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SUMMARY

NASA Manned Spacecraft Center conducted mobility studies with subjects wearing an Apollo developmental space suit pressurized to 3.7 psig near Bend, Oregon, on August 24 to 28, 1964. Activities were performed to determine time and ability for climbing and traversing, and for performing scientific experiments. Velocity for climbing and traversing varied from 0.06 mile per hour for climbing a 30° extremely rough-surfaced slope to 2.84 miles per hour for walking on an ideal surface. Subjects were able to perform the entire range of scientific tasks as long as the task did not require delicate manipulation on a surface at the level of the subject's feet. Only the simpler tasks could be performed at this level. Improvement in both exploration techniques and suit design is therefore required in order to assure that all scientific tasks may be performed.

INTRODUCTION AND PURPOSE

A lunar surface scientific activities test program has been developed to evaluate the capabilities of space-suited subjects to perform tasks representative of normal field geological exploration activities.

Little is known about pressure suit performance capabilities in field exploration activities; therefore, the need exists to determine the potential constraints in terms of time, mobility, and safety in the development of the lunar surface activities segment of the Apollo mission.

The primary purpose of this field test program was to ascertain the capabilities of space-suited subjects to perform lunar-related tasks on terrain representative of that expected on the lunar surface. In addition to determining performance capabilities of the subjects, the test program was designed to provide performance times that would serve as evaluation criteria for constraining final lunar surface exploration procedures.

The tasks accomplished, the problems encountered, and times required to perform the tasks are reported for one phase of the test program. Definite time lines for performing lunar tasks cannot be established until the entire program is more complete.

The task procedures used in this program represented a broad spectrum of normal field exploration activities from which representative performance times could be obtained while the activities were performed on representative lunar surface areas.

Five general types of activities were planned: (1) passive instrument emplacement, (2) geophysical seismic traverse, (3) activities to be used as a base for extrapolating to 1/6g conditions, (4) geological sampling procedures, and (5) anchor bolt emplacement.

For simulation of passive instrument emplacement, models of an integrated instrument-telemetry package, a radiosotope thermoelectric generator (RTG) power supply, and long period seismometers were set up, oriented, and leveled. This procedure determined the time and ability of an astronaut to emplace equipment that would record data and telemeter the results back to earth after the astronaut had departed from the lunar surface.

The geophysical seismic traverse consisted of attaching a miniature cable to a seismic recorder and walking three 200-foot distances while being directed to keep on a straight line. At 200-, 400-, and 600-foot points, a striker plate was placed on the surface and struck with a geologist's pick. This plate provided a source of seismic energy and recorded instant of origination of the energy. A geophone was emplaced to sense future seismic impulses. The geology and terrain were recorded by two photographs taken at right angles to the line of traverse. This test determined time and ability to perform a seismic survey.

Activities used for extrapolating results of the test program to 1/6g conditions consisted of 30- to 100-foot traverses over terrain of varying difficulties and angles of slopes up to 31°. Tests at a later date will use 1/6g devices on built-up surfaces resembling those traversed in the field tests as closely as practical. Time required, using 1/6g devices, will be compared to times measured in the field.

Geologic sampling procedures consisted of measuring time and ability to orient and take geologic samples of various types under varying conditions.

Anchor bolt emplacement activities tested time, ability, and safety aspects of using an explosive stud driver to emplace anchor bolts envisioned for fastening down scientific equipment.

PROCEDURE

Selection and Description of Test Sites

The field test program was conducted near Bend, Oregon. This area was selected because of the freshness and variety of volcanic material types found in the area and the following criteria: (1) an area containing several different geologic surface structures more representative of the terrain which may be encountered on the lunar surface, (2) an area with mild summer temperatures, and (3) an area within reasonable proximity to other government facilities capable of supplying necessary logistic support, that is, heavy transportation, electrical generating equipment, portable lighting equipment, et cetera.

One week before commencing the field test program, test areas for demonstrating performance capabilities were selected and laid out. Three sites were selected, all located within 50 miles of Bend.

Site 1.- Site 1 was located in the Cascade Mountains at an elevation of approximately 5200 feet and consisted of two areas of structurally different basaltic lava. The areas were only a short distance apart. The first was an aa type (blocky basalt) lava field characterized by jagged and craggy rocks which were tightly packed with blocks averaging 1 foot in diameter with a standard deviation of 0.5 foot. The flow is from 1000 to 2000 years old. The forward edge of the flow is a steep, rough, 30° slope, about 50 feet in length. The top of the flow is a plateau with extremely rugged, local protuberances covered by blocks similar to those found along the forward edge. Traverses were made up the 30° slope and over portions of the plateau. The terrain at this site was the roughest encountered on the field trip and is probably worse than any lunar-landing site normally considered for the lunar excursion module. The second area was a pahoehoe type (ropy basalt) lava field characterized by huge, tilted blocks of ropy and undulating, but relatively smooth, lava penetrated by numerous deep fissures (many over 10 feet in depth). This flow is approximately the same age as the first field. Fifty-foot traverses were performed on slopes of 12° and 21°, and 600-foot traverses were performed over a relatively horizontal course. Deep fissures up to 2.5 feet wide were encountered and negotiated about every 50 feet along the horizontal traverse path.

Site 2.- Site 2 is characterized by a smooth, relatively flat plain covered to a depth of from 12 to 20 feet by loose, finely powdered, pumice ash. The plain was formed by a pumice ash fall from the explosion of Mt. Mazama (ancestor to Crater Lake) some 40 miles from the test site. This ash fall is approximately 6500 years old. Elevation at site 2 was 4600 feet. The pumice field was quite soft, especially on some of the local slopes, and the climbing of these slopes (varying from 10° to 30°) resulted in sinking to depths comparable to those encountered when climbing up beach sand slopes. Traversing the pumice plain resulted in considerable kickup of pumice dust.

Site 3.- Site 3 consisted of a obsidian lava field covered by relatively loose, extremely sharp and brittle, non-vesicular glass material intermixed with about 20 percent highly vesicular obsidian blocks. The rubble material has an average diameter of 1 foot with a standard deviation of 0.5 foot. Interspaced over the area were larger blocks, some 5 to 6 feet in diameter. The lava (age estimated at 2000 to 3000 years) had a high silica content. A hard, compacted, pumice ash field is at the base of the flow. Traverses were made on both the obsidian flow and the hard pumice. Traverses on the obsidian flow included horizontal traverses along both the rubble-covered foot of the flow and up 20° and 30° slopes along the forward edge of the flow. Traverses on the hard pumice ash field included traverses along a level surface and climbing traverses up an 18° slope.

