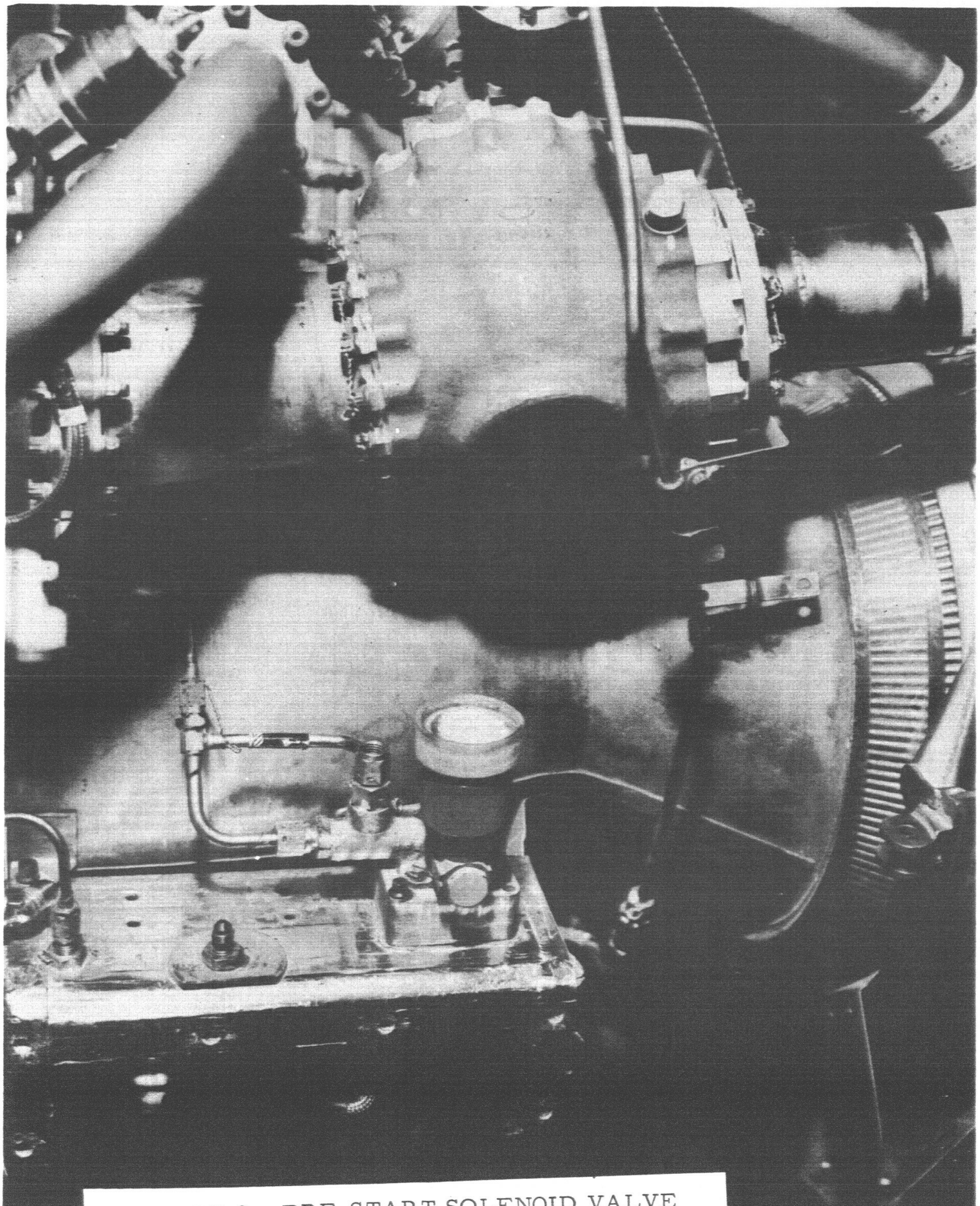

FIGURE 3. PRE-START SOLENOID VALVE

FIGURE 4. BODY TETHERING SYSTEM

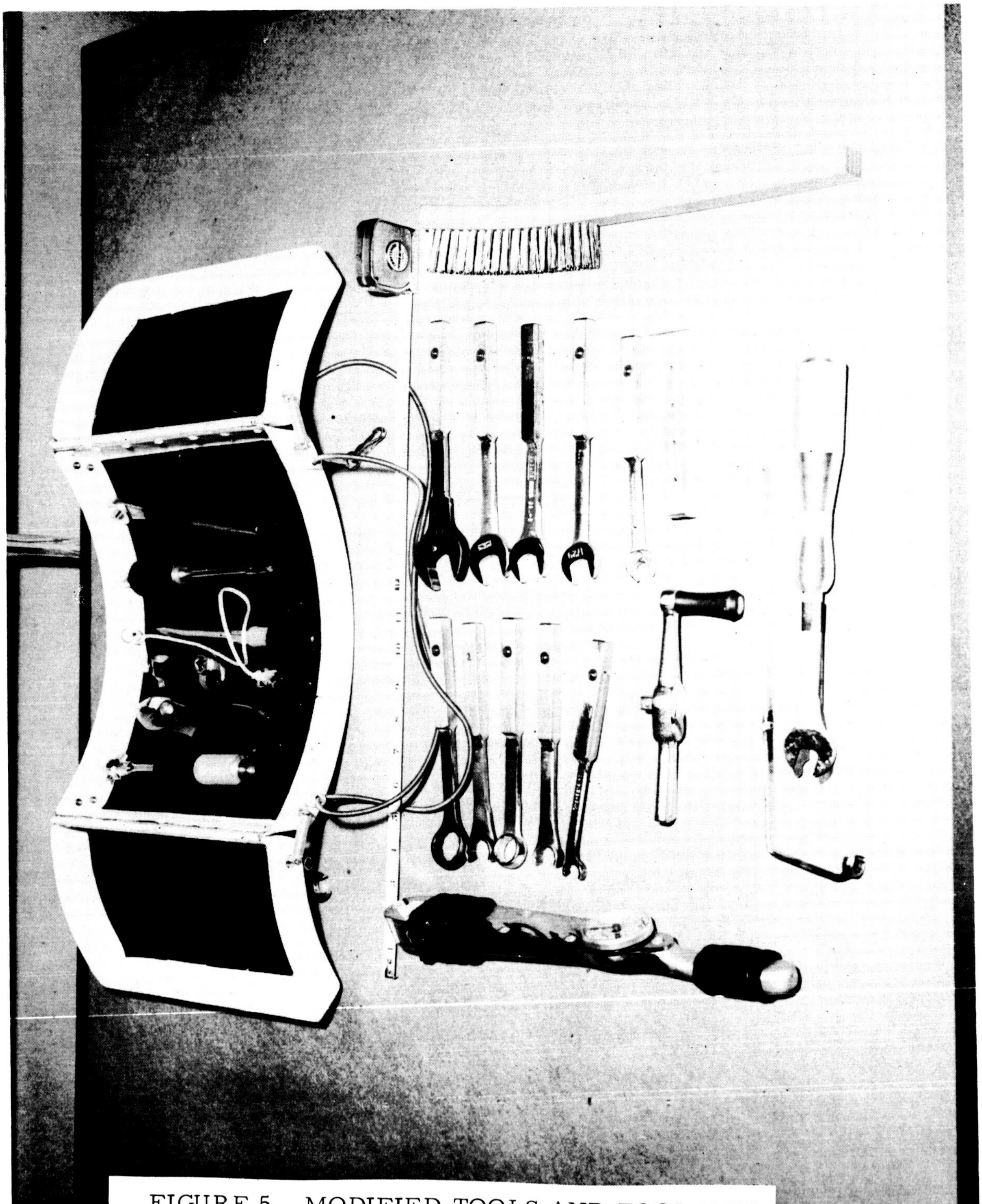

