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SUMMARY

Tests were conducted to compare the effects of a pressurized space suit on man's self-locomotion capabilities at earth gravity and simulated lunar gravity. The suits used were tested at both 0 and 3.5 psi. Langley's reduced gravity simulator described in NASA TN D-2176 was used to simulate lunar gravity.

The test subject could walk, run, and perform both vertical and broad jumps under both gravity conditions; however, the tasks were easier and less tiring under lunar gravity. The subjects could jump vertical heights 6 to 7 times higher and perform standing broad jumps about 2 times further at lunar gravity (1/6 g) than at earth gravity (1 g). In general, pressurizing the suit to 3.5 psi reduced the performance by about 30 percent. The test subjects in the pressurized suits were able to perform at lunar gravity many tasks, such as climbing stairs, ladders, poles, and jumping onto a platform 6 feet off the floor, which could not be accomplished at 1 g.

The simulator technique used adapted easily to the pressure suits. The comments of the test subjects and the results of the tests indicate that the Langley reduced gravity simulator is an effective research and training tool and should be very useful in the development of advanced types of space suits.

INTRODUCTION

The success of initial lunar missions involving excursions on the lunar surface by the astronauts will depend to a very large extent on the ability of the astronauts to walk, run, climb, or perform other useful self-locomotion tasks while wearing a fully pressurized space suit. Results of a recent study in which a newly developed reduced-gravity simulation technique was evaluated (refs. 1 and 2) showed that the self-locomotion performance of test subjects wearing normal street clothing was generally enhanced by reducing the gravity level to that of the moon. It appears that this potential gain in performance will be offset to varying extents by the bulk and restraints imposed by the astronaut's space suit and by the equipment and other loads carried by the astronaut. There is, therefore, some question as to what the net performance of the astronaut and the attendant life-support system equipment will be in lunar gravity and whether the actual performance in lunar gravity can be determined from currently available studies of suited test subjects in the earth-gravity condition. Consequently, a study program has been initiated at Langley Research Center that utilizes the simulation equipment described in reference 1 to evaluate the effects of the suit constraints. It is anticipated that proper evaluation and application of the results obtained from this program will provide information useful in future development of advanced types of space suits, in planning of the lunar mission tasks and logistics, and in acquainting the astronauts with the extent and limitations of their physical capabilities on the lunar surface.

This paper presents the results of a brief exploratory investigation of the effects of the bulk and constraints of the current state-of-the-art space suits on the self-locomotion performance of the astronauts in earth and simulated lunar gravity. The particular suit used was of the "soft" type (that is, constructed primarily of fabric materials), and was manufactured by the International Latex Corporation, and furnished by the Manned Spacecraft Center at Houston, Texas.

Because this investigation was intended to show the general trends in performance of the man, the results are not intended to represent a detailed evaluation of the specific suit. No attempt was made to measure the mechanical characteristics of the suit or to correlate the degree of restraint with the degree of degradation in performance, as these factors were beyond the intended scope of the investigation. Several test subjects having various degrees of familiarity with the suits and the simulation equipment were used. The results are presented in terms of average data for a number of tests, typical data from individual tests, and various subjective comments referring to specific tasks.

EQUIPMENT AND SUBJECTS

Two sizes (1 large long and 1 medium regular) of the current state-of-the-art space suit, shown unpressurized in figure 1, were used in this investigation to accommodate the subjects of different sizes; the subjects' weight, height, and other details are given in table I. The complete suit weighed approximately 26 pounds exclusive of the air-supply system, which for most of the tests consisted of several large air-storage bottles manifolded together, a regulator unit, and about 30 feet of umbilical air hose carrying the supply and exhaust air to and from the suit. For a limited number of tests, a backpack air-supply system weighing about 50 pounds was worn by the subjects and used in place of the external umbilical air-supply system. This suit is considered to be representative, in general, of current space suits. Consequently, specific design details of the suit are only of secondary interest and are not fully discussed. Briefly, the suit utilizes bellows-type joints at several points evident in figure 1 and ball-bearing joints at the wrists and helmet neck ring to provide maximum mobility. The boots had hard leather or composition soles.

TABLE I.- INFORMATION ON TEST SUBJECTS

Subject	Weight, lb	Height, ft	Age, yr	Suit size	Affiliation*
1	180	5.92	29	Large long	LRC
2	153	5.75	22	Med. reg.	LRC
3	185	6.00	39	Large long	MSC
4	158	5.77	26	Med. reg.	MSC
5	165	5.42	31	Med. reg.	MSC

*LRC - Langley Research Center; MSC - Manned Spacecraft Center.