Task Procedure Definition

The task procedures developed by Manned Spacecraft Center represented a broad spectrum of normal field exploration activities. These procedures, which were conducted on all of the surface structures, are outlined in the appendix.

Subjects

Three subjects, designated subjects 1, 2, and 3, were used in the program. Subject 1, an astronaut, participated during 3 days of the testing. Subjects 2 and 3 were test engineers. Three subjects were scheduled because of the anticipated workload and the desire to obtain comparative measures on different subjects performing the same task procedure. Each subject was scheduled for no more than $1\frac{1}{2}$ hours of task activity during a day's run.

DESCRIPTION OF EQUIPMENT

Equipment requirements for support of this test program included: (1) pressure garment assemblies, (2) portable life support systems, (3) external thermal garments, (4) geologic hand tools, (5) communications equipment, (6) geologic equipment mockups, and (7) performance aids.

Pressure Garment Assembly

Two Apollo developmental pressure garment assemblies (PGA) were used in the testing. Each garment was comprised of a limb – torso suit, a moveable visor helmet, and gloves. Each garment was capable of maintaining 3.7 psig. Although the suits were not the latest development model, they were used because they were the most readily available at test time and actually represented little departure in mobility capabilities from the then current Apollo development suit.

Portable Life Support System

Three portable life support systems (PLSS) were built up for this program. Two of the systems when fully charged weighed 40 pounds each, the third weighed 47 pounds. The two 40-pound systems were primary systems, each capable of producing 40 to 45 minutes of oxygen when the suit pressure was maintained at 3.7 psig. The heavier PLSS was used primarily as a backup system. Each PLSS shell contained an open-loop cryogenic ventilator modified to be a recirculating system. Expected output performance for these ventilators included a 12 ft^3/min PGA inlet oxygen flow, 0.156 part/million leakage, and an inlet partial pressure of CO_2 of 15 mm Hg at 3.7 psig (18.4 psia). A pressure gage was used to monitor back-pack performance during the tests.

External Thermal Garment

An external thermal garment (ETG) was supplied for each suit. The two-piece garment was made of multi-layered aluminized mylar with an outer white dacron layer. The upper portion of the ETG encompassed the PLSS. Thermal gauntlets were also available, but were not used over the intra-vehicular gloves since they were too large and did not permit an adequate grasp of equipment. Special overboots of vinyl plastic material were worn. These boots were of a type used by the astronauts in the Mercury program in the final launch site transit phase to the spacecraft. Total weight of each PGA and ETG (less thermal gloves) was approximately 37 pounds.

Geologic Hand Tools and Equipment Mockups

Standard geologic hand tools and equipment used in performing the task procedures included geologic pick, scoop, abney level, Brunton compass, geophones, and scribers. Also included were a metal stud-driving device and mockups of a seismograph, a nuclear power supply (RTG), and a seismic recording package (black box). The simulated seismograph, black box, and RTG unit were used in performing the passive instrument emplacement. In addition, the black box was used in performing the geophysical traverse. The hand tools were used, as required, in all of the procedures. The stud driver, a device that uses a .22-caliber cartridge which imparts a force sufficient to drive a metal stud into the face of a rock, was used for the anchor bolt emplacement.

Performance Aids

Two types of performance aids were used. One was a Jacob's staff which was modified to provide limited tool-carrying capabilities; the other was a luna-walker. Two versions of the walker were used, one a five-legged unit and the other a smaller four-legged unit. The frame of the four-legged unit was rectangular in shape, whereas the five-legged walker was essentially half octagonal. The luna-walkers were designed for the primary function of carrying hand tools and other equipment required in the field. This method of carrying tools eliminated the necessity of hanging the tools on the man or requiring him to carry them in a hand bag, and, in addition, made them readily accessible for use at all times. A secondary function of the walkers was providing body stabilization during times that rough terrain and suit mobility constraints compromised the normal capability. Serving a similar function was the Jacob's staff. It is anticipated that certain types of very rough terrain might restrict the use of a device such as the luna-walker, but that a Jacob's staff, modified to incorporate limited equipment-carrying capabilities, could suffice. The Jacob's staff used in this program was modified by constructing flat surfaces on the lower end of the staff which allowed the attachment of fixtures to hold several of the more frequently used hand tools. This device would assure hand-tool accessibility in the areas where the luna-walker is inappropriate and also would provide assistance in traversing the area.

Communications Equipment

Communications to the test subjects in the pressure garment were by hard-line. Walkie-talkie sets were utilized for maintaining contact between personnel working in different areas too far removed for normal voice communication.

GENERAL PROCEDURE

Field testing began the morning of August 24, 1964, at site 1. Equipment preparation and the setup of a base of operations were completed by 10:00 a.m. A PLSS technician was responsible for furnishing fully charged PLSS, as required, to support the program. The PLSS was filled with liquid oxygen on site. Two to three units were used during a day's work. The two 40-pound systems were used as the primary means for oxygen, ventilation, and pressurization. When minor malfunctions in one of these systems required troubleshooting the system to find the fault, the backup 47-pound system was used. Such occasions were few and caused only minor disruptions during a day's activities. Apollo space suits were serviced by a suit technician who assisted the subjects during donning and doffing of the suit and was generally responsible for assuring the availability of an operable suit when it was required. An MSC medical monitor periodically assessed the physical well-being of the subjects. Pulse rate and body temperature of the subjects were monitored immediately after each task and again after a 5-minute rest period.

Data collection consisted of performance times and subjective appraisal of performance capabilities.

First Day's Activities

Subject 2 performed during the morning session on the aa lava, and subject 3 during the afternoon session on the pahoehoe lava. The first trial of subject 2 was to climb a 31° slope for a distance of 50 feet in the Apollo pressure garment under a vented (0.18 psig) condition. This trial was performed primarily to familiarize the subject with hazards to be encountered in this type of traverse. This was the only trial for which the suit internal pressure was less than 3.7 psig, that is, all other procedures performed during the program were with the suit pressure at 3.7 psig. Subject 3, in regular clothing, followed closely behind and observed the performance of subject 2. After a brief rest period, subject 2 descended the slope and prepared for the second trial which entailed the same procedure except under a pressurized suit condition. The modified Jacob's staff was used as an assist in the climb. After a sufficient rest period (10 to 15 minutes), subject 2 traversed the top of the aa lava flow for a distance of 100 feet using the modified Jacob's staff as an assist.

