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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

APOLLO 17 MISSION

LUNAR ROVING VEHICLE/TRAVERSE GRAVIMETER EXPERIMENT MOTION SENSITIVITY TEST

LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TEXAS

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SUMMARY

The results of the lunar roving vehicle/traverse gravimeter experiment motion sensitivity test shows that the gravity measurements in both the normal and bypass modes should not be adversely affected by motion induced in the lunar roving vehicle by operation of the television camera position drive device or the operation of the surface electrical properties receiver/recorder. Motion of the traverse gravimeter experiment occurred when a 1.4-hertz resonant mode in pitch of the lunar roving vehicle was excited and when a 4-hertz resonant mode of the pallet was excited. Both of these modes were excited by camera elevation changes with the camera axis positioned fore and aft.

PURPOSE

The purpose of the lunar roving vehicle/traverse gravimeter experiment motion sensitivity test was to determine if operation of other lunar roving vehicle equipment, specifically the television camera position drive device and the receiver/recorder for the surface electrical properties experiment, would adversely affect the experiment measurements.

SYSTEM DESCRIPTION

The traverse gravimeter is a semi-automatic, self-leveling instrument which will be used to measure gravity at predetermined stops along the traverses of the Apollo 17 lunar roving vehicle. These readings will be used to prepare a gravity profile of the area.

The gravity sensor for the experiment is a vibrating string accelerometer that is enclosed in a temperature-controlled oven for greater accuracy (fig. 1). The sensor is self-leveled before each reading is taken. The accelerometer consists of two identical masses coupled by a spring. The masses are held apart by two beryllium-copper tension strings which pass through a constant magnetic field. Three cross ties restrain lateral movement of the masses, but allow vertical motion.

Each accelerometer string is the feedback element of an oscillator. Current from the output of the oscillator amplifier passes through the

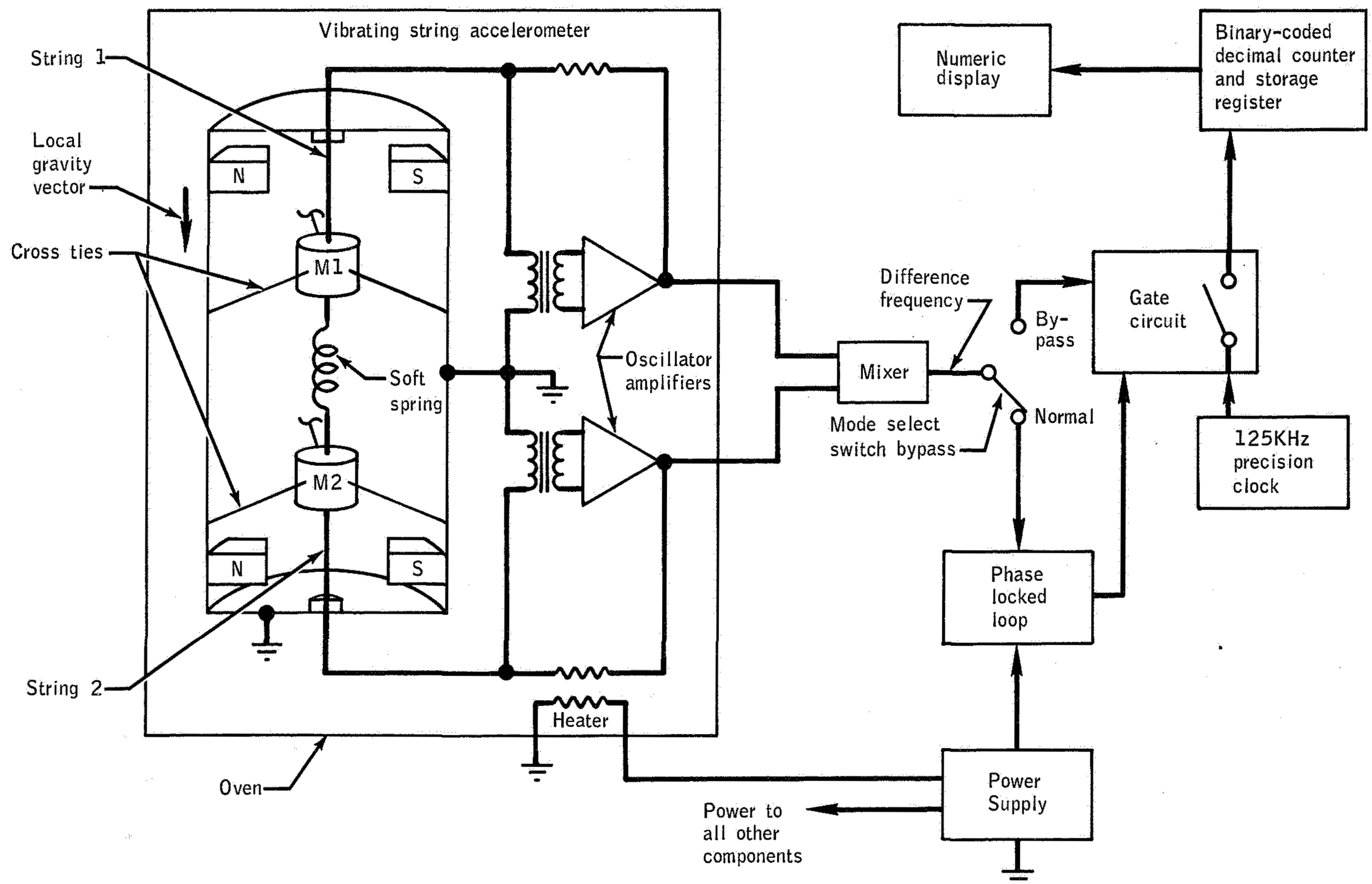


Figure 1.- Traverse gravimeter sensing and display block diagram.

string, mass, and tension cross ties to ground. This current physically displaces the string in the magnetic field and this displacement generates a voltage in the string that is coupled into the amplifier input. The string and amplifier, therefore, oscillate at the resonant frequency of the string (approximately 0.4 kHz).

The resonant frequency of each string is determined by its length and tension. Since the upper string supports the tension in the lower string and the weight of both masses, its resonant frequency will be higher than that of the lower string. The difference in frequency between the two oscillators is determined by the gravity field being measured.

The outputs of the amplifiers are fed to a mixer where a difference frequency is obtained. This difference frequency is fed through a mode select switch to the gate circuit in one of two modes. The normal mode feeds the difference frequency through a phase-locked loop which acts as a narrow-band filter to attenuate possible residual vibrations of the lunar roving vehicle. In the bypass mode, the phase-locked loop is bypassed and the difference frequency is fed directly into the gate circuit. The gate is then opened for a set number of cycles of the difference frequency.

The gate allows a 125-kilohertz precision clock to drive a binary-coded decimal counter for a time equal to the gate width. The number of cycles counted is proportional to the gate width and thus proportional to the local gravity. The binary-coded decimal counter serves the dual function of a counter and a storage register. The contents of the register are transferred to a numeric display. These data, displayed upon command by a lunar surface crewman, are then transmitted by voice back to earth.

A bias measurement is taken before the initial traverse to calibrate the accelerometer. The accelerometer is then inverted, releveled, and a gravity reading taken. The gravimeter automatically slews the accelerometer back to the normal position.

