STATUS REPORT ON RECENT LANGLEY STUDIES OF LUNAR AND SPACE STATION SELF-LOCOMOTION

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SUMMARY

Studies of the self-locomotive capabilities of astronauts both on the lunar surface and in rotating space stations are currently being carried out by the Langley Research Center of the National Aeronautics and Space Administration. New and unique reduced gravity simulators developed for this work permit subjects to experience and report first-hand on the sensations and physical effects produced by the space environments. This paper is a brief status report on some aspects of this work and includes general descriptions of the facilities employed, the types of studies underway, and some observations and comments based on results obtained up to this date.

The lunar locomotion studies are being carried out both by in-house effort and by contract with aerospace industries using an inclined-plane technique developed at Langley for simulating lunar gravity. The initial in-house studies revealed that there were significant differences between earth and lunar locomotive gait characteristics and that in general a gravity level equal to that of the moon had a favorable effect on these locomotive capabilities. These results are being borne out by contracted studies which are investigating in greater detail the effects of the various lunar environmental factors.

The space station studies utilize a Langley developed simulator capable of rotation which together with the inclined-plane technique adapted from the Lunar Walking Simulator can provide weightless and rotational conditions of these studies. It was observed that subjects could initiate and sustain a walk at gravity levels below 0.2 times earth's gravity. In addition to walking, "space soaring" could be employed under these conditions. Use of the hands and arms was found to be advantageous under these conditions. At higher gravity levels, above 0.2 to 0.3 times earth gravity, an annoying effect due to centrifugal forces imposed on the legs as they swung forward in the walking stride was noted. This effect caused the legs to feel excessively heavy but did not prevent locomotion.

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INTRODUCTION

The desire and need for placing man into space, whether in a spacecraft or on some extraterrestial body, is based on his ability to think, to observe, to reason, to manipulate, and to locomote. Because of these characteristics, he should be able to perform many functions which cannot be effectively performed by machines. Of course, one of the basic concerns about space is the question of how well man will be able to utilize these characteristics developed through millions of years of evolution in earth's gravitational field in the weightless and near weightless space environments. Some of the research efforts of the Langley Research Center of the National Aeronautics and Space Administration have been directed toward one aspect of this question, namely, the study of man's self-locomotive capabilities in space. This report will review briefly the progress which has been made to date and plans for continuing work relative to man in a rotating space station and to man on the lunar surface. New and unique reduced gravity simulators developed for this work permit test subjects to experience firsthand the sensations and physical effects essentially equivalent to those produced by space environments. These studies are, of course, directly related to the Apollo lunar mission and to future missions with orbital space stations.

LUNAR SELF-LOCOMOTION

Efforts related to the lunar locomotion field at the Langley Research Center were started several years ago with the development of the Lunar Walking Simulator employing the so-called inclined-plane technique reported in reference 1. Briefly, in this technique the subject is supported, as shown in figure 1, on his side by a series of cables attached to an overhead monorail trolley system running parallel with an inclined walkway on which the subject can walk, run, crawl, and jump. The walkway is displaced from directly beneath the monorail track so that the subject's vertical axis, that is, along his backbone, as shown in figure 2, is inclined about 9.6° from the horizontal, thus alining the subject with a component equal to one-sixth of the earth's gravity vector. Although this suspension restricts body movement to essentially planar motion, very realistic results can be achieved with only minimal interference caused by the suspension system.

Several studies have been carried out under Langley's direction using this technique and are discussed in references 1 through 7. Currently an extensive study, contracted by Langley to the AiResearch Division of the Garrett Corporation at Los Angeles, California, is underway to determine the restraints imposed by specific features of the lunar terrain on the astronaut's capabilities. This work is an expansion of that previously carried out under a Langley contract by the Northrop Space Laboratories as reported in reference 6.

A basic understanding of man's self-locomotive capabilities on the moon can be developed from figure 3 which represents the significant results of some early work reported in reference 4 in terms of stepping rate, in steps per second, plotted against locomotive velocity, in meters per second, achieved under the test conditions. The solid line corresponds to the general trend of data points obtained with three subjects of differing stature wearing conventional flying coveralls while walking and running in earth gravity on a smooth firm surface; the dashed line corresponds to the same test performed in simulated lunar gravity. The termination of the lines indicates the maximum running speed for both gravity conditions and the vertical line depicts the transition speeds between walking and running. Comparison of the two curves, therefore, shows that man's maximum walking and running speeds in lunar gravity would be about 60 percent of his earthly capabilities under corresponding conditions. These results are attributed primarily to his reduced weight and consequent loss of foot traction.

Perhaps, of far more importance than this loss of speed capability is the very significant reduction in the number of steps per second required for a given locomotive speed for the lunar condition. This comes about by the ability to take a longer stride in the lunar gravity condition. Note particularly the disparity between the two curves in the speed region of 2 to 3 meters per second where the lunar stepping rate is essentially one-half of the terrestial rate. If we, logically, relate energy expenditure to stepping rate, the energy costs of lunar self-locomotion can be seen to be markedly less than those related to our earthly experience. The implication here is that in spite of the apparent performance loss due to reduction of speed capabilities on the moon there may be a significant performance gain in terms of energy expenditure and optimum speed of locomotion.

These observations have been borne out by the subsequent work performed in the contract study reported in reference 6. Here two pressure-suited subjects with 32.7-kilogram (72-pound) life-support backpacks performed similar tests while wearing obsolete, but commonly used, Mark IV pressure suits. Some of the data were presented and analyzed in reference 7, from which figure 4 was obtained. In this figure, the range or distance in kilometers which can be traveled without fatiguing the astronaut for both gravity conditions is presented for different speeds, in meters per second, and for different time periods, in hours, for a smooth firm surface. There seems to be an even greater disparity between earth and lunar performance than was indicated by the previously discussed data. This marked difference is due to the effects of the pressure suit and life-support backpack which were found to impose severe penalties in earth gravity but only relatively minor losses in simulated lunar gravity. As a consequence, for any given time period, the lunar explorer can cover about four times the distance as his earthly counterpart assuming, of course, similar conditions. The previously mentioned work currently underway at the AiResearch facilities under Langley direction is expected to expand on these preliminary findings by exploring more fully the effects of surface slope, texture, and bearing strength on the performance of a larger test subject population of six and employing a present-day space suit.