Subject 3 in the afternoon session performed three traverse procedures: (1) traversing up and down a 12° slope, 40 feet in length, using the five-legged luna-walker, (2) traversing up and down a 21° slope, 45 feet in length, using the Jacob's staff, and (3) traversing a 350-foot course which included relatively level stretches, slopes of varying degrees, and several large, wide crevices. On this last traverse, subject 3 used the luna-walker as an aid.

Second Day's Activities

The second day's activities were conducted at the same location as the first. Subject 1 performed during the morning session, and both subjects 2 and 3 during the afternoon session. During the morning session, subject 1 performed traverses on both of the lava types. His first traverse was up the 31° slope of aa lava. He used the Jacob's staff as an aid. Following this, he performed the same exercises as did subject 3 the day before on the pahoehoe lava. On the long traverse, subject 1 negotiated 500 feet of the laid-out course.

Subject 3 performed the first procedures in the afternoon session. He traversed a distance of 200 feet across the top of the aa lava flow. The first 100 feet, he did not use an aid. The Jacob's staff was utilized during the second 100 feet of the traverse. His traverse, up and down, of the 31° slope was accomplished with the aid of a rope which was secured at the top of the slope. Subject 2 concluded the day's activities with a 450-foot traverse on the pahoehoe lava emplacing several anchor bolts (metal studs) into an outcrop of lava. He used the Jacob's staff in the traverse and a stud driving gun for the anchor bolt emplacements. Prior to each emplacement, subject 2 loaded the gun with a metal stud and a .22-caliber blank cartridge which provided the driving force for the stud.

Third Day's Activities

The location for the third day's activities was site 2. Activities at this site included: (1) geophysical traverses, (2) sampling traverses, (3) passive instrument emplacement, and (4) slope climbing.

During the morning session subject 1 performed a 600-foot geophysical traverse and then repeated with a 400-foot geophysical traverse. He completed the morning session by performing the passive instrument emplacement procedure, and by attempting to climb a 30° slope of loose pumice.

During the afternoon session subject 2 performed a 400-foot sampling traverse. Loose rock samples were placed at intervals of 100 feet. Subject 2 traversed each 100 feet carrying the four-legged walker, stopped at the loose sample, knelt down and retrieved it, and placed in in a storage pouch provided on the walker. His second task procedure involved climbing up a 20° loose pumice slope approximately 30 feet in length. He used the four-legged walker as an assist. Subject 2 completed the day's activities by traversing a level distance of 320 feet on the loose pumice, carrying the walker.

Fourth Day's Activities

Site 3 was the location for the last day of activities. Subject 1 again performed during the morning. He traversed up and down an 18° slope of hard, compacted pumice for a distance of 50 feet, carrying a metal container weighing about 30 pounds. He repeated the procedure without the container. Following a brief rest period, subject 1 climbed an obsidian slope ranging from 20° to 28° for a distance of 132 feet. This climb was performed without the aid of the Jacob's staff or luna-walkers.

During the afternoon, subject 3 donned the pressure garment and traversed a distance of 200 feet across a relatively level but very rough area of loose obsidian. At the end of the traverse, he selected a large sample of obsidian and emplaced three anchor bolts into the face of the sample with the use of a stud driver. He loaded the stud driver prior to each emplacement. Next, the strike and dip of the sample were taken with an abney level. Finally, subject 3 traversed 250 feet of hard, compacted pumice.

Subject 2 completed the day's activities by performing a traverse of 75 feet across the level, but rough, obsidian. He placed and leveled a seismometer mockup on a large obsidian rock, the slope of which subtended an angle of 16° from horizontal.

RESULTS

Times required to ascend and descend slopes of various difficulties are listed in tables I and II. The 31° aa slope, with a slope distance of 50 feet (fig. 1) was climbed once each by subjects 1 and 2. Subject 2 climbed the slope, using a Jacob's staff for aid, in 12 minutes 20 seconds. Subject 1, also using the Jacob's staff, climbed the same slope in 8 minutes 8 seconds. However, about two-thirds of the way up the slope, subject 1 fell and punctured one of the intravehicular gloves. A 15-minute delay was required to replace the glove. The fall was caused by a combination of visor fogging and loose material on the slope. After the pause, subject 1 continued to the top. The shorter overall climbing time obtained by subject 1 was, in part, due to the rest at the two-thirds point. However, in general, subject 1 performed tasks more rapidly than the other subjects. Both subjects 1 and 2 were fatigued when they reached the top of the slope.

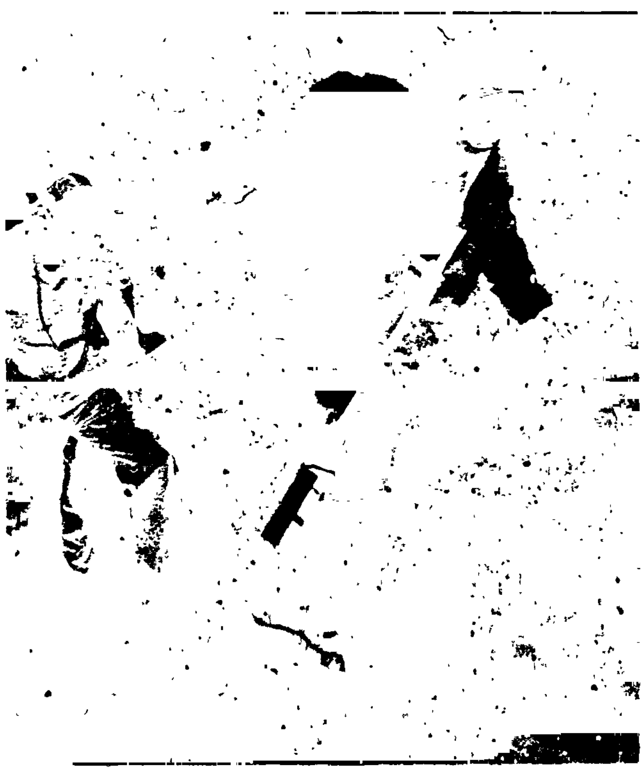

Figure 1.- Subject 2 using a Jacob's staff for aid in climbing a 31° aa slope.