FIGURE 5. MODIFIED TOOLS AND TOOL BOX

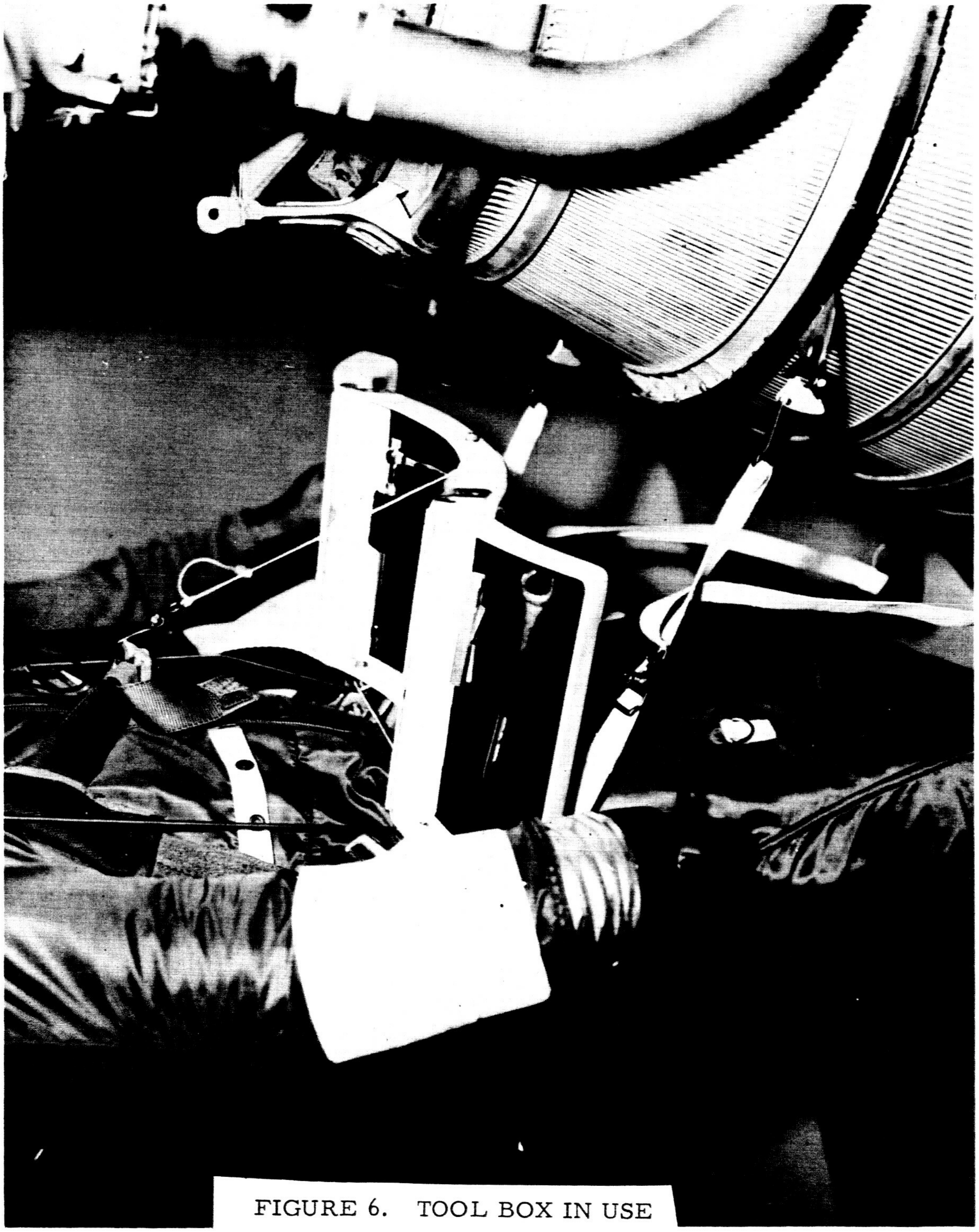

FIGURE 6. TOOL BOX IN USE