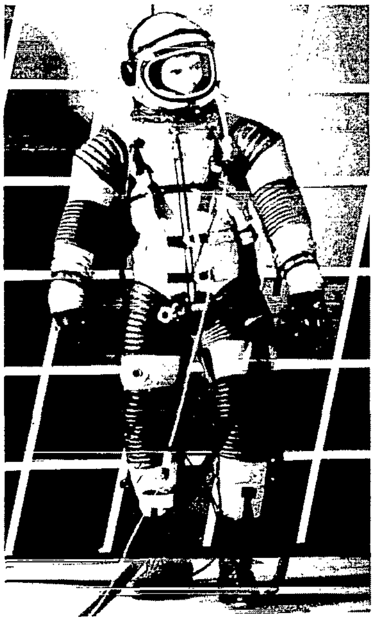

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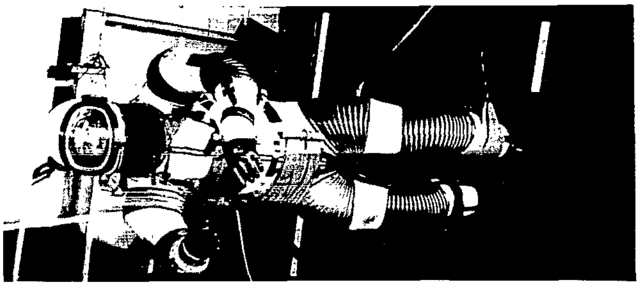
Figure 1.- State-of-the-art space suit used in the test program. Suit pressure, 0 psi.



L-64-1442
Figure 2.- Subject supported in the Langley reduced gravity simulator. Suit pressure, 3.5 psi.

The simulator used to test the subject's lunar walking capabilities is described in reference 1. No major modifications were required for supporting the test subjects in the pressure suits; however, an 8-foot extension to the original 16-foot walkway was used to provide additional working distance. An even longer walkway was desirable but could not be provided at the time of the tests. Figure 2 shows a subject in one of the suits suspended in the walking simulator. The surface of the walkway was painted plywood. No attempt was made to simulate the lunar surface conditions for this investigation.

Acceleration data for the jumping tests were obtained by using a ±5g accelerometer mounted on the back of the subject about waist high with the sensitive axis alined with the subject's backbone. Position and velocity of the subject were obtained from a 10-turn potentiometer and a tachometer driven by a string attached to the front and back of the test subject as shown in figure 3. Complete camera coverage of the test series was obtained for both data and documentary purposes with cameras at ground level and overhead.

Only three of the five test subjects, those from the NASA Manned Spacecraft Center, were experienced in the operation and evaluation of pressure suits and these subjects were used to obtain qualitative comments. The other two subjects, both from Langley were experienced with the lunar walking simulator. All the quantitative data were obtained with the two Langley test subjects.

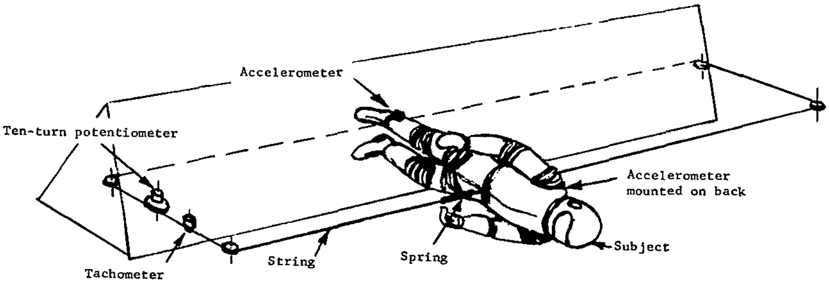


Figure 3.- Sketch illustrating the method used to instrument the test subjects.

BASIC TEST CONSIDERATIONS

The test program covered several modes of self-locomotion that appeared to have practical application to the lunar exploration mission. The subjects were required to walk, run, jump both vertically and horizontally, jump from one elevation to another, and climb ladders, poles, and stairs. These tasks were particularly suited to the reduced-gravity-simulation technique used in this study, inasmuch as the body members move primarily in the sagittal plane, that is, the vertical plane in the fore-and-aft direction, during performance of these specific tasks.

The simulator also imposed some resistance to the subjects' motion because of the weight and drag of the overhead trolley system. The total weight of the support harness (including the lower leg bar), the cables, and the spreader bar was approximately 8 pounds. The coefficient of starting friction of the overhead trolley was determined to be approximately 0.0085. A 180-pound man with a 26-pound suit must generate a force of approximately 1.75 pounds in the direction of motion to overcome the starting friction. This would be equivalent to the test subject leaning forward from a vertical standing position approximately 3°. This 1.75-pound force was about 8 percent of the traction force available and therefore was considered negligible for the purpose of this study.

The tests were conducted in the suit at 0 psi and 3.5 psi at both earth gravity and simulated lunar gravity. In some cases, comparative tests were made in normal street clothing. Prior to participating in the actual tests, each subject was given an opportunity to practice in order to become accustomed to the suit and simulation equipment and to develop the balance, judgment, and technique required to accomplish a given task. The limited length of the simulator walkway made it impractical to conduct endurance and metabolic tests.

RESULTS AND DISCUSSION

A motion-picture film supplement, showing typical results from this investigation, has been prepared and is available on loan. A request card form and description of the film will be found in the back of this paper.

The results obtained from the test were both qualitative and quantitative. The qualitative data were taken from the comments of all 5 test subjects, whereas, the quantitative data were taken only for subjects 1 and 2.

Suit Comfort

Before undertaking a discussion of the test for specific locomotive tasks, some consideration must be given to the qualitative factor of suit comfort. Obviously, an ill-fitted suit or one with poorly designed details will impose much discomfort and degrade the subject's performance from that which he could achieve in a comfortable suit. In the present tests, the suits could be adjusted over a limited range, while unpressurized, to assure reasonable fit and to minimize suit discomfort for the different subjects. With properly adjusted suits, all five subjects found a marked improvement in suit comfort in simulated lunar gravity as compared with that in earth gravity. Consequently, it appears that a pressurized suit may cause less discomfort to the wearer and correspondingly less performance impairment in lunar gravity than in earth gravity. This observation in itself suggests that suit tests performed in simulated lunar gravity may be more generally applicable to lunar self-locomotion studies than those conducted in earth-gravity conditions.