TEST SETUP

The test article (fig. 2) was the qualification lunar roving vehicle that was configured with a qualification ground-controlled television assembly, a flight-configuration lunar communications relay unit, a high-gain antenna, a low-gain antenna, and inactive batteries. Engineering models of the surface electrical properties and the traverse gravimeter experiments were also mounted on the vehicle. The lunar roving vehicle

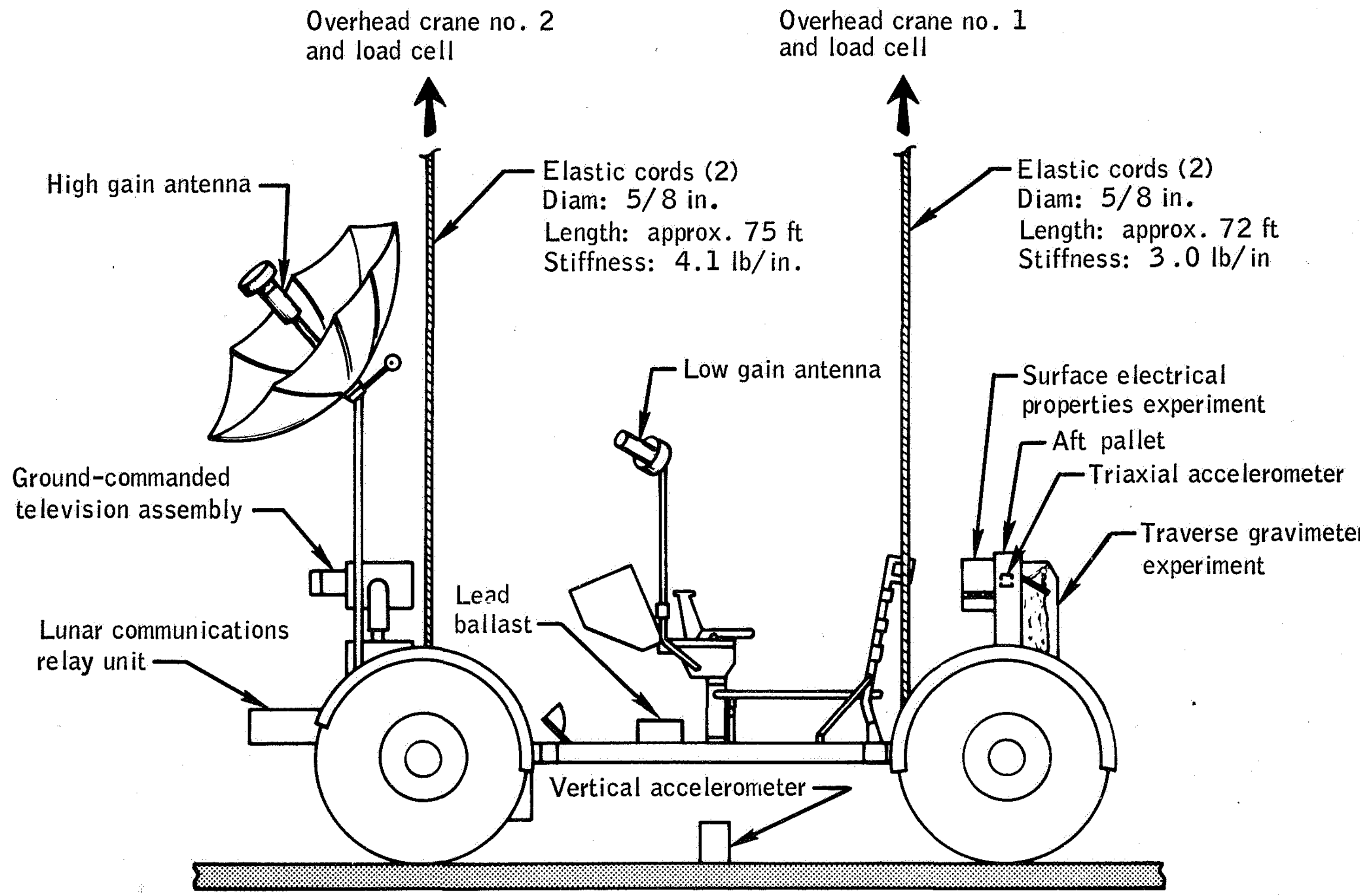


Figure 2.- Test set up with qualification lunar roving vehicle.

aft pallet was modified to the Apollo 17 configuration to accept the mass representation of a tool carrier and a lunar seismic profile experiment.

The vehicle was supported so that the weight representation of the vehicle was that of the lunar gravity (1/6g). The support system consisted of four elastic cords attached to the lunar roving vehicle near the forward and aft assembly hinge points. The two forward and the two rear elastic cords were attached to a forward and rear crane, respectively, through load cells (fig. 3). The outputs of both load cells were digitally displayed to insure proper loading for maintaining 1/6 lunar gravity weight of the lunar roving vehicle on the wheels. Appendix A provides more information on the support system.

Figure 4 shows the predicted loading for determining support system attach points. Additional lead ballast was placed at various locations on the vehicle to produce a weight and center of gravity comparable to that of the flight lunar roving vehicle. The measured fore and aft center of gravity was 0.3 inch from the flight vehicle and the measured weight was lighter by 30 pounds than the flight vehicle. These differences were small and did not affect the test results.

The lunar roving vehicle pallet was instrumented with triaxial servo-type accelerometers oriented along the principle axes of the lunar roving vehicle. These accelerometers were located opposite to the traverse gravimeter experiment mounted on the pallet (fig. 5), and near the surface electrical properties experiment. A single axis accelerometer was mounted on the floor beneath the lunar roving vehicle to monitor motion normal to the laboratory floor (fig. 2). The accelerometer outputs were passed through low-pass filters and recorded on a direct-wire oscillograph. The resolution of the accelerometers was 50 to 100 micro-g's when low passed at 20 hertz and 25 to 50 micro-g's when low passed at 4 hertz. Gravity measurements were read directly from the traverse gravimeter experiment numeric display. For the test gravimeter, one count was equal to 0.12 milligal with one milligal being one centimeter per second per second or approximately one micro-g.

TEST CRITERIA

The normal operating characteristics of the test gravimeter were as follows:

a. Maximum changes between successive readings as high as 20 counts or 2.4 milligals.

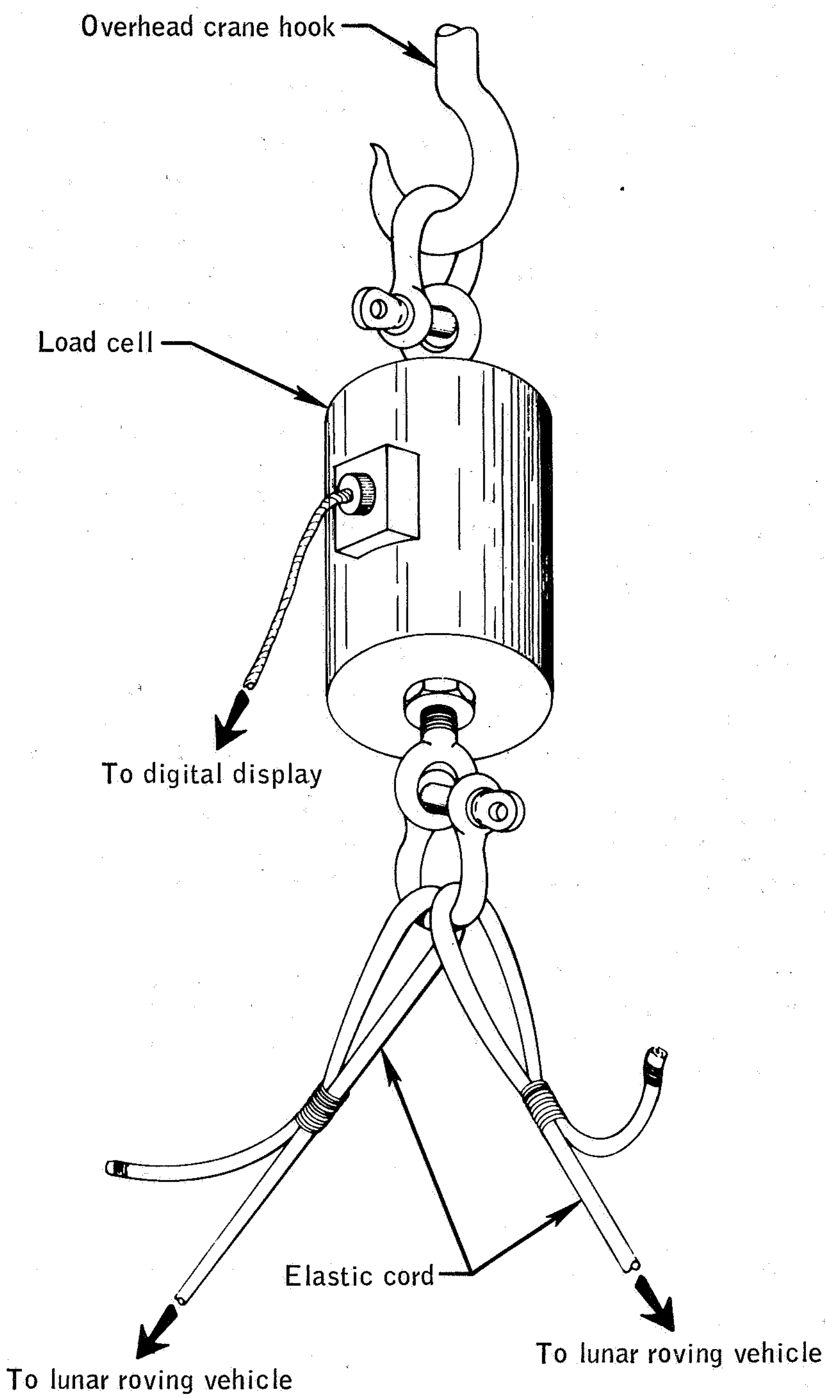


Figure 3.- Typical load cell and support system attachment.