One other aspect of man's self-locomotive capabilities has been explored to some extent in the Langley work, in which various loads up to about 226.8 kilograms (500 earth pounds) were carried on a backpack by subjects wearing conventional flying coveralls in the simulated lunar gravity. The two experienced subjects of average stature and physical condition were able to carry these loads at speeds up to about 4 meters per second, but felt that the 226.8-kilogram (500-pound) load represented the maximum load that they could safely handle. An interesting contrast between earth and lunar load-carrying capabilities was noted when it was observed that a motorized lift truck was required when handling the loaded backpack in preparations for the simulated lunar tests in which the test subjects easily handled the same mass unassisted.

There are, of course, various aspects of the lunar self-locomotion that have not been touched on here but which appear to be more or less self-evident, such as the relative times and distances required to accelerate and decelerate. Perhaps the most significant point to make relative to this subject is that in spite of the markedly different performance capabilities between earth and simulated lunar gravity conditions, the subjects were able to easily adapt to these differences with only brief practice periods.[5]

Rotating Space Station Self-Locomotion

One of the frequently discussed design considerations for space stations is the need for an artificial gravitational environment, and one factor set forth as favoring this need is the requirement for some minimum level of gravity so as to facilitate self-locomotion within the station. To explore the question of the limit value more fully the rotating space station simulator depicted in figure 5 was developed at the Langley Research Center employing the principles of the previously discussed inclined-plane technique and using some of the equipment from the Lunar Walking Simulator. The test subject is supported by a vertical cable so that he is on his side and his normal axis of locomotion is in the horizontal plane wherein the gravity vector is zero. The cable is attached to a trolley unit on a boom-supported monorail; the boom is servo-controlled so as to rotate about the vertical axis of the simulator and keep the cable directly over the subject as he walks along the vertical wall on the periphery of the circular platform. This wall represents the floor of a space station with a diameter of 12.2 meters.

The platform is designed to rotate about the vertical axis at speeds up to about 17 revolutions per minute, driven by the variable speed electric drive unit supported overhead by the tripod frame straddling the rotating platform. The drive torque is transmitted to the platform through the vertical shaft which supports the monorail-boom unit. The servo-drive unit for the boom is also attached to this vertical drive shaft and is activated by an angle sensor located at the attachment point of the suspension cable for the test subject. This sensor detects deviations of the cable from the vertical caused by motion of the subject relative to the boom.

The geometry of the walkway can be modified from the basic cylindrical shape shown in this figure to one composed of flat walkway surfaces such as a hexagonal or octagonal shape. There also is an inner 6.1-meter walkway with a removable panel so that the test subject can effectively move from one level to another within the station by jumping or climbing a pole, ladder, or stairway which can be easily installed. Figure 6 is a plot of station rotational rate in revolutions per minute versus the gravity level, in earth gravity units (g units), produced by this rotation at the center of gravity of the subject standing on either of the two walkways. Also plotted along the abscissa of the figure is the corresponding tangential velocity of the standing subject. Variation of the rotational speed by an assisting operator can change the gravity level at the outer walkway from 0 to nearly 2 times earth gravity. Of course, the gravity level at the smaller diameter inner floor is correspondingly less.

Difficulties in development of the servo-operated boom have delayed the full utilization of this facility; however, a number of exploratory studies have been carried out to date without the servo-drive unit. In these initial tests, the boom was free to rotate so that it did follow the test subject; however, he was required to overcome the effects of bearing friction, windage, and boom inertia. Inasmuch as for most tests the motions of the subjects were relatively slow and uniform, it is believed that the effects of these forces do not alter the observations drawn from these exploratory tests to any significant degree.

Very interesting results were noted in these tests in which attempts to walk at nominal speeds of about 1 meter per second were made by three subjects, experienced in reduced gravity locomotion. The rotational speed of the space station simulator was adjusted over a range of values from 0 to 12 revolutions per minute, providing gravity levels from about 0 to 1g. Only the larger diameter walkway was used. As might be expected, the ability to initiate the walk decreased essentially proportional to the reduction in gravity level. It was possible to initiate a walk at less than 0.1g ; however, the length of time to reach the desired normal walking speed was quite long. Use of the hands and arms to assist in accelerating the body forward by pulling or pushing on available handholds proved to be very effective in overcoming this problem.

When walking in the direction of rotation it was possible to easily sustain locomotion at very low rates of station rotation. As a matter of fact, it was even possible to sustain a walk at zero rotation corresponding to a weightless condition for the station. For this unique condition, assistance from the hands and arms to initiate the walk was essential. Once some forward momentum was generated by the propelling force of the arms, the feet became effective in producing traction to sustain the walking motion along the curved floor.

Although walking at 0.1g was very comfortable, a rather disturbing sensation was noted for gravity levels somewhere above 0.2g to 0.3g where the legs appeared to become increasingly heavy whenever walking motion was attempted. Although this effect did not prohibit locomotion it did appear to be quite annoying. In one instance, one subject reported the sensation of being heavier than his normal 1.0g weight although the artificial gravity due to station rotation was set at only about 0.5g. Accompanying this sensation was the illusion of increased curvature of the walkway which could be likened to walking at the bottom of a gully or small ravine that seemed to move along with you as you attempted to climb up its side.

Another unusual situation was encountered when attempting to walk in the direction opposite to the station rotation at the lower "g" levels of say 0.1g or less. In this case, as soon as the subjects started walking, they would tend to rise from the floor and float helplessly until they could reach out and grab some part of the station as it rotated past them. This form of locomotion can be likened to the "soaring" which can be employed in the nonrotational space station. As a matter of fact, it was found that at the low gravity levels, below about 0.1g, the soaring form of locomotion was quite effective and perhaps in some instances more desirable than walking regardless of the directional movement. In this type of activity, control of the body attitude is not as effective as for walking and the arms and hands must be employed as well as the feet.

During these tests the subjects undertook some jumping activity in which they attempted to jump perpendicular to the floor in the radial direction so as to grab hold of the "overhead" structural members supporting the inner walkway. This was done in an attempt to obtain a feel for their ability to cope with the Coriolis accelerations engendered by such radial motions. In general, the effects of these accelerations were readily apparent as evidenced by the fact that attempts to jump to a spot directly overhead usually resulted in arriving at a spot displaced several inches from the target in the direction of rotation. Compensation for this effect, however, could be achieved quite easily after a few practice attempts. Therefore, the Coriolis accelerations do not appear to present serious problems relative to this form of locomotion.