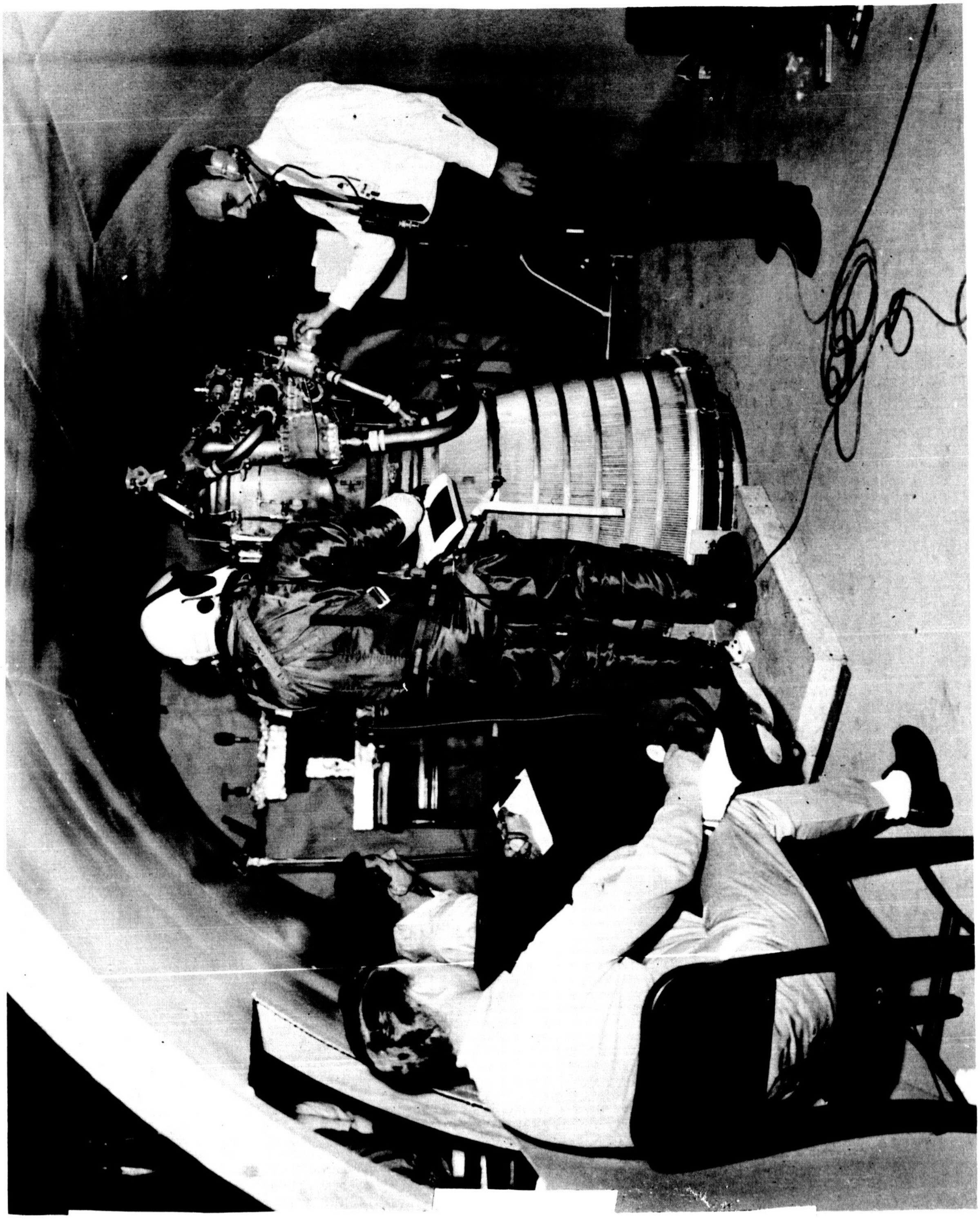

FIGURE 7. TEST AREA AND "G" LOAD DEVICE

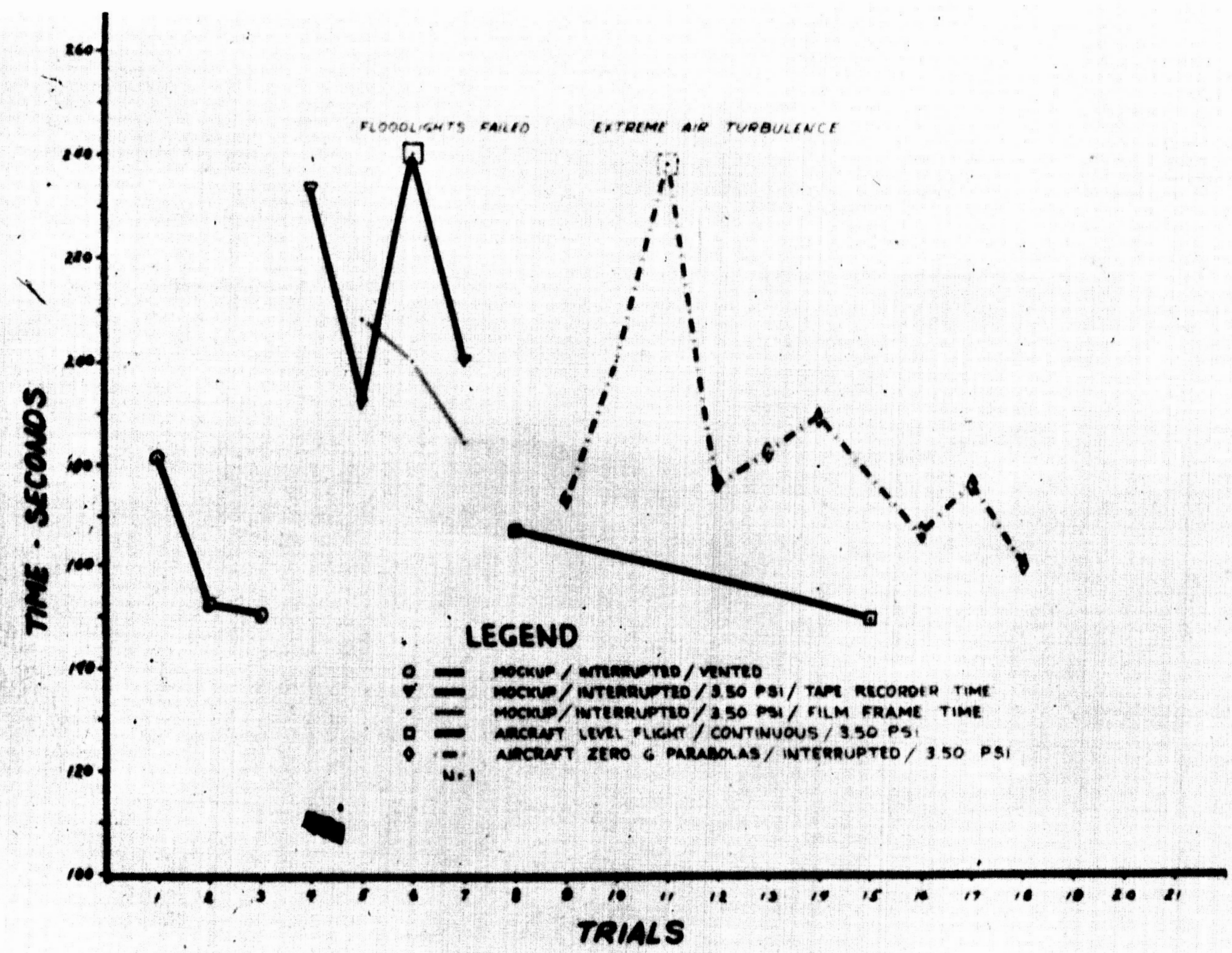

FIGURE 8. PERFORMANCE TIME MEASUREMENTS OF A SUBJECT TYPICAL OF THOSE TESTED AND TRAINED IN THE KC-135 MOCKUP. THIS SUBJECT WAS SUBSEQUENTLY TESTED UNDER ZERO-G CONDITIONS.