TABLE I.- TIME REQUIRED TO ASCEND SLOPES INDICATING SUBJECTS' ABILITY TO CLIMB SLOPES

OF VARIOUS DEGREES OF ROUGHNESS AND STEEPNESS

Slopes, deg	Slope distance, ft	Type material	Time, min:sec	Subject	Aid used	Remarks
31	50	aa	12:20	2	Jacob's staff	
31	50	aa	8:08	1	Jacob's staff	Subject fell when he reached two-thirds way up slope; 15-min pause for repairs
31	50	aa	2:54	3	Rope	
31	50	aa	2:53	2	Unpressurized	
30	50	Loose pumice		1		Not completed; visor fogged and backpack trouble
28	32	Obsidian	4:45	1	None	
21	45	Pahoehoe	1:11	3	Five-legged walker	
21	45	Pahoehoe	1:07	1	None	
20	30	Loose pumice	1:08	2	Four-legged walker	
20	50	Obsidian	2:17	1	None	
20	50	Obsidian	2:25	1	None	
18	50	Hard pumice	0:59	1	None	Carrying 30-lb box
18	50	Hard pumice	0:35	1	None	
12	40	Pahoehoe	0:31	3	Five-legged walker	
12	40	Pahoehoe	0:39	1	Five-legged walker	
12	40	Pahoehoe	0:24	3	Jacob's staff	

TABLE II.- TIME REQUIRED TO DESCEND SLOPE - INDICATING SUBJECT'S ABILITY TO CLIMB DOWN SLOPES OF VARIOUS DEGREES OF ROUGHNESS AND STEEPNESS

Slope, deg	Slope distance, ft	Type material	Time, min:sec	Subject	Aid used	Remarks
31	50	aa	3:52	3	Rope	
21	45	Pahoehoe	1:23	3	Five-legged walker	
21	45	Pahoehoe	0:30	1	None	
20	30	Loose pumice	0:16	2	Five-legged walker	
18	50	Hard pumice	0:18	1	None	Carried 30-lb box
12	40	Pahoehoe	0:28	3	Five-legged walker	
12	40	Pahoehoe	0:19	1	Five-legged walker	

Subject 3 ascended and descended the slope with the aid of a rope attached at the top (see fig. 2). Ascending time was 2 minutes 54 seconds; descending time, 3 minutes 52 seconds. Subject 2 in his unpressurized suit climbed the slope in 2 minutes 53 seconds.

A 30° slope (fig. 3) in the loose pumice area was attempted by subject 1. He reached about the half-way point and stopped because of visor fogging and backpack troubles. This slope was the most difficult of all to climb. Because of the extreme looseness of the material, the subject would slide back almost as fast as he could climb.

Subject 1 also climbed the 28° obsidian slope shown in figure 4. It required 4 minutes 45 seconds to climb a distance of 32 feet along the slope surface. Although this slope looked the roughest, it was the easiest to climb of all the approximately 30° slopes.

Figure 2.- Subject 3 using a rope for aid in climbing a 31° aa slope.

Figure 3.- Subject 1 using a Jacob's staff for aid in climbing a 30° loose pumice ash slope.

Figure 4.- Subject 1 climbing a 28° obsidian slope.

In general, slopes approaching 30° were difficult to climb under earth's gravity conditions. If they are as difficult to climb under 1/6 gravity conditions, then an aid such as a rope should be provided for climbing these slopes. Difficulties encountered in 30° slope climbing are due to poor downward visibility, lack of mobility at the hip joint, and the workload required.

Slopes near 20° were climbed in all areas except the aa area. Subjects 1 and 3 climbed the 21° pahoehoe slope which has a 45-foot slope length as shown in figure 5. Subject 3 used the five-legged luna-walker shown in figure 6. Ascending time was 1 minute 11 seconds; decending time, 1 minute 23 seconds. Subject 1 used no aids in negotiating the slope. His ascending time was 1 minute 7 seconds, descending time was 30 seconds. In the loose pumice area, the 20°, 30-foot slope, shown in figure 7, was climbed by subject 2. It took 1 minute 8 seconds to climb this slope with the aid of the four-legged walker, and 16 seconds to descend the same slope. In the obsidian area, subject 1 climbed two successive 20°, 50-foot slopes. Times for climbing these slopes were 2 minutes 17 seconds and 2 minutes 25 seconds, respectively. Subject 1 climbed a hard surface, 18°, 50-foot slope while carrying a 30-pound container as shown in figure 8. Ascending time was 59 seconds, descending time was 18 seconds. Time to ascend the slope without the container was 35 seconds. No great difficulties resulting from the steepness of the slope itself were encountered in ascending 20° slopes, although a slowing down of the average rate of travel was noted. This amounted to a reduction of surface speed, compared to level terrain

Figure 5.- Subject 3 using Jacob's staff for aid in climbing a 21° pahoehoe slope. Note geology tools clipped to staff.

Figure 6.- Subject 1 climbing a 12° pahoehoe slope carrying the five-legged walker.

Figure 7.- Subject 2 using the four-legged walker for aid in climbing a 20° pumice ash slope.

Figure 8.- Subject 1 climbing an 18°, hard, smooth pumice slope while carrying a 30-pound weight.

speeds, of from 75 percent for the most difficult traverse areas to 34 percent for the easiest traverse area.

Subjects 1 and 3 negotiated the 12°, 40-foot slope in the pahoehoe area shown in figure 6. With the aid of the five-legged walker, the slope was ascended in 31 seconds and 39 seconds, and descended in 28 seconds and 19 seconds by subjects 1 and 3, respectively. Subject 3 also ascended the slope in 24 seconds with the aid of the Jacob's staff. Both ascent and descent of the 12° pahoehoe slope were accomplished at a faster rate than simple traversing over long distances. The subjects did not become fatigued on the short distance; the slope had no crevices to negotiate.

Times required to traverse across relatively level surfaces in all areas are listed in table III. In the aa area shown in figure 9, subject 3 traversed 100 feet in 4 minutes 43 seconds using no aids, and 100 feet in 4 minutes 30 seconds using the Jacob's staff. All three subjects traversed in the pahoehoe area shown in figure 10. Subject 3 traversed 350 feet in 12 minutes 27 seconds with the aid of the five-legged walker. However, some of this time was taken up in an equipment check. Subject 1, using no aids, traversed 500 feet in 11 minutes 28 seconds. Subject 2, using the Jacob's staff, traversed 350 feet in 7 minutes 15 seconds. Subjects 1 and 2 made two traverses each, using the four-legged walker in the soft pumice ash area (fig. 11). Subject 1 walked 600 feet in 5 minutes 13 seconds and 400 feet in 3 minutes 57 seconds. These distances were walked in 200 feet increments with geophysical activities at the end of each 200 feet. Time for these geophysical activities is not included in traversing times. Subject 2 required 2 minutes 51 seconds to walk 400 feet, stopping each 100 feet to pick up a float sample. Time to pick up samples was not included in the walking time. It required 1 minute 23 seconds for subject 2 to walk 320 feet at top speed. At the base of the obsidian flow shown in figure 12, subject 3 required 6 minutes 55 seconds to traverse 200 feet. On the hard, smooth pumice surface in front of the flow, he traversed 250 feet in 1 minute. Traversing speed varied from 0.25 mph in the roughest area to 2.84 mph in the ideal area, an order of magnitude difference. Average speeds for traversing and slope climbing are summarized in table IV.