Walking and Running

In these tests, the subjects were instructed to walk the full distance of the walkway at a rate which was considered to be comfortable to them for each of the test conditions and to note their sensations and reactions. The results of these tests indicated that there were no serious problems that could not be overcome by any of the subjects after a short period of indoctrination. It was noted that the bulkiness and constraint of the bellows joints at the knees and crotch caused the subjects at 1 g to sway from side to side in a stiff-legged walk, especially in the pressurized condition. In the 1/6 g simulator, the subjects did not sway nearly as much as in 1 g, in part, because of the lateral support provided by the simulator. In either case this swaying did not present any serious problems. During the initial walking attempts by the pressure-suited subjects in the 1/6 g simulator, there was a tendency to lean too far forward (30° or more); this tendency caused them to fall forward on their faces. In these cases, because of the restraints of the suit, low foot traction, and the minor restraints of the simulator, the subjects were unable to move their feet and legs fast enough to counteract the increasing forward momentum. Two or three practice tries were sufficient, however, for the subjects to overcome this tendency and to walk the available distance successfully.

Typical values (accurate to about ±10 percent) from individual tests for the walking stride, velocity, and body lean of the two test subjects performing several repeated tests are given in table II. Stride is defined as the distance traveled during a cycle of movement measured from heel strike to the next time the same heel strikes, and the stride values given are the average of at least three complete strides. Body lean is defined as the angle of the subject's back with respect to the local vertical. In general, there is little difference in the results obtained with normal clothing and with the unpressurized suit;

TABLE II.- TYPICAL RESULTS OF WALKING AND RUNNING TESTS OF TWO SUBJECTS

	Earth gravity						Lunar gravity					
	Normal clothing		Unpressurized suit		Pressurized suit		Normal clothing		Unpressurized suit		Pressurized suit	
	Subject		Subject		Subject		Subject		Subject		Subject	
	1	2	1	2	1	2	1	2	1	2	1	2
Walking												
Average stride, ft	5.0	5.3	5.0	5.3	2.5	2.0	5.0	4.5	5.0	4.0	5.0	3.0
Average velocity, ft/sec	5.0	5.0	5.0	5.0	1.5	1.4	3.2	3.5	3.0	3.3	2.3	2.6
Body lean angle, deg	1 to 2						10 to 20					
Running												
Average stride, ft	5.0	6.0	5.0	6.0	4.0	4.0	5.0	5.0	5.4	5.0	5.0	4.5
Average time to travel 20 feet, sec	1.2	1.6	3.2	3.4	4.0	4.0	4.9	4.1	6.5	6.0	8.3	9.0
Maximum velocity, ft/sec	12.0	11.0	12.0	10.0	8.2	8.2	6.5	6.0	5.7	5.4	4.3	3.7
Body lean angle, deg	2 to 5						20 to 30					

however, pressurizing the suit caused significant reductions in the stride and velocity, especially at 1 g. Note that the effects of pressurizing the suit were much less for the lunar-gravity condition than for earth gravity; thus, a comparison of the effects of gravity shows a significant increase in the comfortable walking stride and velocity at reduced gravity.

Because of the limitations of the test equipment, the objectives of the running tests were restricted to measuring the time and maximum velocity attained in traveling a distance of about 20 feet. This distance precludes measurements of maximum speed and endurance attainable under a more realistic condition of unlimited distance, but the tests are believed to represent a measure of the ability to move away quickly from a location where the astronaut's safety may be in jeopardy.

The initial reaction to running in the pressurized suit at 1/6 g was stated by one subject to be "different from earth running but easy as long as the body center of gravity is far enough forward." Another subject stated it was "difficult to run, very hard to get proper (considering usual earth run) arm swing and knee bends; it felt more like waddling than running and was definitely a different process than under earth g with the suit unpressurized. It was extremely difficult to regain balance once you slipped. No matter how hard you tried to run it seemed as if you were only walking at a fast pace." These two quotes from the test subjects indicate the difference in subject reactions. The apparent reason for the difference was in the techniques used. The first subject accelerated smoothly and moved his legs just fast enough to maintain a constant forward body lean of 25° to 30°; the second subject attempted to start as if he were going to run a 100-yard dash in a 1 g environment. The short quick driving steps proved to be ineffective because the low foot traction caused the subject to lose his balance. However, with practice the subject overcame the problem and developed the necessary technique. Consequently, training appears to be an important factor in getting the subject accustomed to running at 1/6 g.

Some averaged results obtained during the running tests of the two subjects with the pressure suit are shown in figure 4 in the form of a plot of the variation of subject velocity with distance traveled and data from typical tests of each subject at each condition are given in table II. Comparison of the data of table II shows that for both gravity conditions the time to reach 20 feet increased slightly because of the increasing bulk and constraint as changes from normal clothing to the fully pressurized suit were made. Furthermore, the times for the lunar-gravity tests were approximately twice those for the earth-gravity conditions as a result of the reduced foot traction. The effects of reduced traction are illustrated in figure 4. The curves given are the average of ten runs (5 by each subject) for each suit and gravity condition, the position and velocity were averaged at 1/10 second intervals from the tachometer and potentiometer records. The curves show that the average maximum velocity reached for the 1/6 g condition is approximately 40 to 50 percent of that for the 1 g condition. Note also that pressurizing the suit for both gravity conditions reduced the average maximum velocities by 20 to 30 percent.