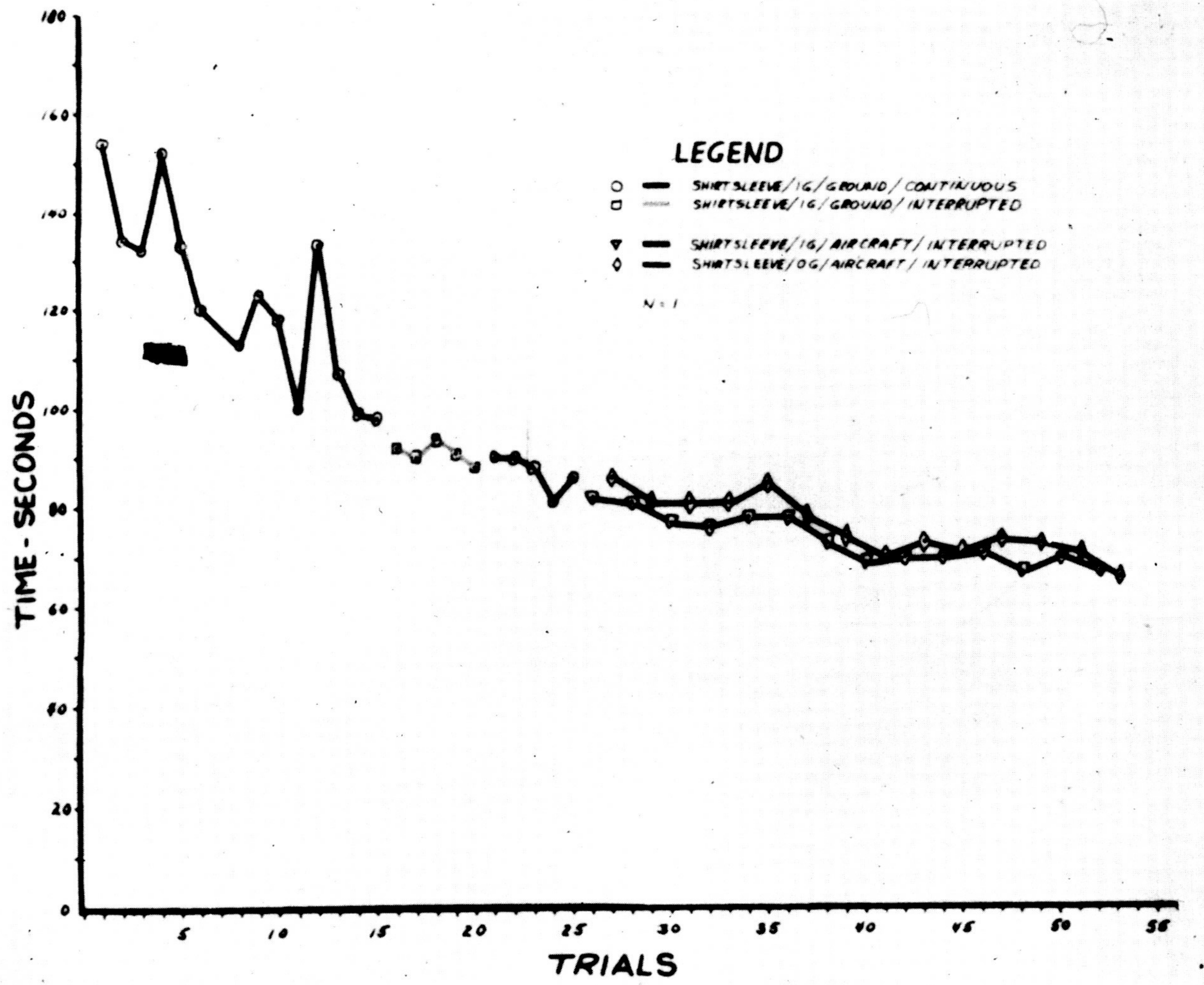

FIGURE 9. RL-10 ENGINE TASK PERFORMANCE UNDER SHIRTSLEEVE CONDITIONS (NO PRESSURE SUIT USED). ZERO-G AND ONE-G FLYING CONDITIONS IMPOSED.