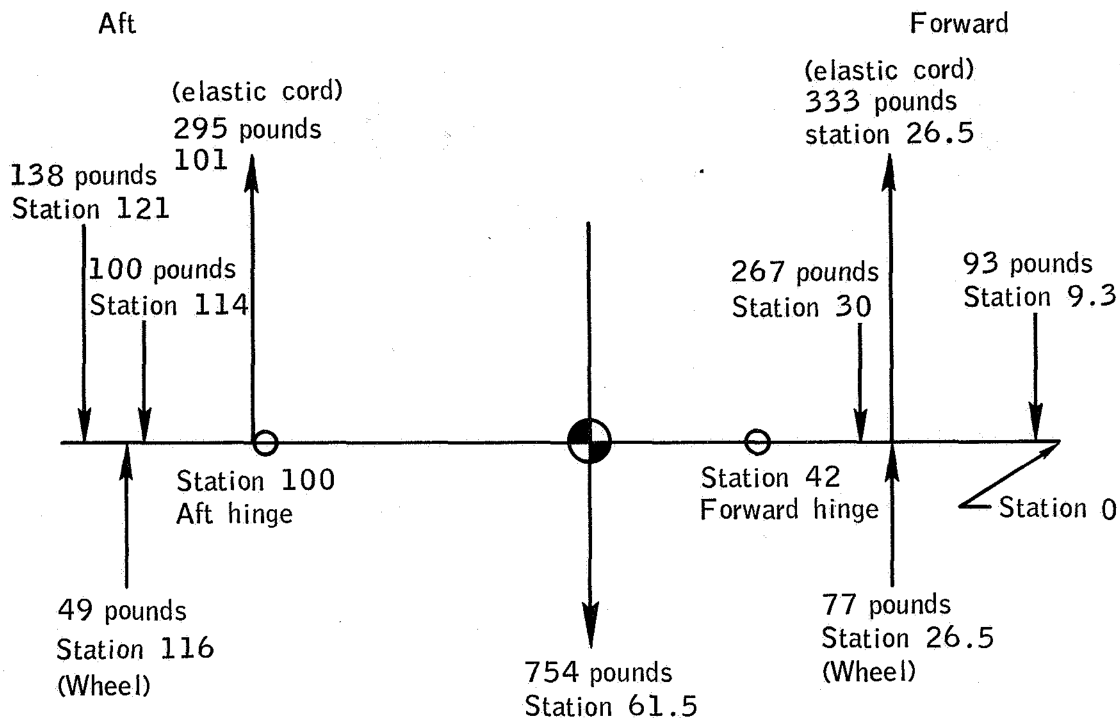


Figure 4.- Lunar roving vehicle chassis load distribution for test.

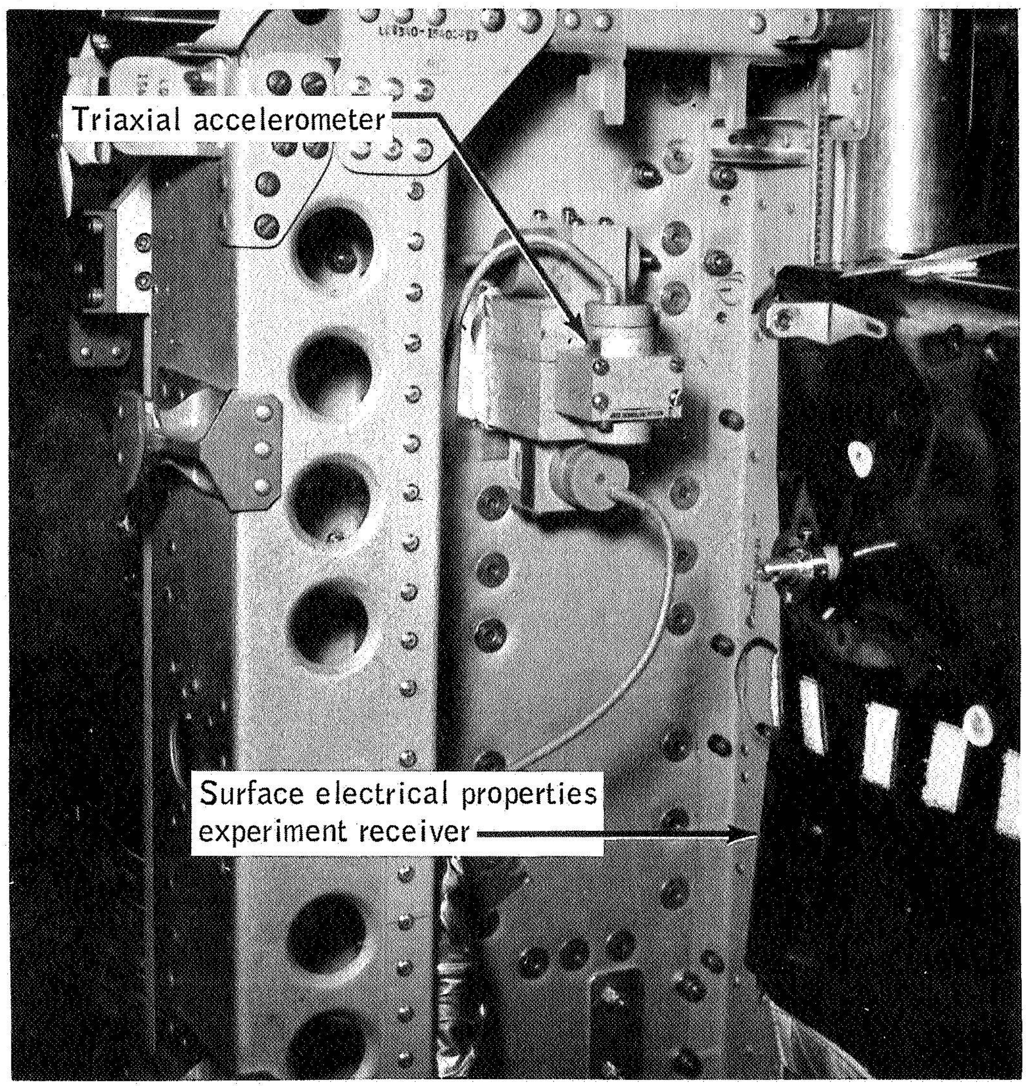


Figure 5.- Accelerometer location and mounted on the aft pallet.

b. The one sigma deviation of a group of 5 to 10 readings is no more than one milligal. ($\sigma = \sqrt{\frac{\Sigma d^2}{n-1}}$ where d is the standard deviation and n is the number of data points).

For the purposes of this test, any reading which fell outside of the above limits could be caused by the operation of the surface electrical properties recorder, the television camera, or human interference. Consequently, the cause of any such reading was determined.

The test outline for this special test is contained in appendix B.