Detailed analysis of the observations discussed herein are beyond the scope of this discussion; however, a few brief comments are in order so as to place these observations in their proper perspective. The first comment to be made is that even in the weightless environment with a nonrotational station a gravitational increment is generated by the process of locomotion along the curved floor as illustrated in figure 7, which shows the variation of this gravity level with different walking speeds for the case of the 12.2-meter walkway. If it is assumed that a nominal walking speed of 1 meter per second was maintained in the tests with zero rotation of the station, then this figure indicates that a gravity level of about 0.02g was developed. This then accounts, at least in part, for the ability to walk in the otherwise weightless state. It is noteworthy to point out here, however, that the use of a flat segmented floor rather than the continuously curved floor would have negated this ability to walk in the nonrotational tests inasmuch as the walking would not have generated the necessary curvilinear motion.

Some consideration must be given to the dynamic effects of the walking gait which involved rotational action of the legs. Simple calculations of the additional centrifugal accelerations due to the leg-swing motion were performed to illustrate this point and the results are presented in figure 8, which shows the variation of the calculated total effect of leg-swing motion with the gravity level produced by station rotation. The solid line represents the gravity level experienced by one leg as it swings forward during the half-stride free-swing phase. Inasmuch as the leg represents only about 20 percent of the total body mass, the effect on the body as a whole is less, as depicted by the long-dashed curve. Comparison of these curves with the short-dashed curve reveals the calculated incremental effect due to the leg-swing action. The large incremental accelerations on the leg at the higher gravity levels are undoubtedly the cause of the unusual "heavy-leg" sensation discussed earlier.

The results of walking with and against the direction of station rotation can be explained with the aid of figure 9, showing the variation of the effective gravity level with station rotational rate and equivalent tangential velocity for three conditions; walking with the rotation (long-dashed curve), walking against (short-dashed curve), and standing still (solid curve). This figure is essentially a reproduction of a portion of the curve for the 12.2-meter walkway from figure 6 but with this same curve also shifted along the abscissa by the amount and in the directions equal to the incremental velocity due to walking, which in this case was assumed to be 1 meter per second.

Comparison of these three curves reveals that walking in the direction of rotation has the same effect as does increasing the station tangential velocity or rotational rate. Likewise, walking in the opposite direction has the same effect as does reducing the station rotation. Consequently, walking against the direction of rotation tends to produce the condition of weightlessness on the occupant as was observed in the tests.

One point to make relative to this effect is that a rotating space station may tend to become a natural "one-way street" as far as walking is concerned; that is to say, the occupants may find walking in the direction of rotation to be more natural or comfortable. This could be especially true when they are carrying objects which restrict the use of the hands for assisting locomotion.

REMARKS

Perhaps the most pertinent closing remark to make relative to these two on-going projects that have been discussed here briefly, is that there seem to be significant differences between self-locomotion, involving rectilinear motion, as typified by walking on the moon or in a space station with flat floors, and self-locomotion involving curvilinear motion as in the case of the space station with floors curved about the axis of the rotation. Care should be exercised, therefore, when attempting to speculate on the problems of locomotion in one medium on the basis of experience in the other. Certainly, these few initial observations of self-locomotion in reduced gravity provide some interesting food for thought and point out the need for continuing studies in these areas because of the implications on mission planning, equipment design, and operational procedures.

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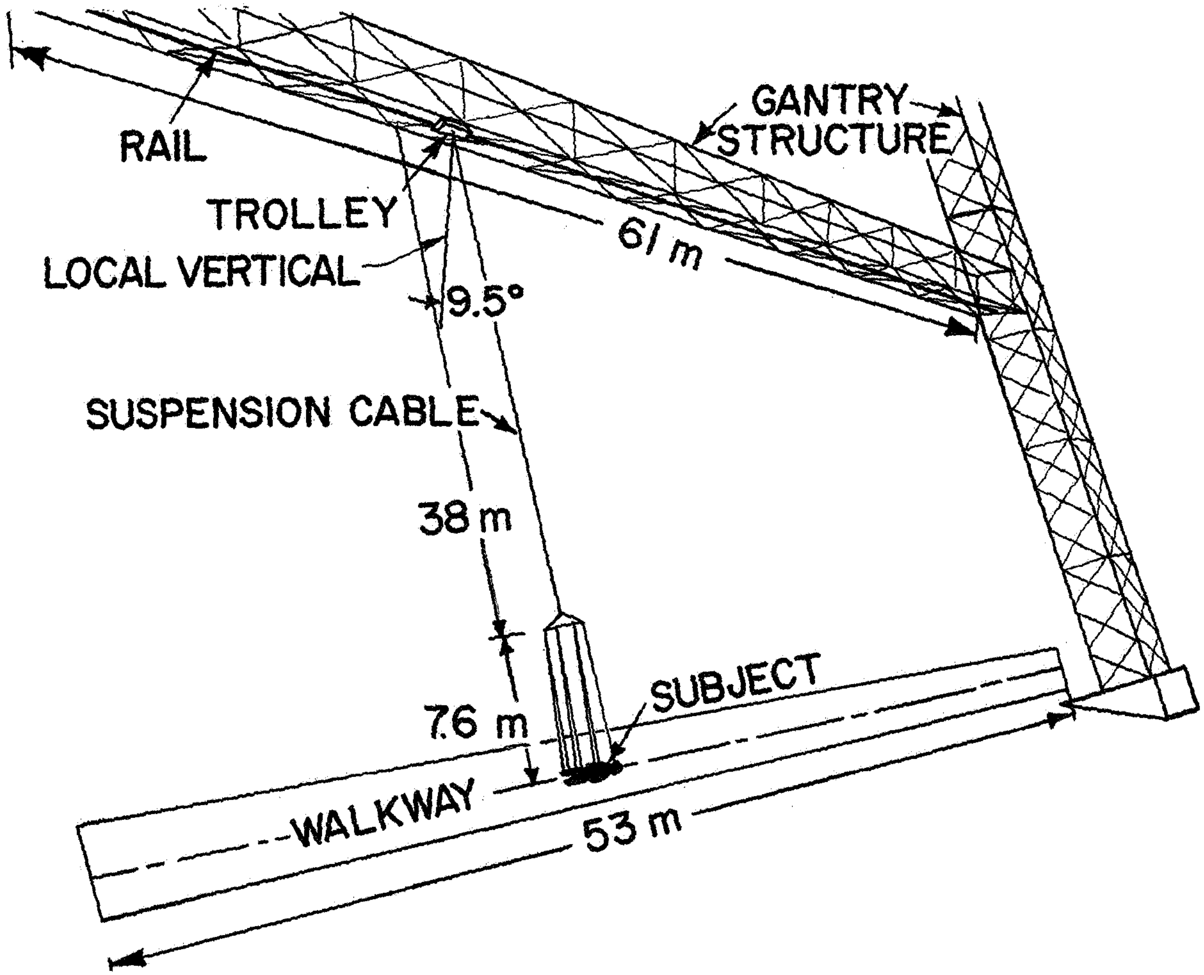

Figure 1.- Sketch of the Lunar Walking Simulator employing the inclined-plane technique developed at the Langley Research Center.