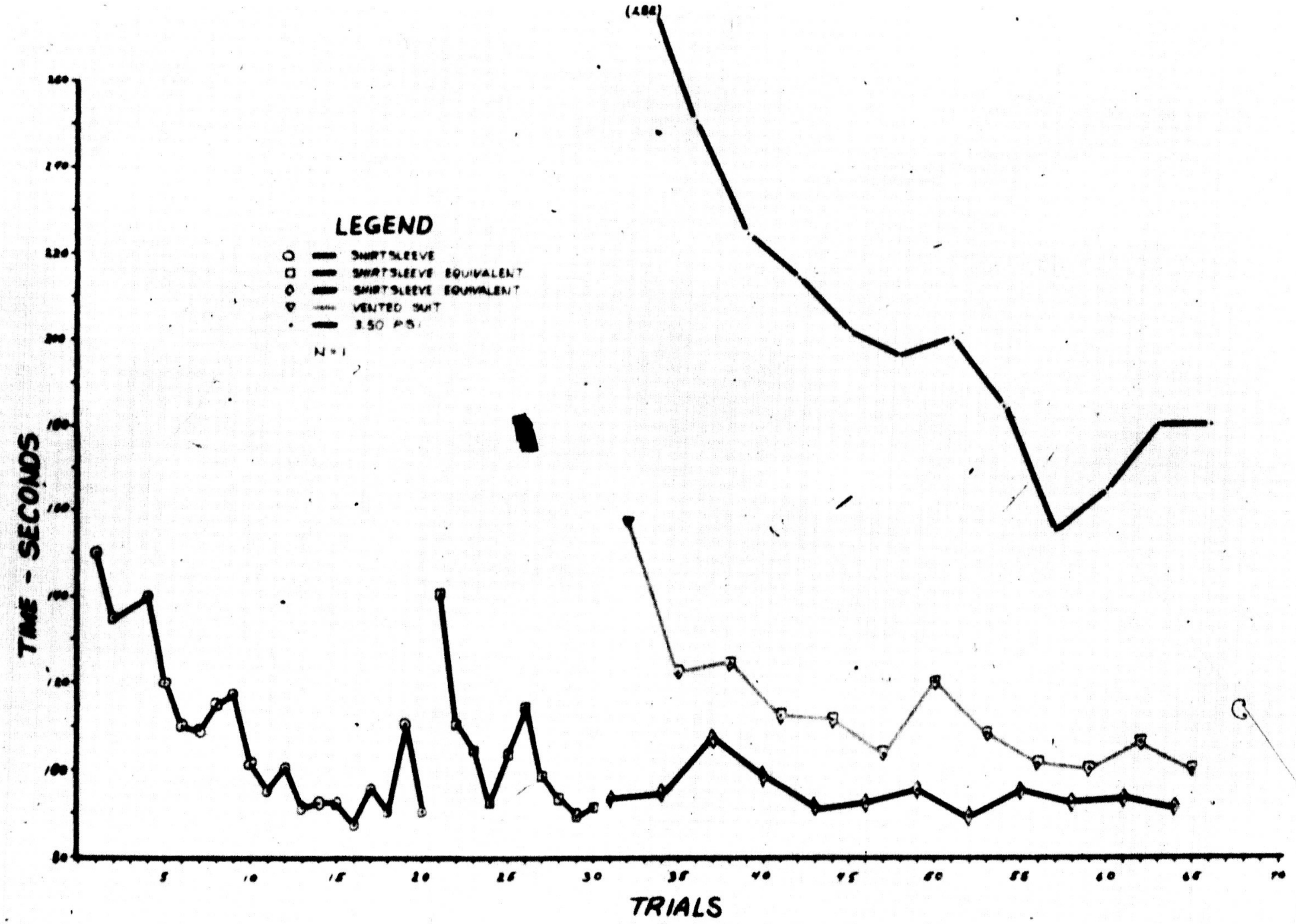

FIGURE 10. RL-10 ENGINE TASK PERFORMANCE EFFECTS UPON PERFORMANCE TIME OF SYSTEMATICALLY VARIED SUIT PRESSURIZATION LEVEL. NO FLIGHT CONDITIONS IMPOSED.