TEST RESULTS

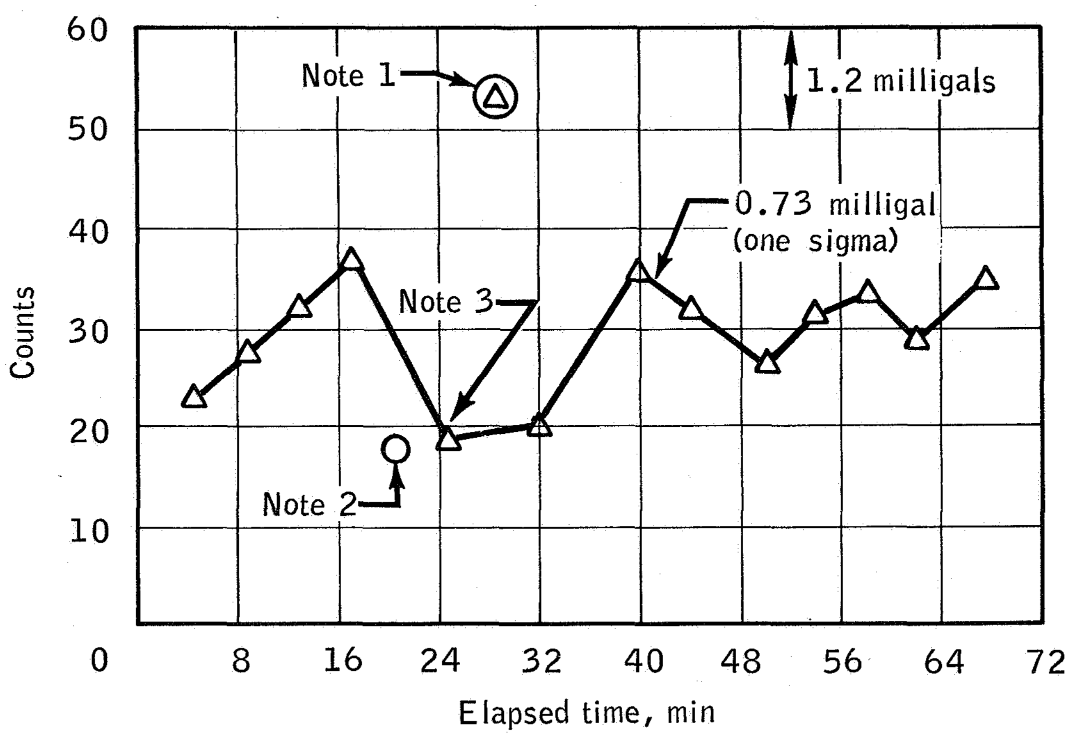
The test gravimeter was an engineering model that differed from flight hardware in two respects. First, the vibrating string accelerometer had weak cross ties (fig. 1). Consequently, external disturbances of sufficient magnitude, such as bumping the lunar roving vehicle, caused bias shifts. In some cases, the bias shift was of a transient nature which would recover in a period of 10 to 20 minutes. Data errors due to bias shift were discernible.

Secondly, the test gravimeter contained an additional heater circuit to maintain the vibrating string accelerometer at a constant temperature during earth operations (not required on lunar surface). The heater constituted about one fourth of the power supply load when switched on and caused a transient which affected the phase-locked loop. Some data readings had larger deviations than expected, but in all cases, these were correlated with the switching of the heater.

The first five test steps involved mechanical adjustments of the test configuration. The sixth test step was a series of gravity measurements with the surface electrical properties recorder operating. These data indicated that the recorder will not affect the gravimeter measurements. Since this was expected, the data for these measurements are not presented.

Further testing was concerned with the degradation of gravimeter measurements caused by television camera motion.

In test step 7, normal and bypass mode gravity measurements were taken while camera power was being switched on and off. The first four normal-mode gravity measurements (fig. 6) indicated a continuing upward bias shift. A bypass reading was taken for comparison and this led to a search for disturbances external to the test vehicle. The disturbances



Notes:

1. Heater switched, disregard reading
2. Bypass reading
3. Repeat of test after water tower turned off.

Figure 6.- Television camera switching in test step 7.

were identified and stopped (facility water tower) and the test continued. The nine normal mode gravity measurements taken yielded a one sigma of 0.73 milligal.

In test step 8, normal-mode gravity measurements were taken during camera azimuth motions. Also, two bypass readings were taken, followed by two bypass-mode baseline checks. A normal-mode reading was taken to further check the baseline. Figure 7 shows the data and again the one sigma for the normal-mode gravity measurements was 0.73 milligal.

Test step 9 involved gravity measurements during camera elevation motions. As shown in figure 8, seven normal mode gravity measurements yielded a one sigma of 1.1 milligals and this was 0.1 milligal higher than the allowable. (The phase-locked loop for the test gravimeter was found to be noise sensitive, so the test was repeated at a later period in the bypass mode as test step 23). This was followed by three normal-mode and one bypass-mode measurements to check the baseline. Two bypass-mode readings were then taken with camera elevation commands given in 10-second intervals.

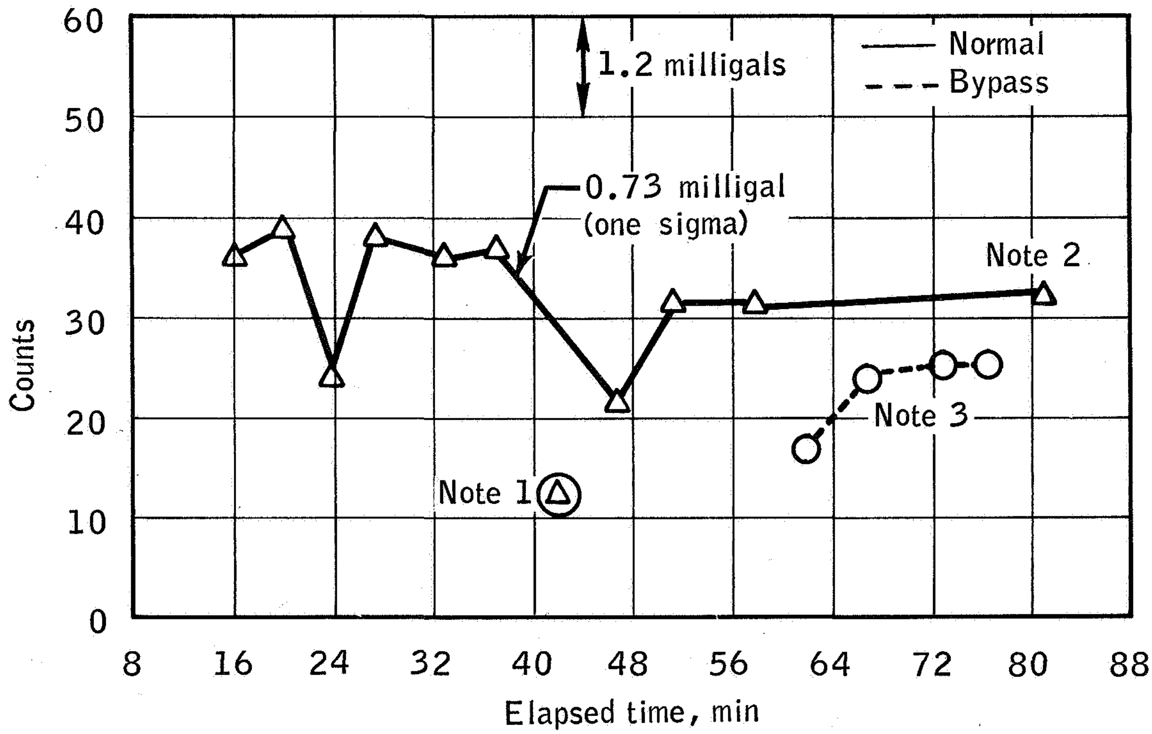
In test step 10, four gravity measurements, in both the normal and bypass modes, were taken during camera-zoom and iris-change operations. The data (fig. 8) shows that the peak-to-peak spread in the readings is within the 20-count allowable, but because of the small number of usable data points, a one sigma value was not computed.

In test step 11, both normal- and bypass-mode gravity measurements were taken during combined camera elevation, azimuth, and zoom operations. The data (fig. 9) show that the variation in gravity readings was small. This was followed by a repeat of the camera elevation test (step 9) and baseline checks in both normal and bypass modes. The data (fig. 9) show no significant variations.