A comparison of walking and climbing rates is given by the graph in figure 13. Since walking rates on level surfaces were studied in greater detail than climbing rates, these data were used to plot a normalized curve. The most difficult surface to traverse was plotted on the left edge of the graph and the most easily traversed on the right edge. Intermediate surfaces were plotted in such a manner that points representing traversing velocity and traversing difficulty fell on a straight line drawn between the two extreme surfaces. Velocities for ascending and descending slopes of various degrees were then plotted by using the horizontal positions (position representing traversing difficulty of the surface) thus established. Both ascending and descending slopes consisting of loose pumice ash were more difficult than level traversing. In ascending these slopes, the effect of slope angle on velocity was large. For level traversing, loose dust material was midway in difficulty between the most difficult and the least difficult surfaces; but ascending the 20° slopes was almost as difficult as ascending 20° obsidian slopes. Although an actual time was not taken, ascending 30° pumice ash slopes appeared as difficult as ascending

Figure 9.- Subject 3 using a Jacob's staff for aid in traversing a level aa surface.

Figure 10.- Subject 1 using five-legged walker for aid in traversing typical pahoehoe surface.

Figure 11.- Subject 1 performing geophysical traverse in loose pumice ash using four-legged walker to carry equipment.

Figure 12.- Subject 3 using a Jacob's staff for aid in traversing along the base of obsidian flow.

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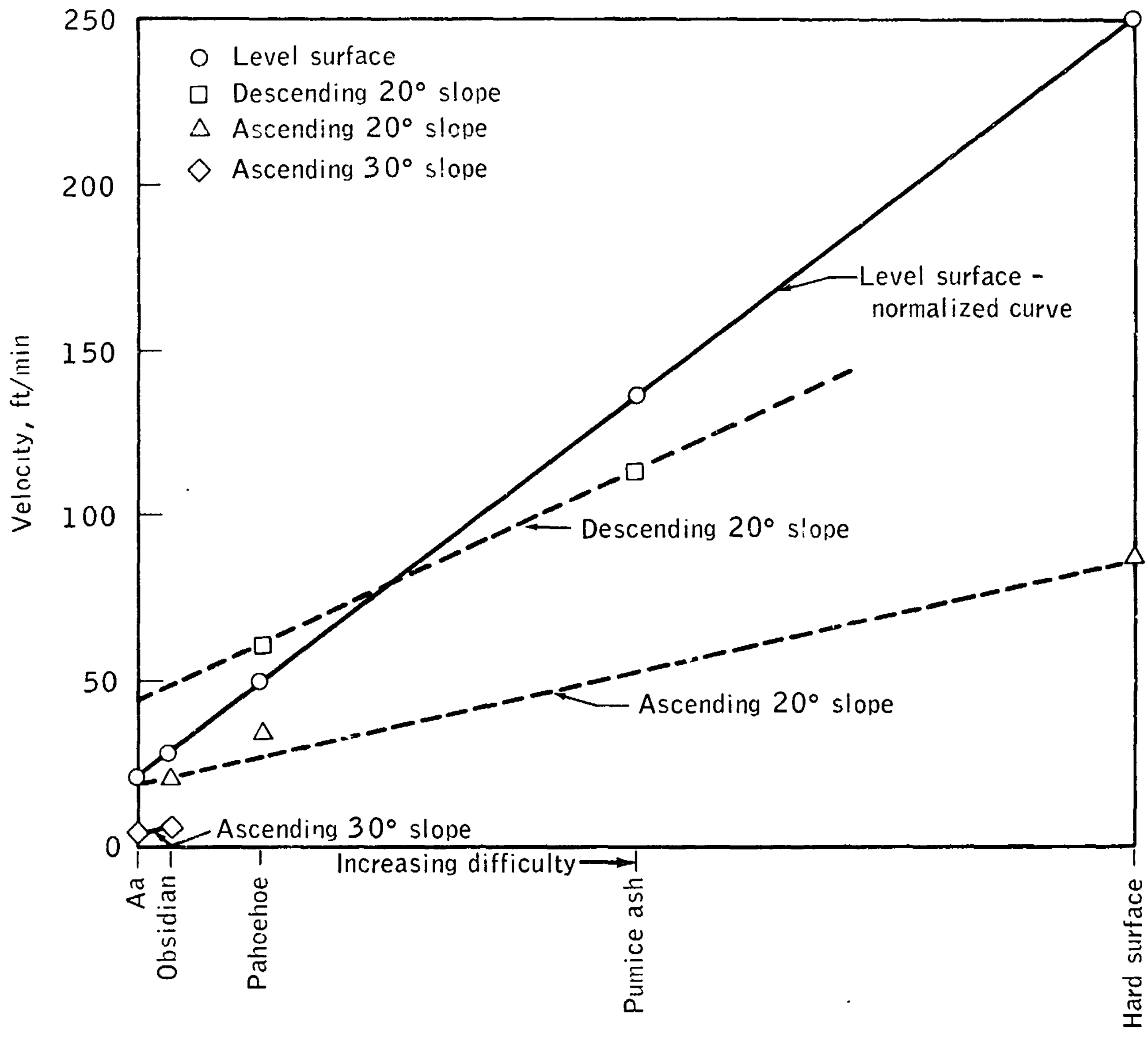

Figure 13. - Relationship between surface type, slope angle, and velocity

TABLE III.- TIME AND ABILITY TO TRAVERSE OVER APPROXIMATELY LEVEL COURSES

Distance, ft	Type of material	Time, min:sec	Subject	Aid used	Remarks
100	aa	4:43	3	None	
100	aa	4:30	3	Jacob's staff	
350	Pahoehoe	12:27	3	Five-legged walker	Some of the time was used for equipment check
500	Pahoehoe	11:28	1	None	
350	Pahoehoe	7:15	2	Jacob's staff	
600	Loose pumice	5:13	1	Four-legged walker	Walked in 200-ft increments during geophysical traverse
400	Loose pumice	3:57	1	Four-legged walker	Walked in 200-ft increments during geophysical traverse
400	Loose pumice	2:51	2	Four-legged walker	Walked in 100-ft increments during sampling traverse
320	Loose pumice	1:23	2	Four-legged walker	Walked at maximum possible walking speed
200	Obsidian	6:55	3	Jacob's staff	
250	Hard pumice	1:00	3	None	Walked at maximum possible walking speed