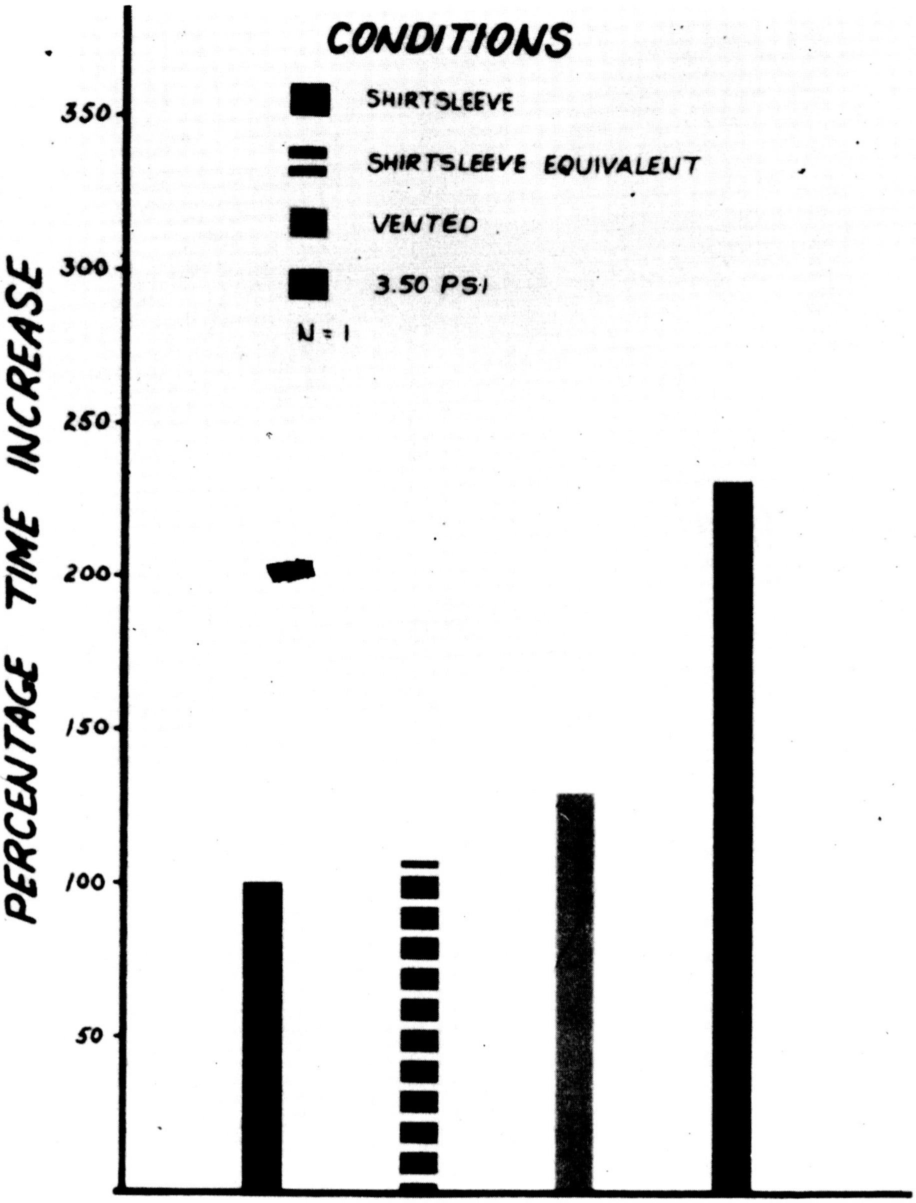

FIGURE 11. EFFECTS UPON PERFORMANCE TIME OF VARIOUS SUIT PRESSURIZATION LEVELS. DATA FROM FIGURE 10. CONVERTED TO PERCENTAGE SCORES.