Test steps 12 through 17 involved normal- and bypass-mode baseline readings to determine bias shifts while making mechanical adjustments to the test vehicle. Test step 18 and 19 were not used. In test step 20, three normal-mode baseline checks, alternated with three bypass-mode baseline checks, were performed. The data for test steps 12 through 17 and 20 indicated nothing unusual and are not presented in this report.

Test step 21 was a repeat of step 7 (camera power switched on and off) except the gravity measurements were taken in the bypass mode. These data are not presented because the variation in readings was small (four-count maximum).

In test step 22, bypass mode measurements were taken while the camera was moved in azimuth. The first eight data points (fig. 10) were



Notes:

1. Thermostat switched, disregard reading
2. Normal baseline check.
3. Bypass run - first 2 readings
   second 2 readings - quiescent (baseline)

Figure 7.- Television azimuth motions in step 8.

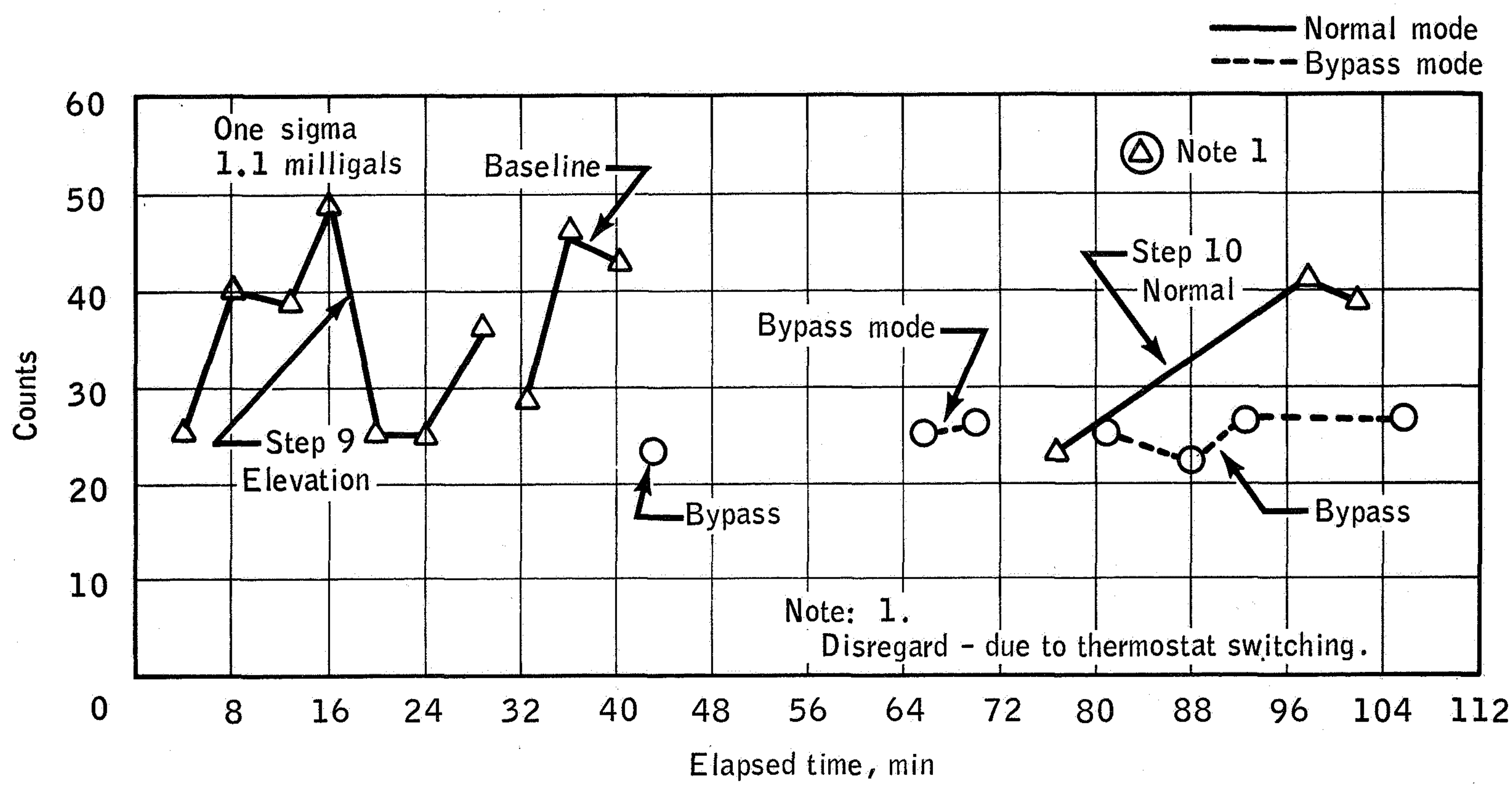


Figure 8.- Television elevation motions in test step 9 and camera zoom and iris commands in test step 10.

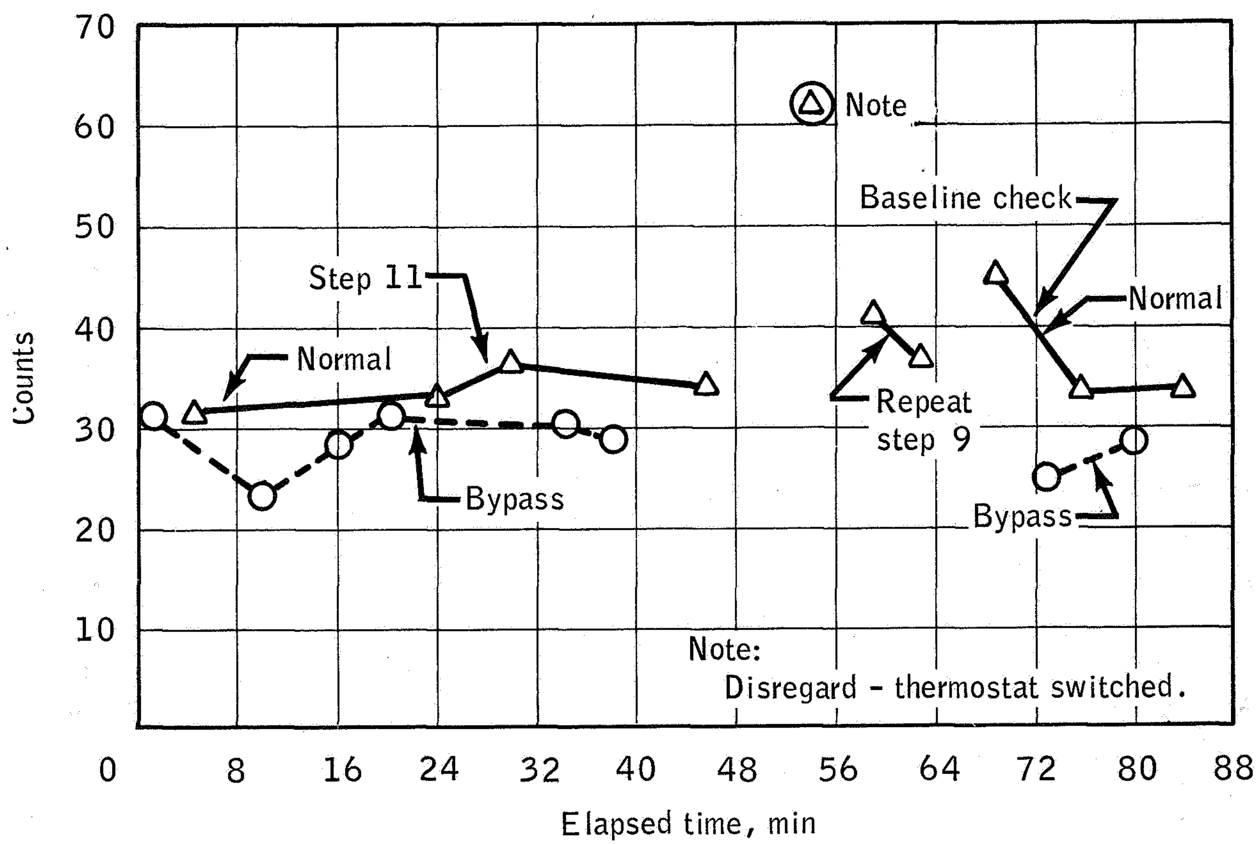


Figure 9.- Combined elevation, azimuth and zoom operations in test repeat of camera elevation tests of test step 9.