As indicated previously, the maximum velocities reached in these running tests were not expected to be the maximum attainable when longer distances are available. It is expected, however, that the effects noted here will apply generally; that is, the maximum running velocity in the lunar gravity will be about one-half that for earth gravity and pressurizing the suit will cause a further reduction of about 25 percent in both gravity conditions.

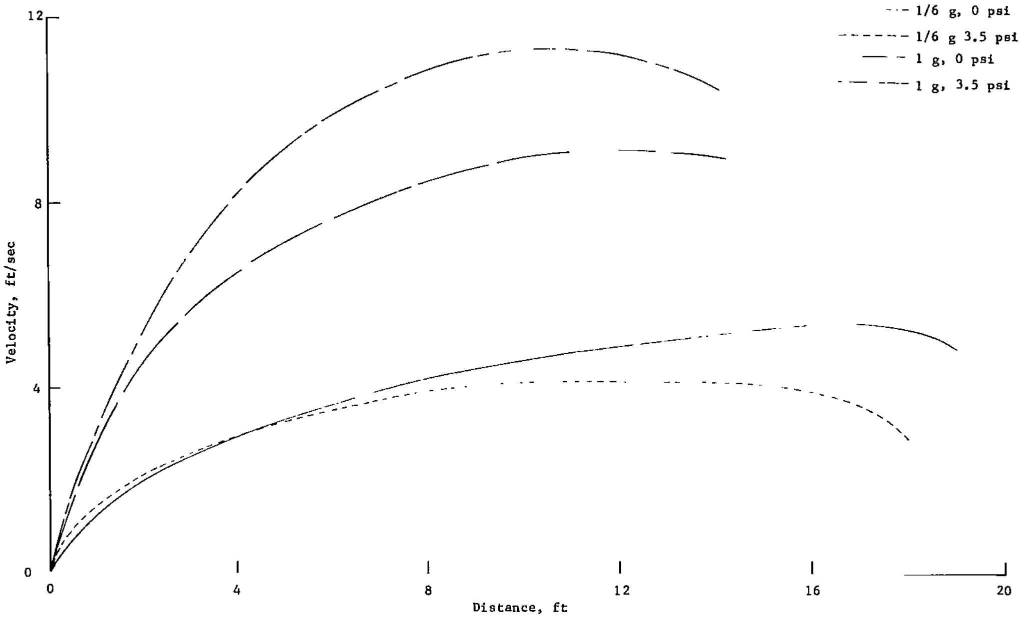


Figure 4.- Variation of velocity with distance traveled during the running maximum-acceleration test.

Jumping

Measurements were made to determine the average maximum vertical heights and horizontal distances that two of the test subjects could jump under the influence of earth and simulated lunar gravity with the suit unpressurized as well as pressurized. The average was obtained from a series of five jumps by each subject for each test condition, with the jump height being measured from head height in an erect standing position to maximum head height during the jump. The subjects were also required to jump up and land on a platform at different heights to determine how well this type of maneuver could be performed.

Vertical jump heights achieved while wearing normal street clothing were reported in reference 1 to be 1.6 to 1.8 feet under the condition of 1 g, with heights equivalent to 12 to 14 feet under the 1/6 g condition. The term "equivalent height" is used in the simulated 1/6 g condition because a height correction must be applied to the measured jump height to account for the gravity gradient produced by the test equipment as the angle of the support cables increases with respect to vertical. Figure 5 shows the actual height compared with the equivalent height for the test conditions.

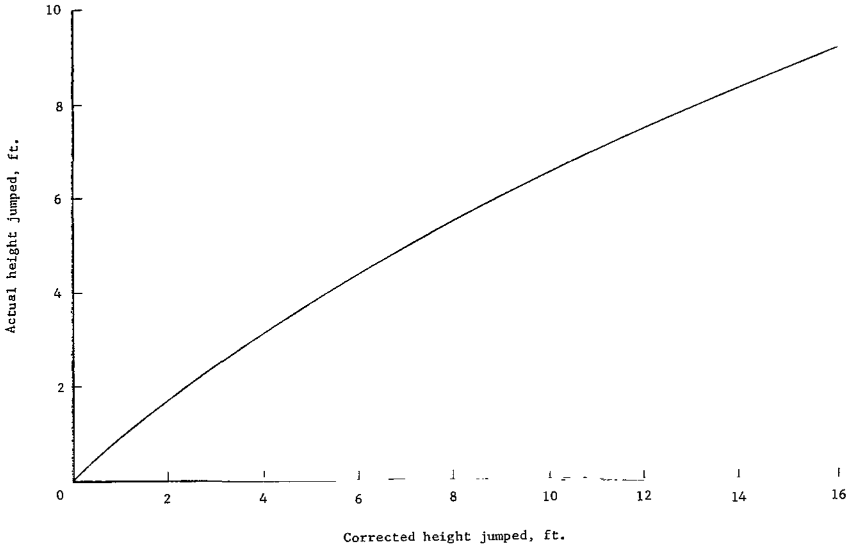


Figure 5.- Actual height compared with equivalent height jumped when a 37-foot suspension cable was used.