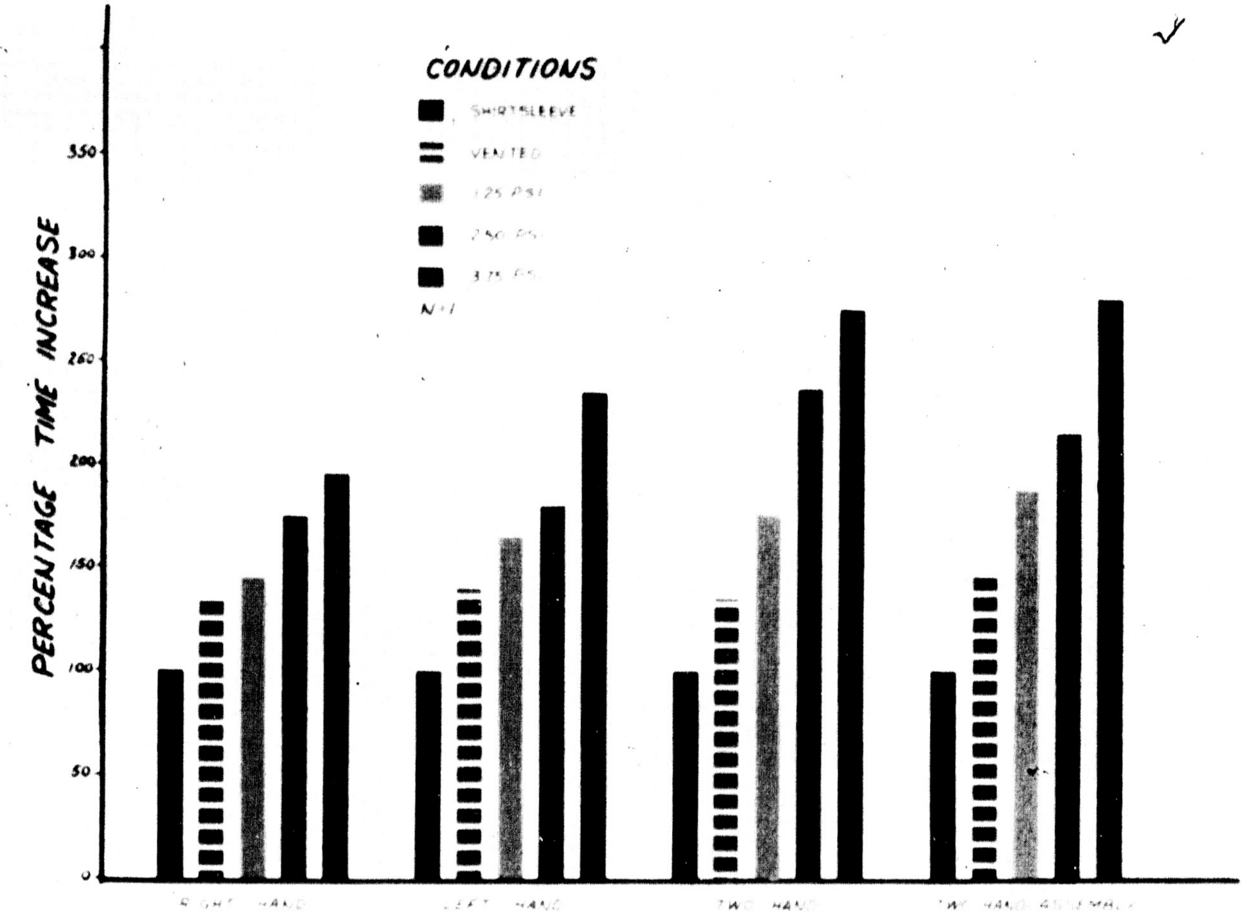

FIGURE 12. PURDUE PEGBOARD PERFORMANCE DATA UNDER FOUR SUIT PRESSURIZATION LEVELS. DATA CONVERTED TO PERCENTAGE SCORES MEAN SHIRTSLEEVE CONDITION 100%.

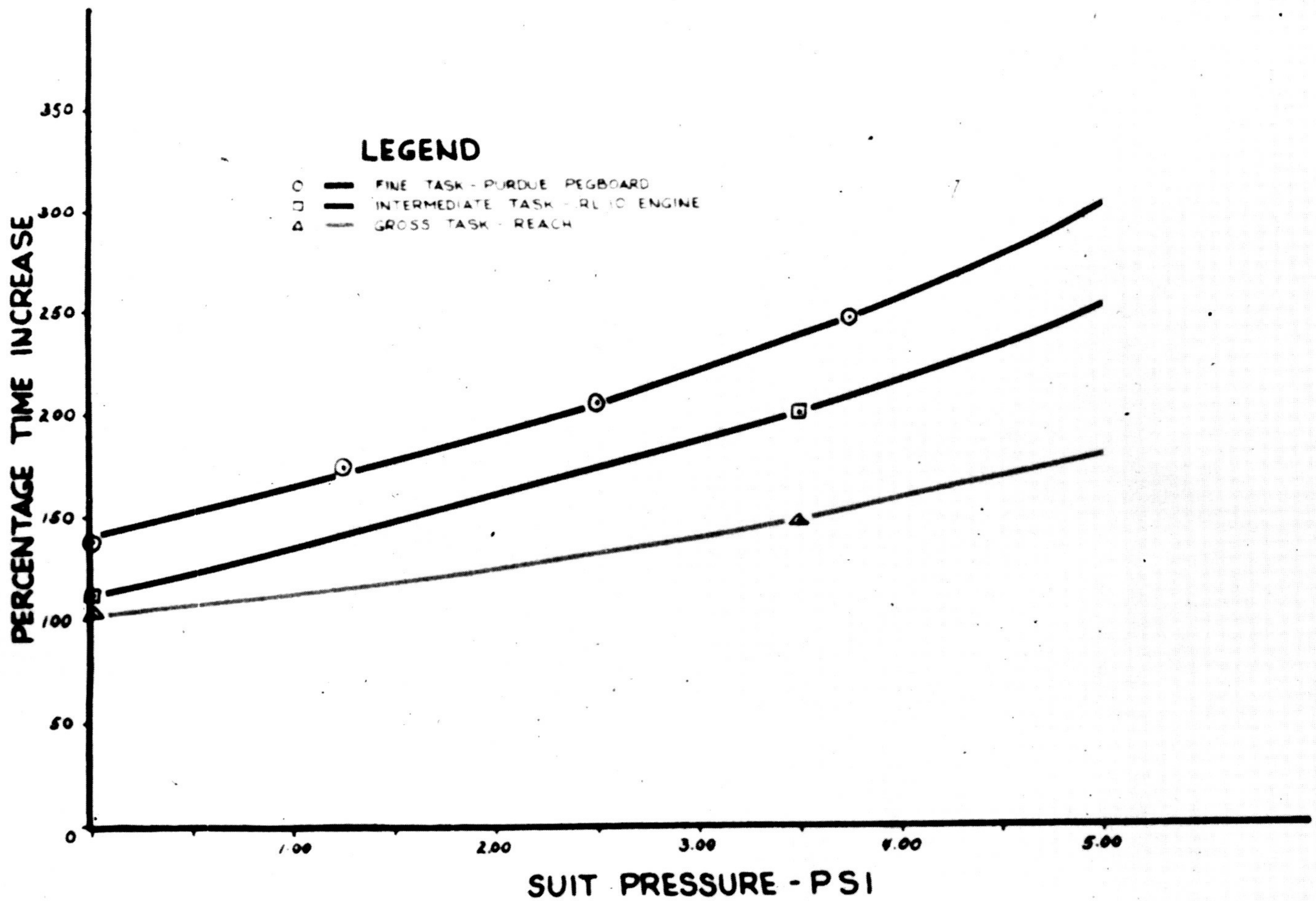

FIGURE 13. COMPARISON OF PERFORMANCE TIME PERCENTAGE INCREASES FOR ONE SUBJECT UNDER VARIOUS SUIT PRESSURES FOR THREE PSYCHOMOTOR TASKS.

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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