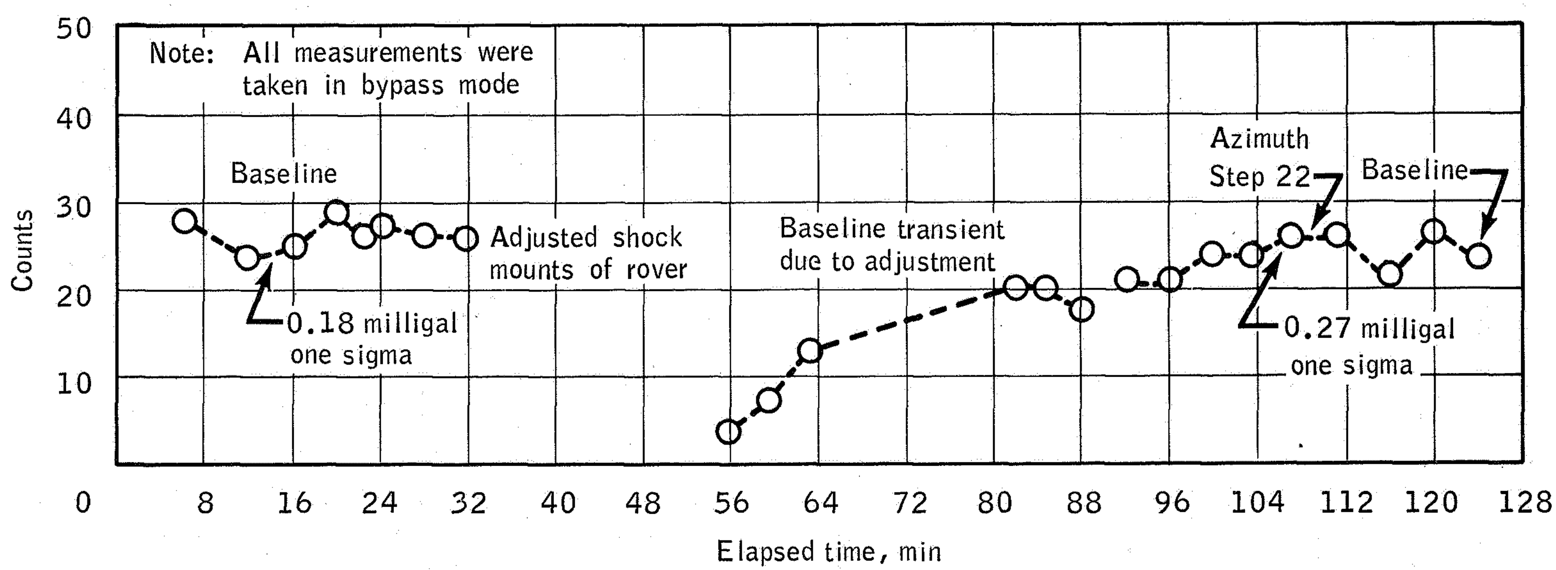


Figure 10.- Camera azimuth motions in test step 22.

baseline readings which yielded a one sigma of 0.18 milligal. However, the lunar roving vehicle shock-mount dampers were locked. The dampers were unlocked and six more baseline readings were taken. These measurements indicated a bias shift. The bias slowly recovered, however, and test step 22 was performed yielding an acceptable one sigma of 0.27 milligal. The last data point was a baseline reading that indicated a slight upward drift in bias.

Test step 23 was a repeat of gravity measurements during camera elevation motion (step 9) except that readings were taken in the bypass mode (fig. 11). Eight baseline measurements were taken first and these indicated a small upward drift in bias. Seven measurements were then taken (test step 23) with a one sigma of 0.27 milligal. Two more baseline measurements were taken and a slight upward drift was still indicated. If this drift was taken into account, an improved one sigma value would be obtained.

In test step 24, bypass measurements were taken during camera elevation motions between plus and minus 15°. These measurements were taken at camera azimuths of 0°, 90°, 180°, and 270°. The data (fig. 11) yielded a one sigma of 0.34 milligal; well within limits. Two baseline measurements then followed, and these still indicated an upward bias shift.

In test step 25, bypass measurements (fig. 11) were taken during a simulated collection bag removal from the pallet. This caused a transient in the vibrating string accelerometer.

Test step 26 was performed to obtain baseline data following the unlocking of the lunar roving vehicle shock-mount damper. The effect was similar to that discussed under test step 22.

In test step 27, twenty-five different motions of the camera were performed and the triaxial accelerometer oscillograph data (set at low pass of 4.8 Hz) was evaluated for worst case effects. Three worst case camera motions were performed at the beginning and end of the gravimeter counting cycle when the instrument was most susceptible to vibration induced errors. Five measurements were taken in both the normal-gravity mode and the bypass mode with the initiation points being varied by one second. The data show no degradation in gravity measurements due to the worst case motions and are not presented.

Test step 28 was performed to establish a baseline for test step 29. Data were taken in both the normal and bypass modes, and are presented in figure 12. The one sigma for the bypass mode was 0.14 milligal and for the normal mode was 0.43 milligal. The time interval required for each measurement was established for use in subsequent tests.

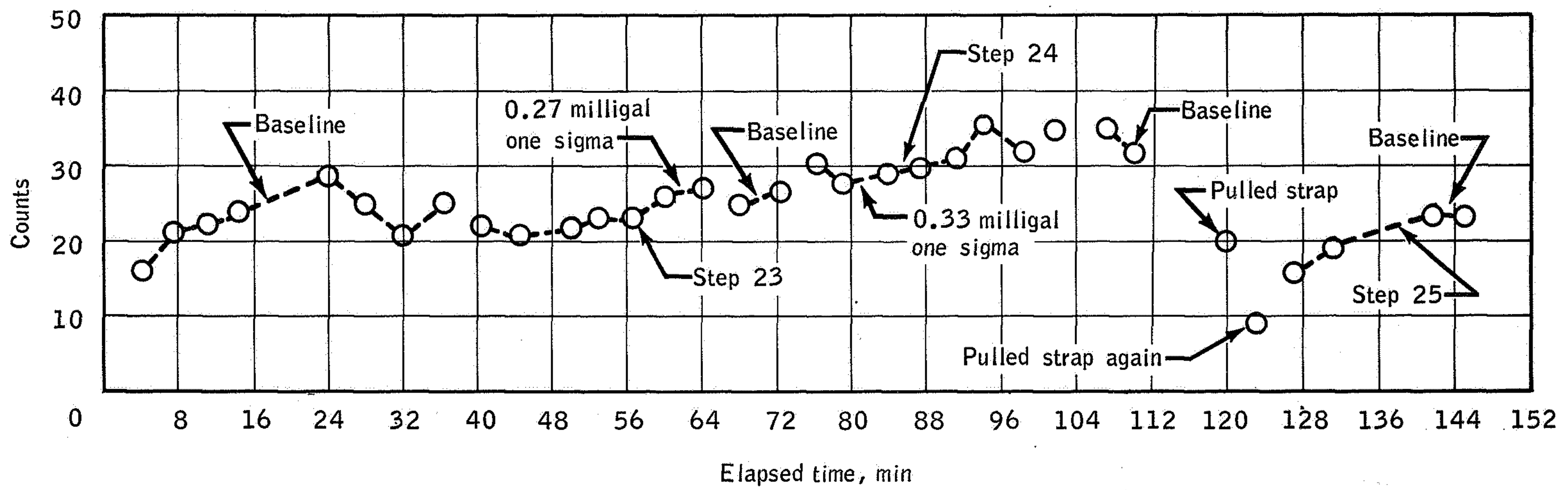


Figure 11.- Camera elevation motions in test step 23 (repeat of test step 9) and test step 24
Simulated collection removal in test step 25.