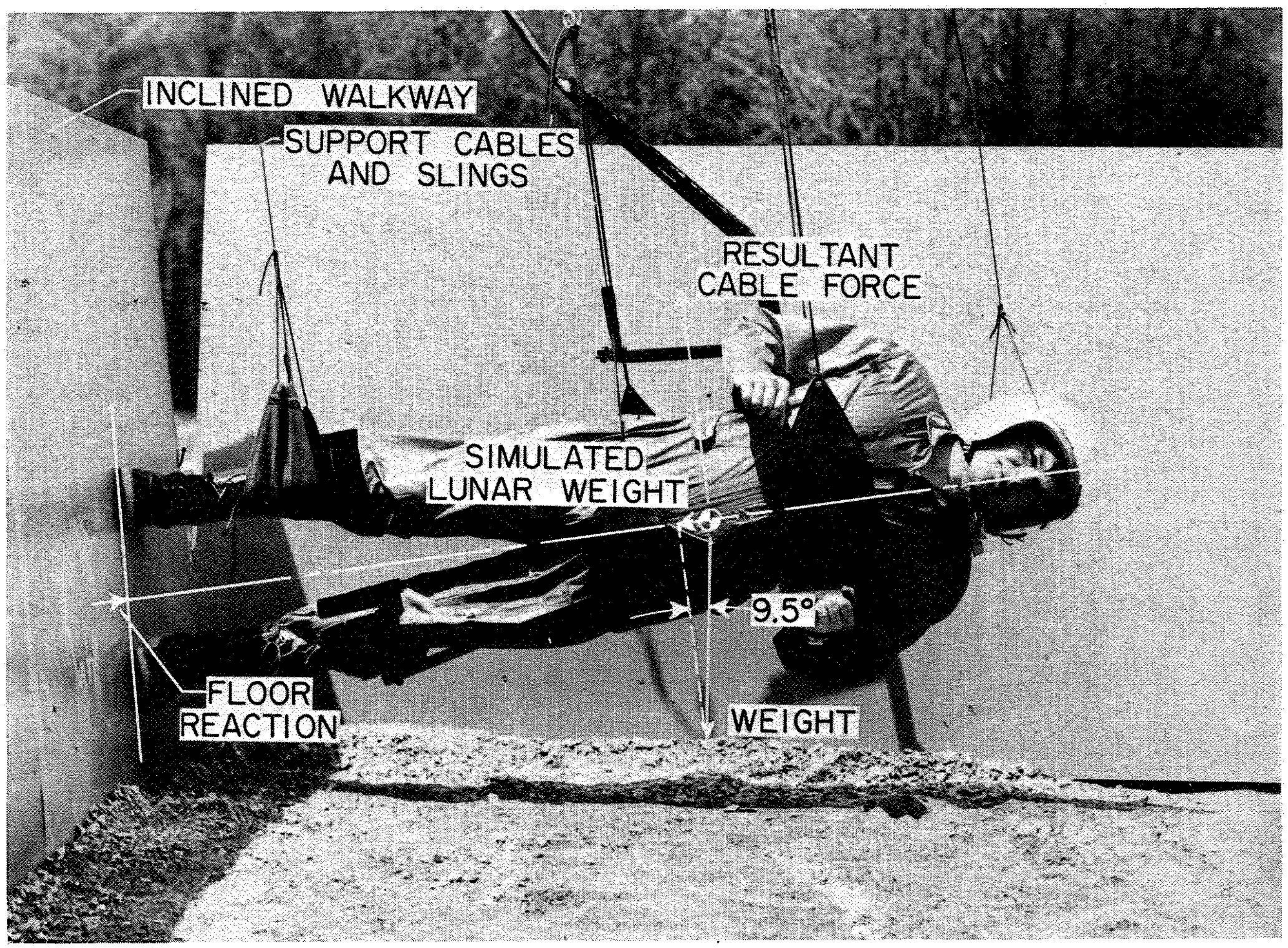

Figure 2.- Details of sling support system for test subject in the Lunar Walking Simulator.