The average equivalent vertical jump heights obtained from this investigation and the tests reported in reference 1 are presented in figure 6. Typical jump heights and the peak push-off acceleration for two of the test subjects are given in table III. Comparison of the results presented in figure 6 for the unpressurized suit and for the normal clothing shows that the increased bulk and the fit of the suit caused a 10- to 15-percent decrease in height for both gravity conditions. Pressurizing the suit to 3.5 psi caused a further reduction in height of about 30 percent as compared with the unpressurized condition. In general, while wearing the same type of clothing in both gravity conditions, the subjects could jump 6 to 7 times higher in the lower gravity.

The following remarks typify comments of test subjects for the 1/6 g condition with the suit pressurized: "It was impossible to obtain the same amount of leg stroke (knee flexion) with the suit pressurized as with the suit unpressurized. The bulk and restrictions of the suit not only limit the stroke but also make it difficult to obtain the coordination required for a good jump." The term "good jump" in this quote is interpreted to mean a jump with maximum height in lunar gravity of about 7 feet. In this context even a "poor" jump resulted in jump heights three to four times better than the jump heights reached in earth gravity. In general, there appeared to be much less tendency to lose balance at these heights with the pressure suit than was the case with the much higher

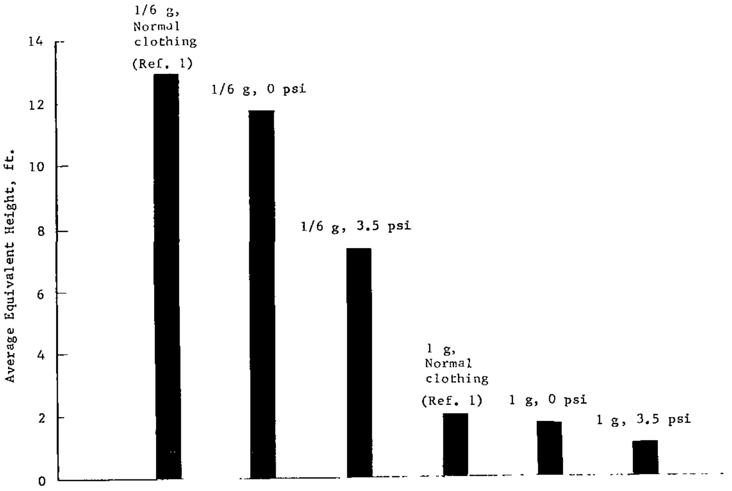


Figure 6.- The average vertical heights obtained during the vertical jump test. (The values listed are the average of 5 jumps each by subjects 1 and 2.)

jumps attained without the pressure suit as reported in reference 1. This difference is attributed to the shorter duration of the jumps in these current tests.

The mechanics of a standing broad jump requires the subject to assume a partial squat position while allowing his torso to lean forward from the vertical. When the proper body lean is reached, the subject extends his legs, and this causes him to spring forward. In order to resume a standing position at the landing, the subject must rotate rearward prior to landing to approximately the same angle as used for initiating the jump. During these tests it was found that large amounts of body lean were required at 1/6 g and 3 to 4 practice jumps were required before the test subjects could develop the timing and judgment necessary to initiate properly the rotation required. The difficulty is attributed primarily to the lack of experience of the two test subjects in performing the task with a full pressure suit.

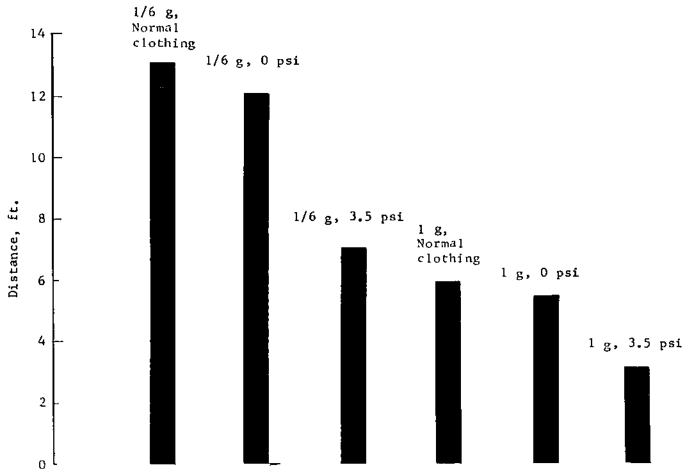


Figure 7.- The average horizontal distances obtained during broad jump test.

After the test subjects had mastered the required technique, test jumps were made to determine how far they could jump under the 1/6 g condition as opposed to 1 g conditions. The averaged results of these tests are presented in bar chart form in figure 7, and typical results for two of the test subjects are given in table III. A comparison of the data shows that the subjects jumped about twice the distance under 1/6 g that they could achieve under 1 g for any condition of clothing. It also shows that pressurizing the suit reduced the distances obtained by 30 to 40 percent in both gravity conditions. This reduction was attributed by the subjects directly to the increased restrictions of the suit.