Test step 29 involved both bypass- and normal-mode gravity measurements taken while camera elevation movements were performed at the start and end of the difference frequency count (measurement cycle). Previous data reviews had indicated that camera elevation motions would have the greatest effect on the gravimeter readings. The following sequence was used:

a. Set camera to 0° azimuth

b. Initiate gravity measurement and wait 86 seconds (approximate start of difference frequency count)

c. Command camera to -15°, then back to 0°. Wait 70 seconds (approximate end of difference frequency count)

d. Command camera down to -15°, then back to 0° elevation.

Three baseline measurements were also taken in the bypass mode and four baseline measurements were taken in the normal gravity mode. The baseline measurements were interspersed with the test measurements. The data are shown in figure 12. Initially, it would appear that camera motions caused a slight upward bias shift. However, the differences between the averages of the two sets of readings (camera motion and baseline) for the bypass mode was less than 0.5 milligal. For the normal mode, the difference in the averages was 0.2 milligal. Since the scattering of normal gravity measurements is greater than the bypass measurements, a bias shift, if any, was not apparent.

Test step 29.1 was a repeat of test step 29 except the following sequence was used:

a. Set camera initially to 0° azimuth and -45° elevation

b. Initiate gravity measurement

c. After 81 seconds, command camera up for 5 seconds, then stop, and return camera to -45°

d. Wait 70 seconds and repeat the camera motions in step c.

The data for this test are shown in figure 13. The first five data points were taken in the bypass mode and yielded a one sigma of 0.37 milligal. These were followed by three bypass mode and three normal-mode baseline measurements. The next six data points were normal-mode measurements which yielded a one sigma of 0.84 milligal. These were followed by four normal mode baseline readings. The normal gravity mode baseline data before and after the step 29.1 normal mode test yielded a one sigma of 0.54 milligal.

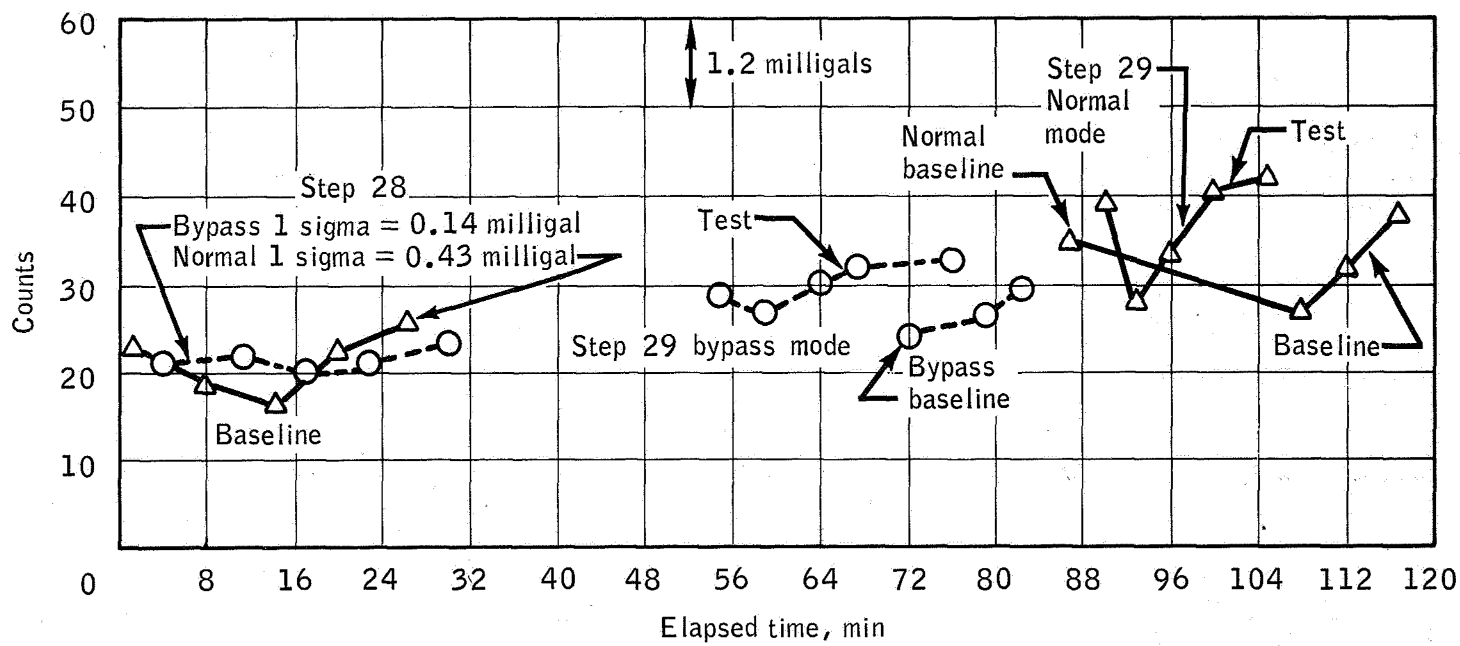


Figure 12.- Baseline measurements and camera elevation motions at start and end of gravity measurement cycle test step 29.

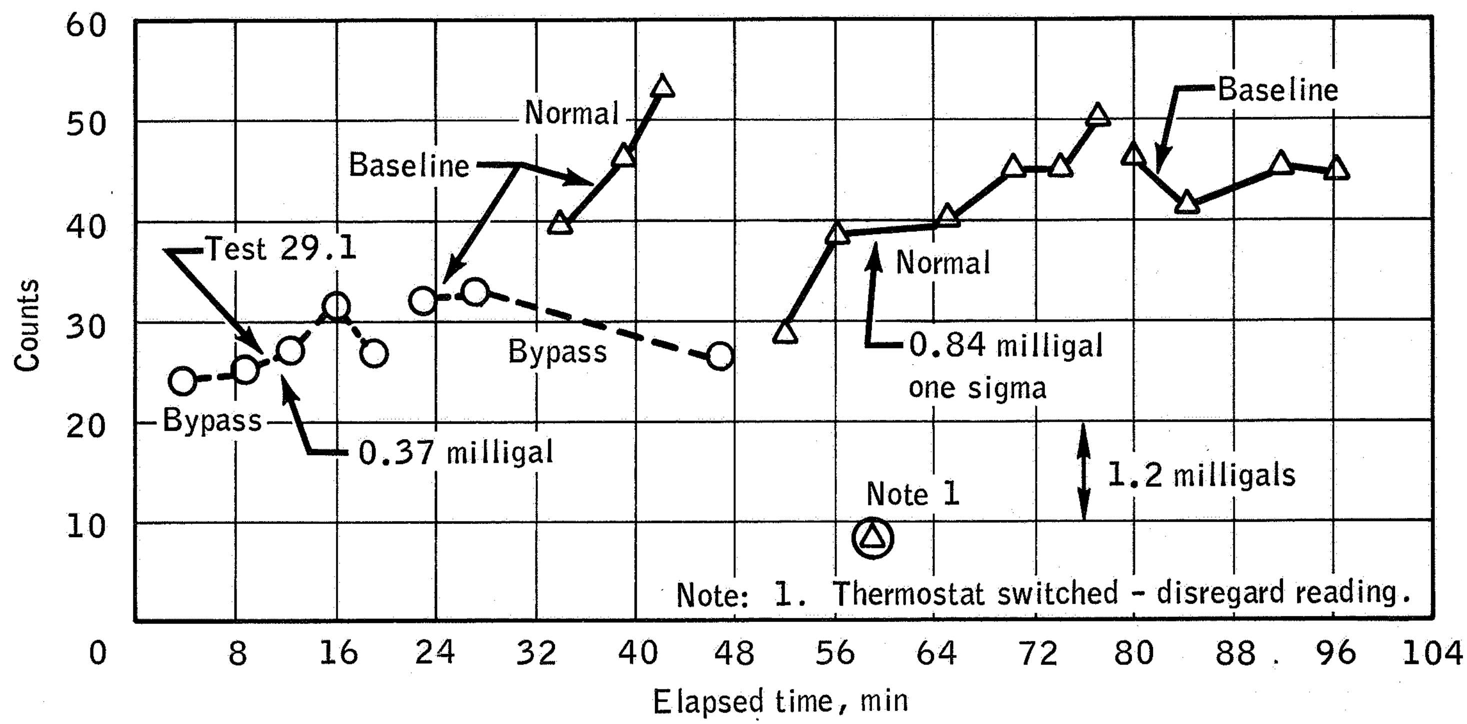


Figure 13.- Worse case camera elevation motions in test step 29.1.