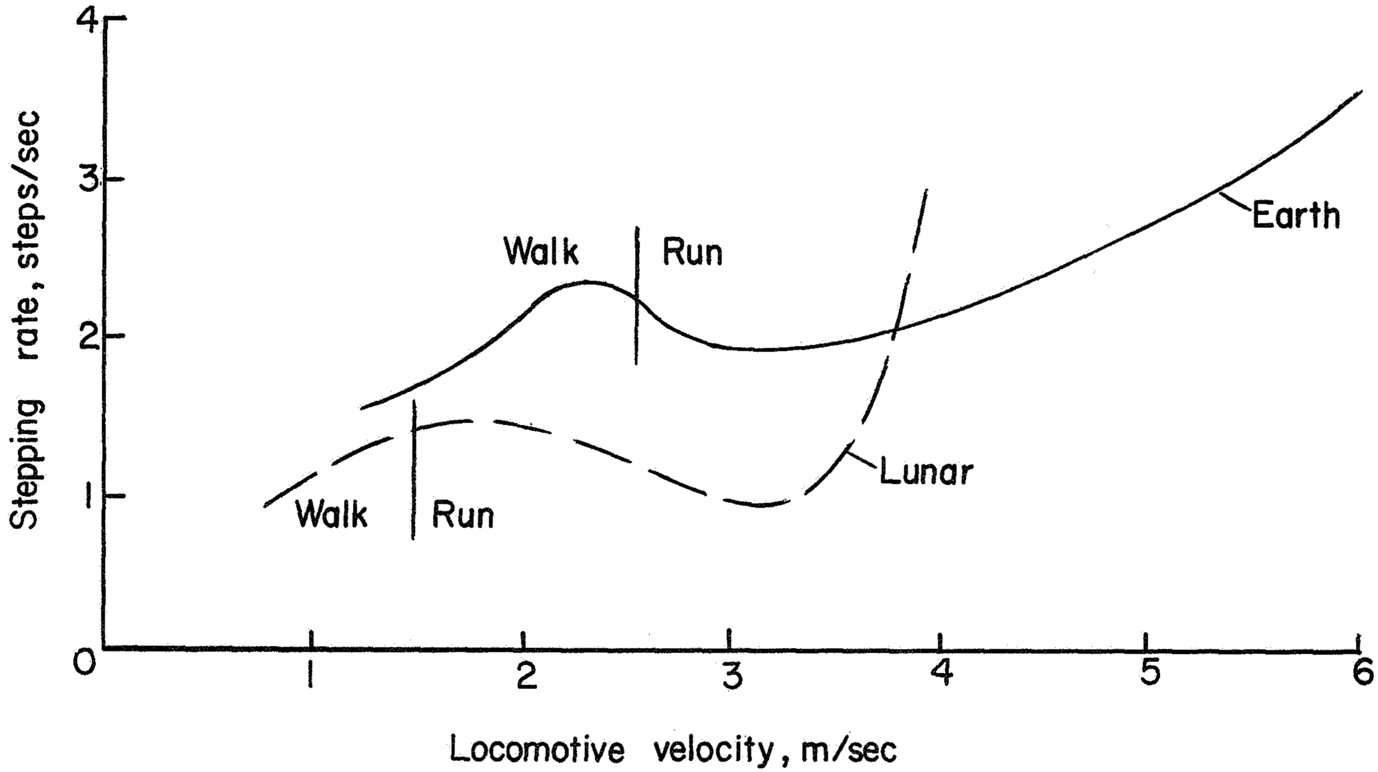

Figure 3.- Variation of stepping rate with locomotive velocity for earth and simulated lunar gravity as derived from data presented in reference 1. Subjects were wearing conventional flying coveralls and walking on a smooth firm surface.

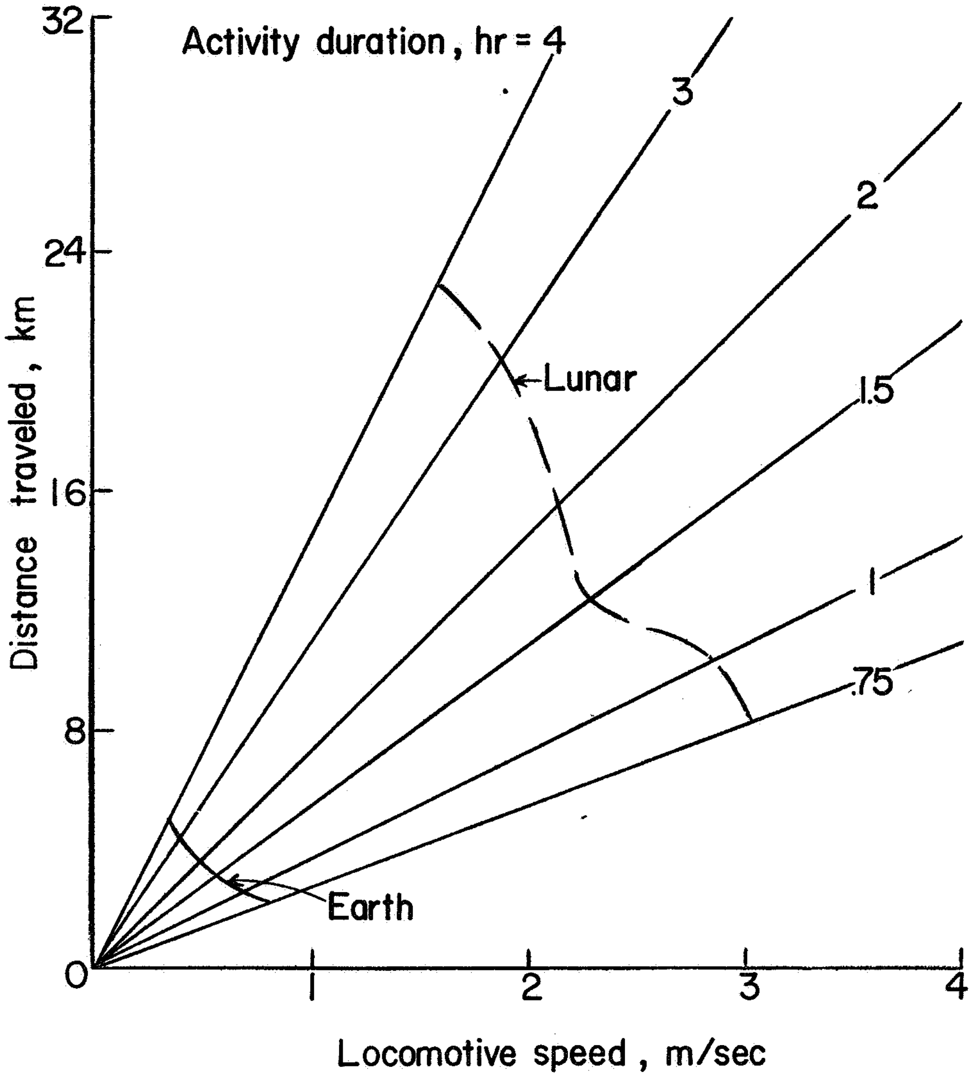

Figure 4.- Calculated range capability or distance traveled for different locomotive speeds for test subjects wearing pressurized Mark IV suit and 32.7-kilogram (72-pound) backpack in earth and simulated lunar gravity obtained from reference 7.