TABLE III.- TYPICAL RESULTS OF JUMP TESTS OF TWO SUBJECTS

	Earth gravity						Lunar gravity					
	Normal clothing		Unpressurized suit		Pressurized suit		Normal clothing		Unpressurized suit		Pressurized suit	
	Subject		Subject		Subject		Subject		Subject		Subject	
	1	2	1	2	1	2	1	2	1	2	1	2
Vertical jumping												
Jump height, ft	1.9	---	1.6	1.5	1.0	1.0	13.8	---	11.8	12.2	7.7	8.5
Peak push-off acceleration, g units	3.0	---	1.7	1.6	1.5	1.9	1.0	---	1.5	1.5	1.4	2.1
Broad jumping												
Jump distance, ft	6.2	---	5.5	7.0	5.0	4.5	13.0	---	13.0	13.0	11.0	9.0
Average forward velocity, ft/sec	---	---	12.0	5.7	10.0	8.3	----	---	6.2	5.5	4.9	3.8

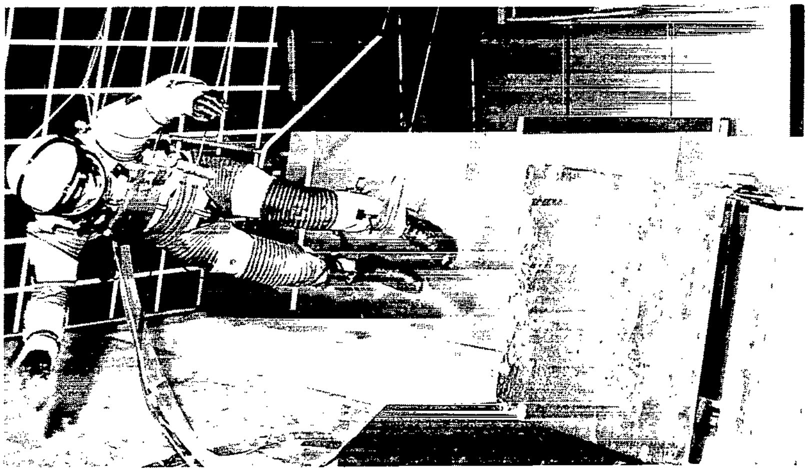


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Figure 8.- Subject at 1/6 g jumping to a platform 6 feet above the walkway surface. Suit pressure, 0 psi.

After the subjects had mastered the body control necessary to perform vertical jumps and standing broad jumps under 1/6 g in the pressurized suit, they were required to jump onto a 3-foot-square platform placed first at equivalent heights of 4.5 feet and at 6 feet above the walkway. Figure 8 shows one subject in an unpressurized suit jumping to the 6-foot platform. Inasmuch as jumping to a platform as high as the one used, is an unusual earthly experience, a sense of judgment concerning the necessary forward momentum and the proper take-off point had to be developed. The subjects found that they could not generate both the height and forward momentum needed from a standing position; however, after taking $1\frac{1}{2}$ to $3\frac{1}{2}$ steps to build up forward momentum, they could crouch and spring upward in a well coordinated maneuver. The final half-step was needed so that the spring could be accomplished by using both feet.

Jumping to the 6-foot platform was more difficult than jumping to the 4.5-foot platform, mainly because the 6-foot height was close to the 7- to 8-foot limit of the subject's vertical jumping capabilities. When the subjects had insufficient forward momentum and did not succeed in reaching the platform, they were usually able to maintain their balance and land on their feet. However, in a few instances the subjects landed in a sitting position with legs outstretched but did not injure themselves or the suit.

Climbing

Simple tests consisting of walking up or down a set of four steps to a landing at an actual height of 4 feet above the walkway revealed that the subjects under 1/6 g with the suit either pressurized or unpressurized experienced no serious problems in maintaining balance or footing. The subjects appeared to be able to ascend or descend the stairs at any desired pace and, in fact, found it easier to jump to the landing. The descent of the stairs was a more exacting task than ascending, especially in the pressurized suit, as the subject could see neither the platform nor where the stairs started and, consequently, had to judge where the steps were located with respect to his position. One of the subjects attempted to climb the same set of steps in the 1 g condition. With the suit unpressurized the task was easily accomplished; however, with the suit pressurized the subject found that he could not even climb onto

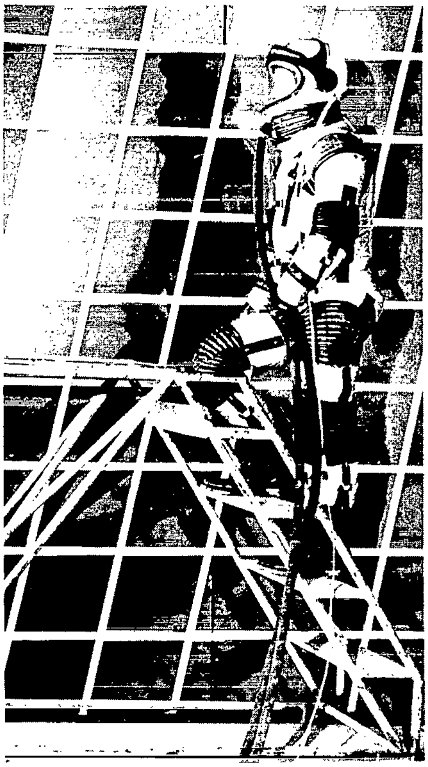

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Figure 9.- Subject at 1 g climbing the stairs used during the test series. Suit pressure, 0 psi.

the first step. Once one foot was on the step the subject could not maintain his balance while shifting the weight from the lower foot. The inability to maintain balance can be attributed primarily to the test subject's lack of full pressure suit experience and training in this type of maneuver. The steps used and shown in figure 9 were not equipped with handrails, which would have provided some assistance to the subject.