TABLE IV. - AVERAGE SPEEDS FOR WALKING AND CLIMBING

Type of surface	Unit of speed	Level surface	Ascending slope of -			Descending slope of -		
			12°	20°	30°	12°	20°	30°
Aa slope with loose blocks averaging 1 ft in size	ft/min mile/hr	21.7 .246			4.9 .056			
Same aa slope but with subject using rope	ft/min mile/hr				17.2 .195			12.9 .147
Pahoehoe surface of collapsed slabs having fissures 50 ft apart	ft/min mile/hr	49.5 .562	81.1 .921	39.5 .449		107.8 1.22	60.6 .688	
Loose, pumice ash fall area	ft/min mile/hr	135.7 1.54		26.5 .301			112.3 1.28	
Hard, pumice ash surface	ft/min mile/hr	250 2.84		86.2 .979				
Hard, pumice ash surface with subject carrying 30 lb	ft/min mile/hr			50.8 .577			166.7 1.89	
Front of obsidian flow with loose blocks 1 to 2 ft in size	ft/min mile/hr	28.9 .328		21.3 .242	6.8 .077			

30° aa slopes, the most difficult of all surfaces to traverse. Other variations of climbing velocities were normal.

Times required to perform various active and passive experiments are listed in tables V and VI. Stud-driving, by means of a .22-caliber stud driver (fig. 14), was attempted by subjects 2 and 3. Subject 2 first attempted to drive the stud into a flat pahoehoe surface at the level of his feet. In the kneeling position, the subject could not reach the working surface and keep one hand free to strike the stud driver. The activity was then attempted from a prone position, but the subject was too immobile to place his arms in front of himself to accomplish the work. Stud-driving was then attempted on a surface 28 inches high. Four stud-drivings were attempted. Two were completely successful. One attempt was too near a weathered edge of the rock, and the rock broke loose. The other attempt was on a slightly sloping surface, and the stud driver was not held flat against the surface and the stud bent. In the successful attempts, there were no flying rock fragments. In the two unsuccessful attempts, there were some fragments ejected, but the velocity was not sufficient to damage the thermal garment or visor. Subject 3 drove three studs successfully into a slightly vesicular obsidian rock about 14 inches above the land surface. Time required to load the gun and drive three studs was 3 minutes 6 seconds. Starting nuts on the studs for fastening down equipment presented no problems.

Simulated active and passive geophysical experiments were carried out by subject 1 in the loose pumice area. For the active experiment, time required to set up and level a package attached to a photographic-type tripod (see fig. 15) and to attach a minature cable to it was 1 minute 32 seconds. In the passive instruments portion of the study, 1 minute 5 seconds was required to perform the same exercise without connecting a cable. Time required to kneel down, remove the striker plate from the four-legged walker, place it on the ground, and remove the geologist's pick varied from 20 seconds to 1 minute 40 seconds. Average time was 1 minute 10 seconds. Time required to place the geophone (fig. 16) with the spike base in the ground, replace the striker plate, rise, and take two photographs at right angles to the line of traverse varied from 37 seconds to 2 minutes 13 seconds with an average time of 1 minute 1 second. Time required to walk the 200 feet between stations was discussed previously. For the passive instrument emplacement, it required 2 minutes 8 seconds to carry the seismograph model 80 feet, set up and level it; 1 minute 20 seconds to take the cable to the black box and connect it; 40 seconds to carry the radiosotope thermoelectric generator (RTG) model 40 feet and place it on the ground; 1 minute to take the power cord to the black box and connect it; and 1 minute 5 seconds to orient and level the black box (fig. 15) for a total time of 6 minutes 13 seconds. Difficulty was encountered in leveling the seismograph on a soft surface because the small feet did not adequately support the model; as a result, the model could be only roughly leveled. If a long-period seismometer is to be emplaced on a loose dust surface, it should be designed to be emplaced on a large flat base. Leveling of the seismometer on a hard surface (fig. 17) was achieved in 6 minutes 47 seconds. This time is probably more representative than time required in the pumice area.

TABLE V.- TIME REQUIRED TO PERFORM ACTIVE EXPERIMENTS INDICATING ABILITY OF SUBJECT TO GATHER DATA WHILE ON THE LUNAR SURFACE

Activity performed	Time, min:sec	Subject	Remarks
Hitting striker plate with geologist pick - for seismic source - five attempts	1:15 1:40 1:35 1:00 0:20	1	Subject kneels, removes plate from walker, places on ground, removes pick, and strikes plate
Emplacing geophone and photograph taking - five attempts	2:13 0:40 0:59 0:37 0:38	1	Subject replaces pick, removes geophone, emplaces it, and takes two photographs with camera
Marking sample for orientation	3:33	3	Subject finds strike of surface, scribes it, and takes dip
Removing dust layer	1:30	2	Subject removes 2 in. dust layer from surface of rock
Cumulative time for 200-ft walk, seismic source, and geophone placing - five attempts	5:14 3:55 4:26 3:18 3:13	1	

TABLE VI.- TIME REQUIRED TO PERFORM PASSIVE EXPERIMENTS

Activity performed	Time, min:sec	Subject	Remarks
Emplacing anchor bolts	3:06	3	Time is total time for subject to load stud driver and emplace three bolts.
Leveling instrumented box	1:32	1	Box with bull's-eye bubble on top is leveled by adjusting tripod head.
Leveling instrumented box	1:05	1	Box with bull's-eye bubble on top is leveled by adjusting tripod head.
Crude leveling seismometer	2:08	1	Model of long period seismometer was roughly leveled on soft surface.
Fine leveling seismometer	6:47	2	Model of long period seismometer was accurately leveled on a 16° slope.
Laying out and connecting 80 feet of cable	1:20	1	Cable from seismometer was carried and connected to instrumented box.
Laying out and connecting 40 feet of cable	1:00	1	Cable from power supply was carried and connected to instrumented box.
Setting out power supply	0:40	1	Power supply was carried 40 feet from instrumented box and placed on ground.

Figure 14.- Subject 3 using a .22-caliber stud driver to emplace anchor bolts. Note anchor bolt emplaced to right of stud driver.

Figure 15.- Subject 1 fastening cable to simulated instrument-telemetry package mounted on photographic tripod.

Figure 16.- Subject 1 emplacing geophone on loose pumice surface.

Figure 17.- Subject 2 fine leveling a long period seismometer.