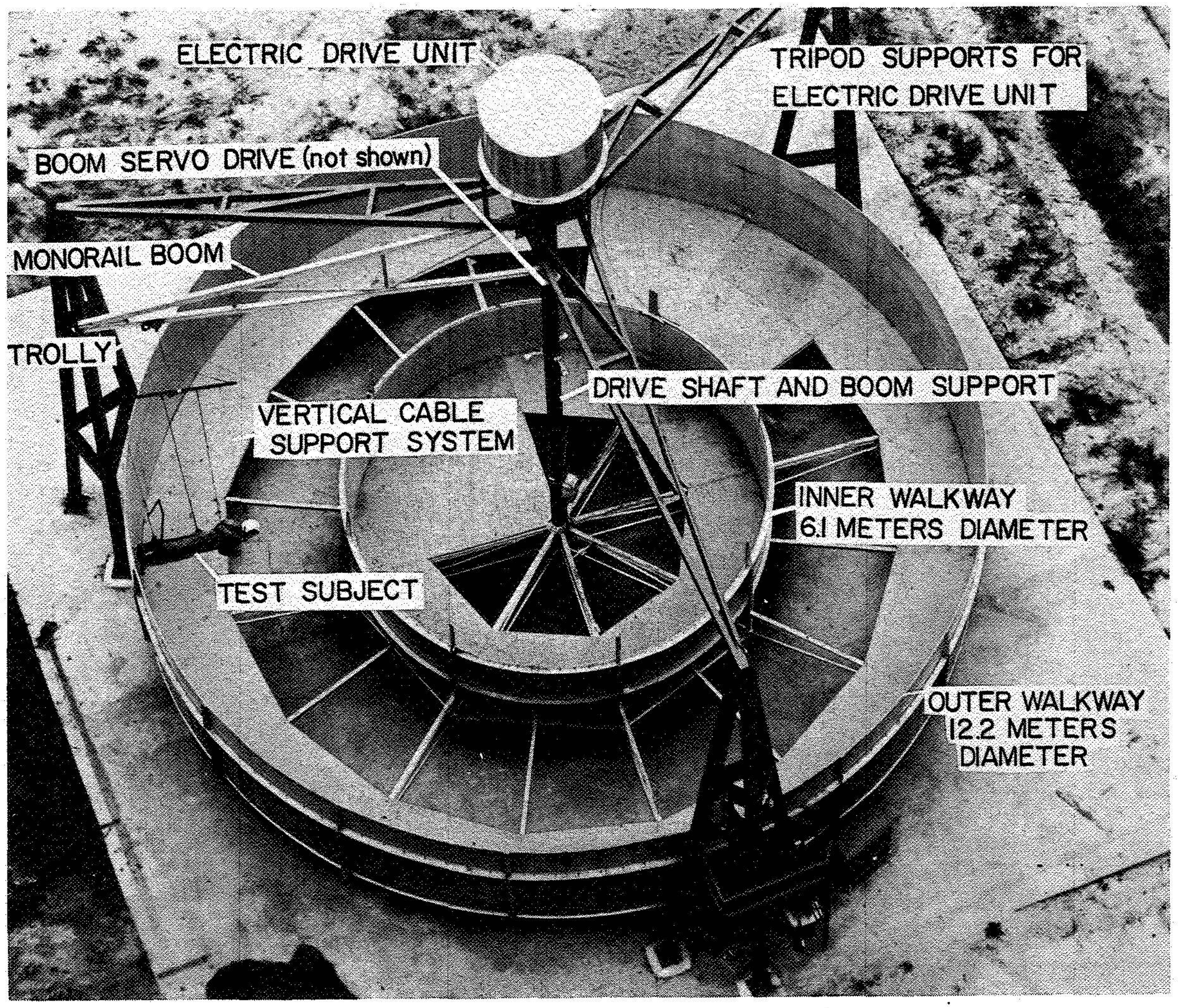

Figure 5.- Photograph of the Rotating Space Station simulator developed at the Langley Research Center.

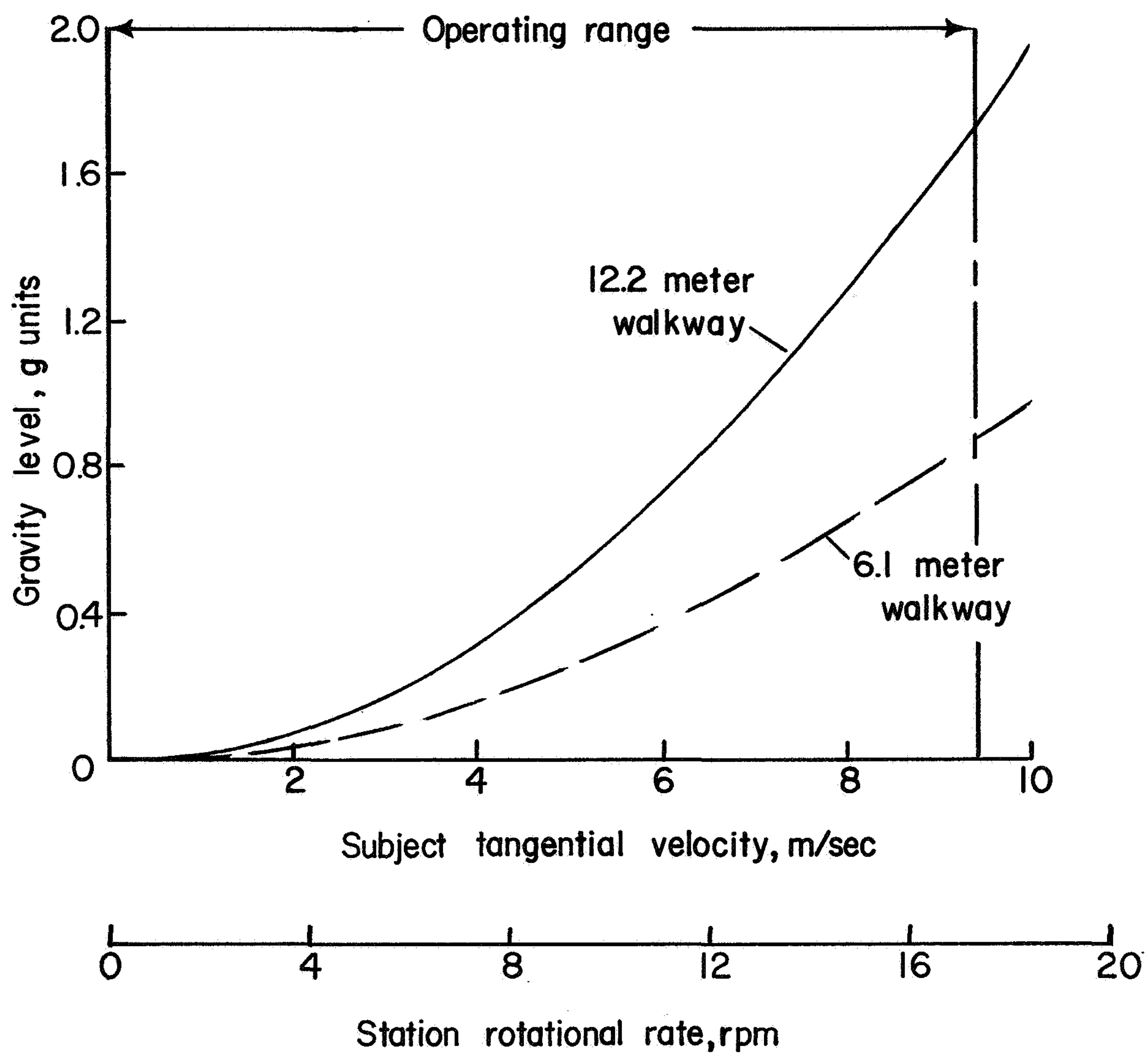

Figure 6.- Variation of simulated gravity level with station rotational rate and tangential velocity at center of gravity of subject standing on the two walkways with diameter of 12.2 and 6.1 meters.