As noted in reference 1, climbing a ladder with normal clothing in simulated lunar gravity posed no serious problem as long as a slow deliberate pace was used to allow time for proper placement of the feet on the rungs of the ladder. The same result was true for the current tests with the space suit unpressurized. With the pressurized suit, however, the effort required to move the legs and feet was noticeably increased as a result of the increased stiffness of the knee and hip joints. Also stiffening of the shoulder and elbow joints increased the effort required to place the hands onto the ladder rungs.

Although the shoulder joints of this particular suit configuration move relatively easy as the wearer swings his arms fore and aft (flexion and extension), the joints are quite resistant, in the pressurized state, to sidewise motions (adduction and abduction) of the arms. Both types of movement are required for the placement of the hands on the ladder rungs while climbing. In an attempt to alleviate the workload, the subjects climbed the ladder by gripping the back of the side pieces as shown in figure 10. This method which required only flexion and extension motions proved to be slower but much easier to execute.

L-64-1377
Figure 10.- Subject at 1 g climbing the ladder and using his hands to grip the back of the uprights. Suit pressure, 0 psi.

Typical comments from the test subjects indicated that climbing the ladder at 1/6 g was not difficult. One subject was able to climb the ladder starting from a prone position on the floor by using his hands to grip the side of the ladder. Climbing the same ladder under 1 g with the suit pressurized was extremely fatiguing and difficult.

Climbing a pole was impractical while wearing the pressure suit at 1 g but proved to be a relatively simple task at 1/6 g. The average climbing rate and length of stroke is given in table IV. Pressurizing the suit increased the effort of the task due to resistance in the region of the shoulder joint. Except for this problem the subjects felt "...climbing hand over hand was easy and did not require much physical effort."

TABLE IV.- AVERAGED RESULTS OF CLIMBING TESTS OF TWO SUBJECTS

	Earth gravity						Lunar gravity					
	Normal clothing		Unpressurized suit		Pressurized suit		Normal clothing		Unpressurized suit		Pressurized suit	
Ladder climbing												
Subject	1	1	1	1	1	1	1	1	1	1	1	1
Hand placement	Rungs	Side pieces	Rungs	Side pieces	Rungs	Side pieces	Rungs	Side pieces	Rungs	Side pieces	Rungs	Side pieces
Climbing rate, ft/sec	2.7	---	1.2	1.1	0.2	---	2.4	---	2.1	1.5	1.0	0.8
Pole climbing												
Subject	1	2	1	2	1	2	1	2	1	2	1	2
Climbing rate, ft/sec	1	---	Not attempted		Not attempted		1.7	---	2	1.7	0.6	0.9
Average hand stroke, ft	0.5	---					1	---	1	0.9	0.5	0.6

Miscellaneous Tasks and Observations

The 1/6 g environment had no marked effect on any of the subjects' ability to stand. In reference 1 it was noted that the subjects tended to seek a vertical position by rocking back and forth, assuming a spread footing, or by rising to the toes in an effort to "feel" the normal foot pressure present under 1 g. The fact that this was not the case for the subjects in the pressure suits can probably be attributed to the type of foot gear and constraint of the suit which provided cues to replace the ones normally received.

Kneeling in the pressurized suit at lunar gravity was accomplished by first trying to assume a squatting position and then leaning forward to a kneeling position. Although the maneuver was not hard to execute, the restrictions (bunching in the popliteal area) of the suit allowed the subjects to flex only a limited amount. This position, in turn, caused the subjects to lean forward over the knees as they touched the floor, and required the subjects to brace themselves with their hands to keep from falling forward.

After assuming a kneeling position, the subjects attempted to pick up objects from the floor; for this test the object used was a roll of tape. A typical comment was, "...no difficulty in picking up the roll of tape; however, you still have to control yourself because of the forward rotation on your knees." Getting up from a kneeling position was accomplished simply by pushing off from the floor with the hands to a half-squat position, and then standing.

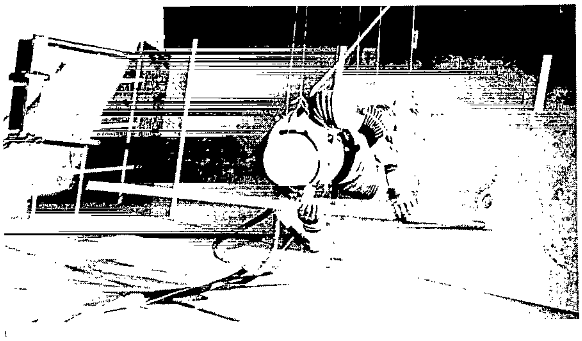

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Figure 11.- Kneeling with the aid of a support stick. Suit pressure, 3.5 psi.

Kneeling with the aid of a support stick $\left(\text{a } 1\frac{1}{2}\text{-inch-diameter aluminum pole 6 feet long}\right)$ made the task easier and provided the subjects with better control as exemplified by the comments, "...no trouble in kneeling with the stick or rising back to a standing position" and, "...better control in kneeling with the support stick." Figure 11 shows one of the test subjects using the stick as an aid for kneeling.