Time required for subject 3 to take strike and dip of an outcrop surface (fig. 18) was 3 minutes 33 seconds. Subject 2 used a scoop (fig. 19) to remove loose material, about 2 inches thick, from a buried sample. Time was 1 minute 30 seconds for removing material sufficiently to work on the surface of the sample.

Collecting small, float samples was performed in the loose pumice area and obsidian flow area rapidly and efficiently. No times were taken for this activity.

Figure 18.- Subject 3 using an abney level to determine dip of outcrop surface.

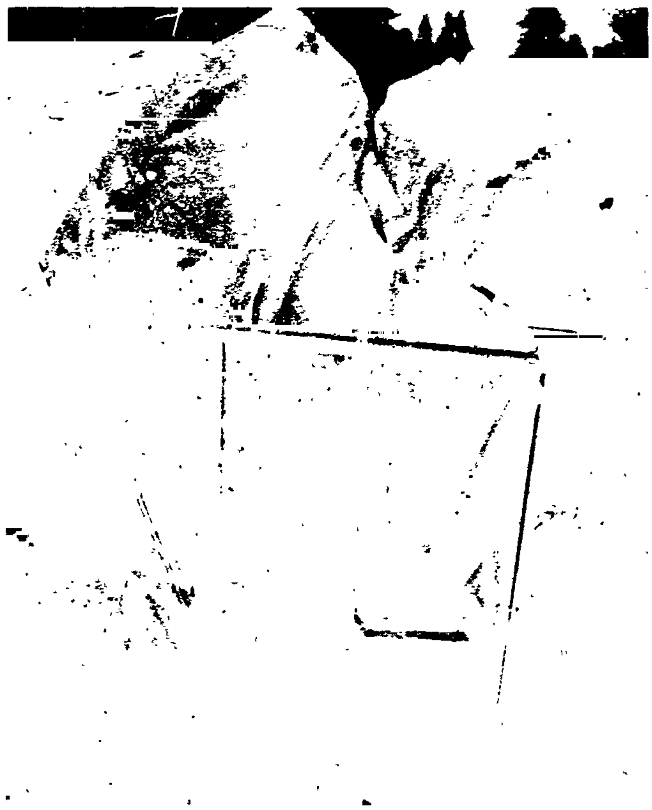

Figure 19.- Subject 2 using scoop to remove loose pumice ash from a buried rock sample.

RECOMMENDATIONS

As a result of these tests, it was found that a method must be found for performing tasks requiring good visibility and mobility at the ground level. This could be accomplished by improving pressure suit mobility, designing equipment or task structure so that tasks could be performed with the hands and fingers no less than 12 inches above ground level, and designing a supporting harness system so that the astronaut could be supported in a prone position, that is, upper torso supported but legs and feet on the ground at an elevation convenient for work at the ground level.

The luna-walker must be redesigned to incroporate the suggestions and recommendations that emanated from the test program.

The scientific activities requiring descent into craters whose walls subtend angles of 30° or more from the horizontal will require a performance support. The luna-walkers and Jacob's staff are not fully adequate.

The extravehicular gloves to be designed to provide protection against high temperature levels on the lunar surface require a high degree of finger and hand mobility.

Further performance tests are already scheduled for $\frac{1}{6}$ gravity simulator devices. These tests will be performed on inclined and level planes covered with material closely simulating the field test surfaces at Bend, Oregon, to determine the effect of reduced gravity in performing tasks. In addition, a more comprehensive mission activities test program will be performed at Manned Spacecraft Center using the lunar surface simulation area and a lunar excursion module mockup. These tests will establish more precise times for each phase of lunar exploration. Tests will also be performed in aircraft flying $\frac{1}{6}$ gravity trajectories to determine the mass and bulk carrying ability of a space-suited subject.

CONCLUSIONS

It is generally concluded from the results of the field test program that the performance requirements for lunar-related tasks are well within the performance capabilities of the astronauts. Performance of the three subjects, including one astronaut, was better than expected when the nature of the terrain and the pressure suit constraints upon shirt sleeve mobility are considered.

More specific conclusions are as follows:

(1) Performing scientific tasks requiring delicate manipulation with the hands and fingers at ground level was essentially impossible under 1 g because of the immobility of the developmental pressure suits.

(2) Performance aids, such as the luna-walker and Jacob's staff, appear justified both to carry tools and to aid in walking. When only the aid to walking was considered, opinions of the subjects varied as to the usefulness of the luna-walker and Jacob's staff. One subject preferred to use neither; another used the Jacob's staff and the luna-walker to advantage; and the third used the walker more than the Jacob's staff. The luna-walker was not useful on steep, rocky slopes, but was useful in crossing crevices on the pahoehoe surface. It also aided in rising from a kneeling position during the active geophysical traverse and in climbing the 20°, loose, pumice ash slope. It appeared to be useful for transporting equipment. Perhaps part of the material covering the front of the walker could be eliminated for better visibility. The Jacob's staff was useful in traversing the more rugged terrain in addition to being a

convenient carrier for geologic tools. Consensus of the subjects was that both the Jacob's staff and the luna-walker were useful devices. Also, a rather simple support such as a rope attached at the top of the crater could serve as a useful aid in descending into craters whose walls subtend angles of 30° or more from the horizontal.

(3) Performance of a 3-hour extravehicular lunar excursion could require both a luna-walker and a Jacob's staff. Attachment points on the walker would be provided for attaching the Jacob's staff.

(4) The Apollo intravehicular glove used during the tests provided sufficient finger dexterity required for the many tasks to be performed on the lunar surface.

(5) Space-suit helmet design must consider visor fogging problems and downward vision capabilities.

All tasks performed in the Bend, Oregon, area were performed under earth gravity conditions. Under lunar conditions of 1/6-earth gravity many of the tasks may be less difficult to perform. This fact must be kept in mind in applying the numerical results obtained in these tests. Future simulated 1/6-gravity tests will be performed to obtain information needed to extrapolate these data.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, August 17, 1965

APPENDIX

TASK PROCEDURES

Activities to be Used to Extrapolate to $\frac{1}{6}$ Gravity

These activities will be short traverses over difficult terrain. All walking will be confined to 30- to 100-foot traverses. Each action will be repeated.

Equipment.- Jacob's staff and luna-walkers.

Procedure.- Two types of tasks will be performed: walking on a level surface and climbing a slope.