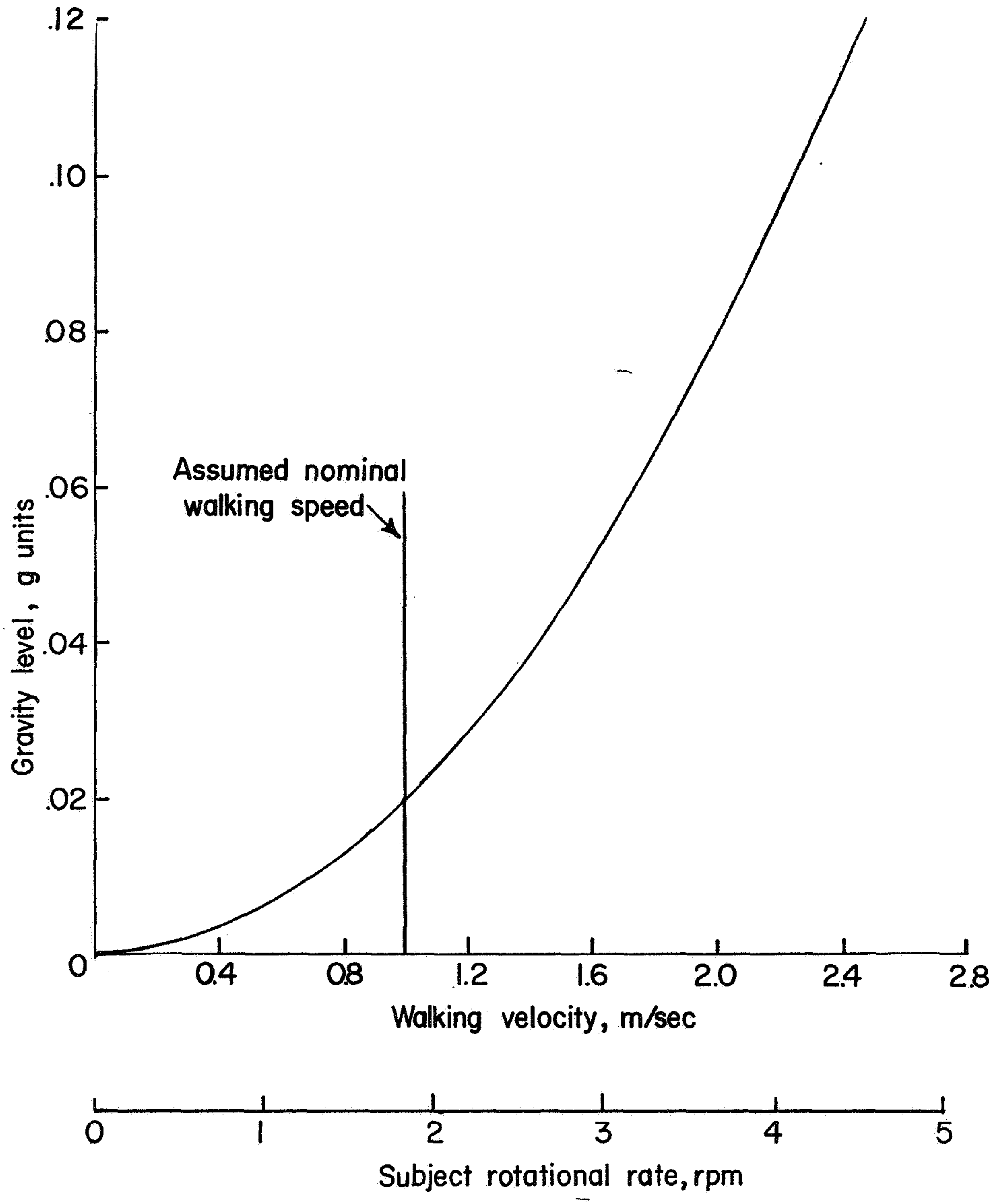

Figure 7.- Variation of gravity level with walking speed of subject on walkway with diameter of 12.2 meters and no rotation.