During the various test series the subjects inadvertently fell distances up to 7 or 8 feet because of loss of balance or other reasons while wearing the pressure suit and in no case did any injuries or damage to the suits result from these falls. It was left to the ingenuity of the test subject to regain a standing position. If the subjects were lying face down, standing was accomplished by simply pushing against the floor with the hands and arms with sufficient force to regain a standing position. In the case where the subjects were in a supine position, they found it difficult to regain an upright position, as indicated by the following comments from two test subjects: (1) "Pushing on the support stick, I was able to gain an upright position. It was very difficult to resume an upright position without the aid of the stick. The limitations of pressure-suit mobility hampered me from gaining enough momentum with just my arms and legs to attain an upright position." (2) "Using the support stick, I was able to propel myself from the surface and use my body momentum to rotate forward to an upright position. Without the support stick, it was difficult to gain enough body momentum to rotate forward and stand upright."

With the suit pressurized under simulated lunar gravity, the test subjects could still perform all the gymnastic feats reported in reference 1, which included head and hand stands as well as forward and backward flips. Although it is not expected that the first lunar explorer will attempt to perform gymnastics, the ability to do so indicated the extent of body control and maneuverability the astronauts will have under lunar gravity while encumbered by a full pressure suit.

Although no attempt was made to evaluate the duration limits for the various locomotion tasks and the effects of fatigue, it was noted that the test subjects were able to perform the many tasks without becoming overly fatigued for periods up to about 3 hours in the lunar-gravity condition. At the same time, fatigue was encountered in much shorter times when the subjects performed in earth gravity. This fact suggests that the metabolic heat loads for a given task may be significantly less for the lunar-gravity case than for earth conditions. Additional tests are required, however, before this observation can be substantiated.

A limited comparison between the feel of performing tasks in an aircraft flying 1/6 g trajectories and in the reduced-gravity simulator was obtained from one of the test subjects who had completed some flight tests with the pressure suits just prior to participating in this investigation. He stated that the "feel" and illusion present in walking, running, and kneeling with or without the aid of a support stick were very similar, and, in the case of kneeling, identical.

While performing several of the tasks previously discussed, the subjects observed that their visibility with the suit pressurized was limited. Their downward visibility was such that they could not see the floor within approximately 4 feet of their position while standing in an upright posture. This restricted downward visibility while annoying in all the tests was a particular problem while ascending and descending the stairs and jumping up to a platform. Although the subjects were able to develop the sense of judgment required to successfully execute the specific tasks in these tests with sufficient practice, it appears doubtful that training for a lunar mission will remove the problems which may arise as a result of limited visibility under actual circumstances.

In general, the data presented herein indicate a marked difference in the kinematics of locomotion at 1/6 g compared with that at 1 g and in most cases indicate that the net performance of the astronauts will be enhanced by the reduction in gravity. Therefore, it appears that a lunar-gravity simulation technique should be used, in addition to the currently employed techniques, for determining man's physical capabilities while encumbered by a full pressure suit on the lunar surface.

RÉSUMÉ

The following is a summary of the results obtained in this exploration study of the self-locomotion capabilities of man wearing a space suit in simulated lunar gravity:

1. Performance in a sample configuration of a pressure suit was found to be better, more comfortable, and less fatiguing for the lunar-gravity simulation than for the earth-gravity condition.

2. In the pressurized suit the comfortable lunar walking pace was faster than that for earth walking, but the maximum lunar running speed for the short distance used in this study was slower by about 40 to 50 percent, probably because of less traction.

3. The vertical and horizontal jumping distances from a standing position were increased about six times and about two times respectively by reducing the gravity level from 1 g to 1/6 g.

4. In general, changing from normal street clothing to the unpressurized suit used in this test series made only a small difference, whereas, pressurizing the suit reduced the subject's ability to run and jump by about 30 percent at both gravity levels.

5. Climbing stairs, ladders, and poles was very much easier in the pressure suit when done in the lunar gravity than when done in earth gravity. Use of the pressurized space suit imposed some difficulties which probably could be minimized with training experience.

6. Lack of adequate visibility due to the suit design (the inability of a subject in a standing position to see the ground within about 4 ft of his feet) was a particular problem in both jumping and climbing onto or off of the platform used.

The results of this study must be treated as preliminary inasmuch as all tests were performed under conditions that could be described as ideal insofar as lunar operations are concerned; that is, the temperature was moderate, lighting was excellent, the walking surface was hard and consistent, generally adequate cooling and moisture removal from the suit were provided, and the subject was not required to carry his life-support system. These factors and others such as differences in suit-design details, subject's physical and psychological condition as well as fatigue can have significant effects on the capabilities of the astronauts in an actual operation. The simulator equipment also produced some constraints on the test subject which were considered to be minor. Consequently, these results must be applied with some caution to studies of lunar operations. It is believed, however, that the results are indicative for the lunar operations tested and can be used as such with some confidence.

An evaluation of the test results indicates that an explorer wearing a pressurized space suit on the moon will be able, with practice, to walk and run provided, of course, that the terrain is relatively firm and not too rough. He should also be able to perform many other self-locomotion tasks such as jumping and climbing and will be able to out-perform his earth counterpart with the exception of body motions requiring rapid accelerations along the surface such as running which requires traction.

During this test series neither the metabolic rates nor the resulting heat loads imposed on the man or the life-support system were considered. Additional tests are needed to determine these loads inasmuch as this will affect the requirements of the life-support system.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., January 5, 1965.

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