A. Walking on a level surface under the following conditions:

1. Loose, rough material.

2. Protuberances that can be stepped over.

3. Protuberances that can be walked around.

4. Protuberances that must be negotiated.

5. Loose, soft material.

(a) Carrying luna-walker with hand tools mounted on it, start at point marked by paint or a flag with walker in hands ready to walk on signal; start walking at a deliberate pace (start stop watch and count number of paces needed to reach end point). When end point is reached, stop stop watch, and record the time and the number of paces. Pause for a short rest and then turn around and prepare to repeat procedure going in the other direction. Repeat procedure.

(b) Walk with luna-walker, carrying hand tools, and play out piano wire. Use same procedure as described in (a) except set star drag on reel to play out line, and, at start of procedure, have an assistant stand at the starting point and hold the end of the line.

(c) Walk using Jacob's staff. Use same procedure as described in (a) except use Jacob's staff instead of luna-walker.

These three procedures are the same for all five surface conditions except for condition 3, procedure (b), where care must be taken to keep line straight as it is being played out.

B. Slope climbing under the following surface conditions for 10°, 20°, and 30° slopes:

1. Loose, rough surface.

2. Protuberances that can be stepped over.

3. Protuberances that can be walked around.

4. Protuberances that can be negotiated.

(a) On all slope climbing, start at point marked by paint or flag, with luna-walker in hand ready for walking. On signal, start climbing the slope at a deliberate pace. Using a stop watch, take the time for climbing slope, and count the number of paces required. The end point will be marked with either paint or a flag. After sufficient rest time, turn around and repeat the procedure, descending the slope. After another rest period, if required, repeat the climbing and descending procedure.

(b) Repeat all steps in (a) with a Jacob's staff instead of the luna-walker.

Geophysical Traverse

Equipment.- Black box with male plug connected to simulate seismic recorder, female plug attached to end of piano wire, three geophones, striker plate, geologist's pick, luna-walker, camera, tripod or Jacob's staff, and Brunton compass.

Procedure.- Place black box to simulate seismic recorder at starting point with plug facing in the direction of traverse. Have observer with radio communications to subject stand behind box and sight through Brunton compass. Pick out landmark on horizon for subject to walk toward. Start with equipment on luna-walker, standing facing the black box. Set star drag on reel to keep sufficient tension on piano wire so that it will lie out straight. Take plug on end of piano wire and pull off enough wire to reach plug on box. Bend down enough to attach plug to box, stand up, turn around, and grasp luna-walker. Then pick up the walker and walk toward the landmark indicating the direction of the traverse, allowing the piano wire to play out while walking. If subject gets more than 2 or 3 feet off the line of traverse, the assistant sighting along the Brunton compass sites directs him back to the line of traverse. Roll piano wire off the reel in such a manner that it passes under one of the cross members of the reel and when the 200-foot mark is reached there will be a noticeable catch.

When the catch is noticed, stop, set the walker down, turn around and by either grasping the reel by hand or setting the star drag to tightest position, pull the piano wire tight. If the piano wire is not laid straight, lift the frame as high as possible and, by making a jerking motion, straighten the wire out. Set the walker down so that the wire remains tight. Remove striker plate from stored position and place on the ground below the 200-foot mark. Remove geologist's pick from stored position, kneel or stoop down and strike the plate once with the geologist's pick. Replace the striker plate and pick. Remove camera and take two photographs on opposite sides of the line of traverse at right angles to the line of traverse while standing. Replace camera and reset star drag to play out line. Pick up walker and start walking again in direction of the landmark, being directed by observer in order to stay close to straight line.

At catch indicating the 400-foot point, repeat the procedure and, in addition, after the striker plate is struck, remove a geophone from the kit and install it on the ground near the position where striker plate was struck. After finishing procedure, pick up walker and continue until catch indicates the 600-foot point. Repeat the striker plate, geophone emplacement, and photographic procedure.

Sampling Traverse

Equipment.- Jacob's staff, luna-walker, sample bags, sample carrying bag, geologist's pick, scoop, scriber, camera, and abney level.

Procedure.- Sample traverse will already be laid out. Equipment will be attached to luna-walker or Jacob's staff. Pick up walker with sampling equipment attached and walk to point where fresh surface is available for sampling. Set frame down in an easily reached position near the sampling location. Use abney level to locate level line across sample. Scribe this line and measure the slope at a right angle to the level line with the abney level. With abney level still on the sample spot, take a photograph of the sample location. Remove the level and use a geologist's pick to break off the sample. Place sample in sample bag, and then in sample carrying bag. Replace all equipment in walker. Get up and pick up walker and walk to point where weathered rock is located. Set walker down where it is convenient to reach from sample location. Use pick to remove weathered surface. Scribe level line, measure slope, take picture, break off sample and place in carrying bag. Replace equipment and get up, pick up walker, and walk to area where rubble covers sample location. Place walker in convenient location and remove rubble either by hand or with the scoop and follow procedure for marking and taking sample. Replace tools, pick up walker, and carry it to point where dust covers the sample point. Place walker in convenient position and remove dust from the sample point with the scoop, and follow sample taking procedure.

Repeat the same procedure as described previously except use the Jacob's staff instead of the walker.

Passive Instrument Emplacement

Equipment.- Black box with two female connectors, model of seismograph with 100-foot cord attached and with male connector on end, and model of RTG with 50 feet of cord attached and male connector on end.

Procedure.- Black box, RTG, and seismometer are placed in an area where black box is to be set up. Select positions for setting up RTG and seismometer in advance. Bend over, pick up seismometer and carry it to a pre-selected location for setting it up (80 to 90 feet from the position where the black box is initially located). Set seismometer down, pointing one leg in the direction of the black box and, by using adjustable legs, center leveling bubble by turning the required threaded bolts to raise or lower the legs. When instrument is level, unwind the 100 feet of cable attached to the seismometer and take end with male coupling on it to black box and connect to black box. Pick up model of RTG and carry to selected site about 40 feet from black box. Place RTG in position behind an obstruction that will shield black box from line of sight to RTG, then unwind the 50 feet of cord and take connector to black box so that compass on top points North, and level black box with the leveling knobs on the tripod and the bull's-eye bubble.

Anchor Bolt Emplacement

Equipment. - Model of seismograph to simulate head of core drill, three steel straps with slots that fit over the leveling screws of the seismograph model .22-caliber stud driver, blank cartridges, and studs.

Procedure. - Place model in position on surface of rock outcrop and level roughly. Slip the straps over the leveling screws and arrange on the surface so that each points in the direction of the leg on which it is attached and away from the model itself. Load stud gun and place where the stud will go through the strap and fire, driving the stud into rock outcrop. Repeat this procedure for the other two legs. Tighten level bolts to take up any slack in the straps in such a manner that the model remains level.

NASA-Langley, 1965 S-76