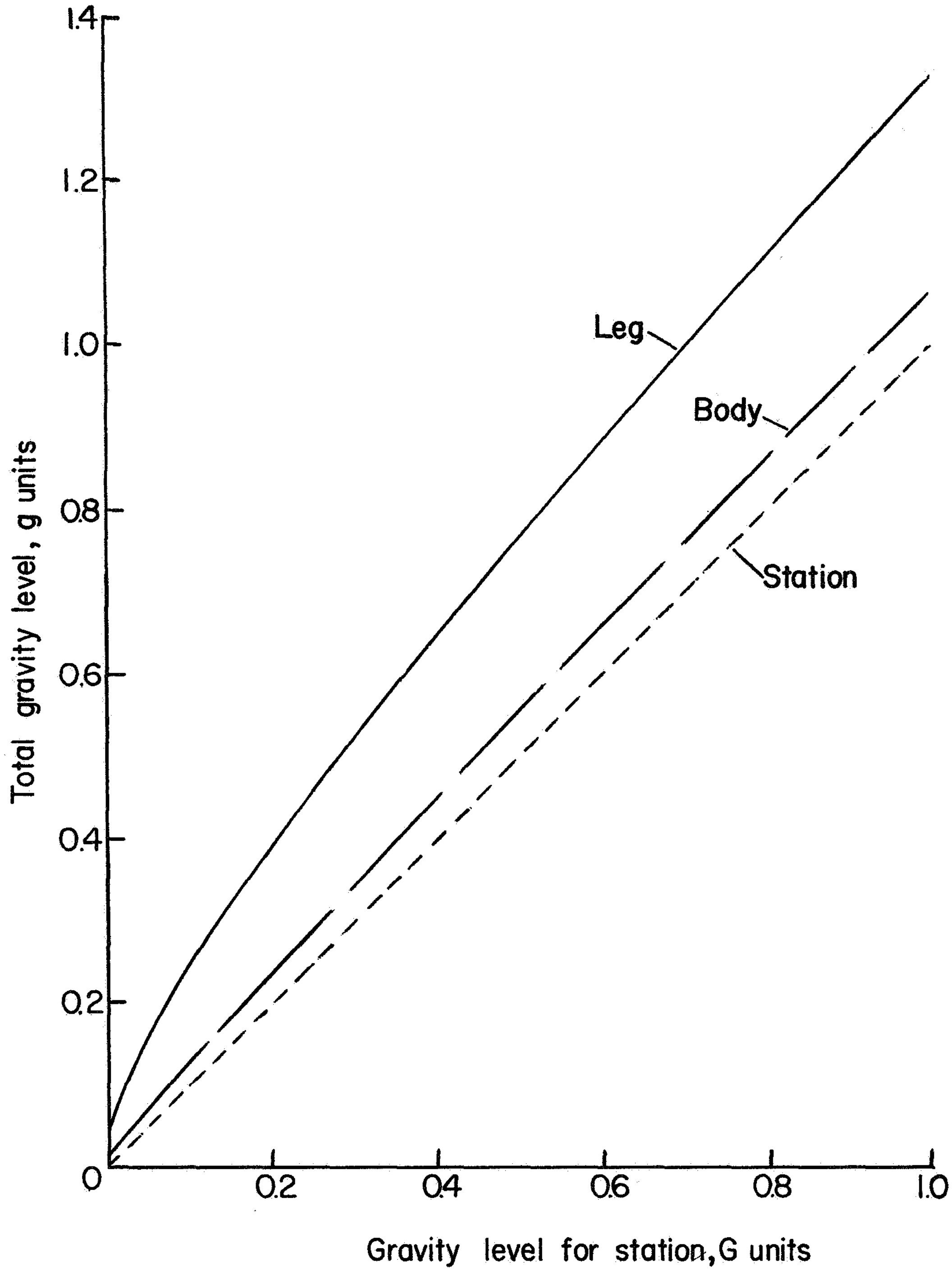

Figure 8.- Calculated variation of the gravity level due to swinging motion of leg as experienced by the leg and the body as a whole during a walk at 1 meter per second on the walkway with a diameter of 12.2 meters.

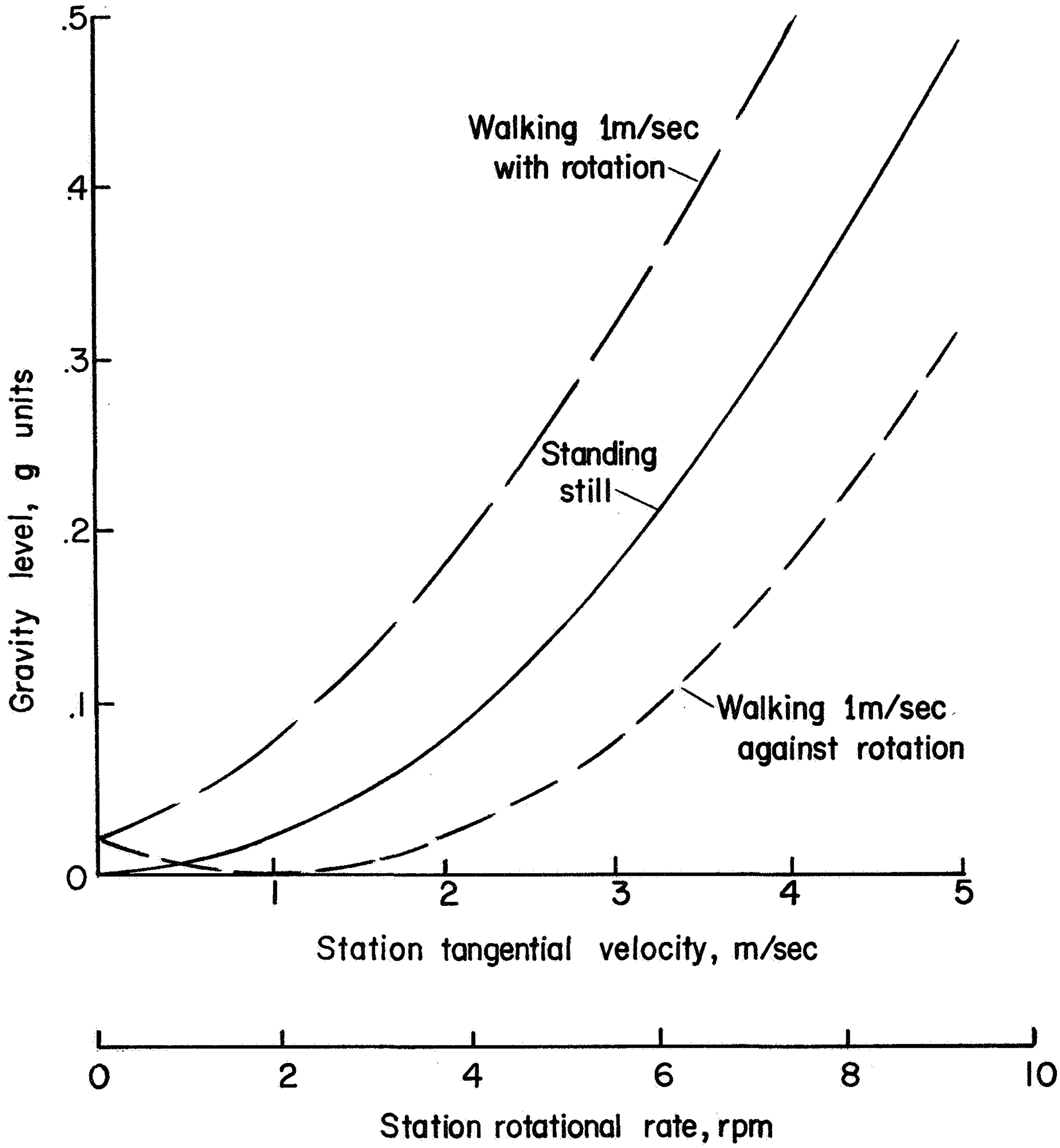

Figure 9.- Effect of walking at 1 meter per second on the gravity level produced by rotation of the 12.2-meter walkway.

NASA-Langley, 1967