In test step 29.2 the following sequence was used:

a. Position camera to 90° azimuth and +85° elevation (upper mechanical stop)

b. Command camera down for 5 seconds and stop, then initiate gravity measurements. Wait 86 seconds and proceed with next step

c. Command camera up to mechanical stop, then down for 5 seconds and stop. Wait 70 seconds and proceed to next step

d. Repeat camera motions in step c.

The data are shown in figure 14 with two bypass-mode baseline readings taken for bias shift check. The next five data points are bypass-mode readings, and yielded a one sigma of 0.168 milligal showing no apparent effect from the camera motions. A baseline check in the normal gravity mode followed. The next five data points were normal mode readings that produced a one sigma of 0.68 milligal. This indicates that driving the camera into the upper stop while taking gravity measurements had no apparent effect. Two normal/mode baseline measurements were then taken and showed a slight upward shift, which from previous data, appears to be normal drift for the test instrument and not caused by camera motions in this test.

The final test was as follows:

a. Initiate gravity measurement

b. Eighty six seconds later, bump lunar roving vehicle at the Lunar Module Pilot's seat.

The data are shown in figure 14 also for one measurement in the bypass mode and two measurements in the normal mode. In all cases, the effect of the bump resulted in a transient in the gravimeter that caused the instrument to relevel for several seconds. In bypass mode, the count changed by an equivalent of 2.8 milligals. In the normal gravity mode, the count changed by 1.6 milligals.

CONCLUSIONS

The test data indicate that the traverse gravimeter gravity measurements, as expected, will not be affected by the operation of the surface electrical properties experiment recorder.

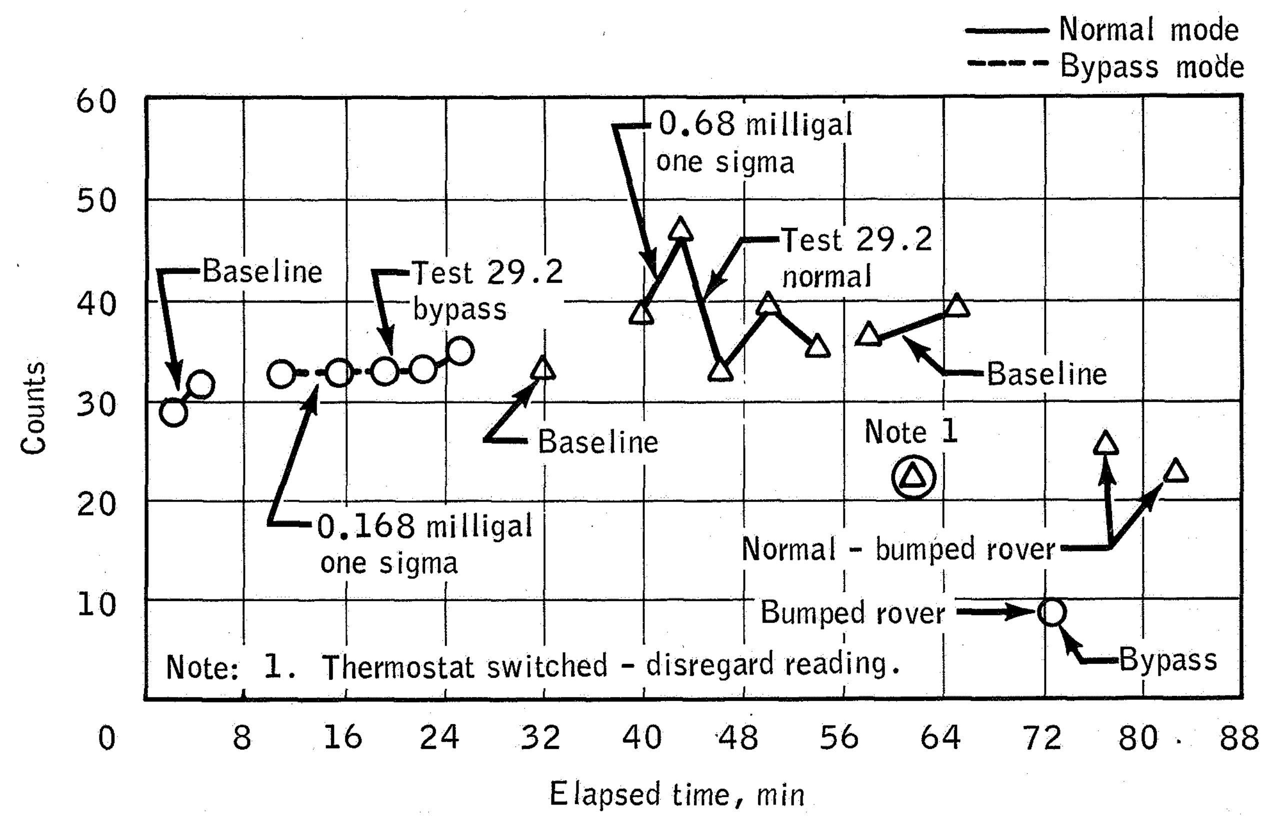


Figure 14.- Worse case camera elevation motions in test step 29.3 and rover bump test.

The test data indicate that the gravity measurements will not be affected by camera motions in azimuth and zoom.

Camera motions in elevation and bumping the lunar roving vehicle do affect the gravity measurement. Camera elevation motions with the camera positioned fore and aft induced motion at the traverse gravimeter experiment due to excitation of a 1.4-hertz pitch mode at the lunar roving vehicle and excitation of a 4-hertz mode at the pallet to which the experiment is attached. Although a large number of gravity measurements was obtained during the test, especially for camera elevation motions, the number of data points is insufficient to positively conclude that the camera motions will not affect the gravity measurements in any way. The data indicate, however, that the effects, if present, should be small, and will be caused by camera operations only in elevation.

The lunar roving vehicle bump test (final test) indicated that a disturbance of sufficient magnitude to cause the instrument to relevel will introduce a significant error in the gravity measurement. If the lunar roving vehicle is accidentally bumped while a gravity measurement is in progress, the measurement should be invalidated and repeated.

APPENDIX A

TASK OBJECTIVE

The objective of this task was to design and fabricate a support system to be used to alleviate 5/6 of the lunar roving vehicle weight such that the dynamic characteristics of the lunar roving vehicle in a 1-g environment would simulate those of a lunar roving vehicle in a 1/6-g (lunar surface) environment.

DESCRIPTION

The system used to support 5/6 of the earth weight of the lunar roving vehicle was constructed using 5/8-inch elastic cord manufactured per specification MIL-C-5651 type I. Four lengths of cord were attached to the lunar roving vehicle at four points and were supported from two overhead cranes. A load cell was included between the top of the elastic cord and the crane hook to monitor the amount of lunar roving vehicle weight being supported by the support system. The two cords attached to the forward end of the lunar roving vehicle were each 33 feet 4 inches long and the two cords attached to the aft end of the lunar roving vehicle were each 34 feet 6 inches long in the unloaded condition. When 5/6 of the lunar roving vehicle was being supported by the cord, the forward and aft cords were elongated to approximately 75 and 73 feet and carried loads of 325 pounds and 283 pounds, respectively.

Since the elastic cord had a high creep rate under sustained loads, steps were taken to reduce the creep rate to an acceptable level for the tests. This was accomplished prior to each activation of the support system by cycling the load in each elastic cord assembly approximately ±20 pounds about the anticipated sustained load.

EVALUATION OF SUPPORT SYSTEM

The support system design objective was to design the system with as high a compliance as was practicable. Design constraints included the maximum height available in the laboratory, availability of standard stock elastic cord, weight of the lunar roving vehicle, and acceptable attach points on the lunar roving vehicle chassis. The 5/8-inch elastic cord was chosen, based on load-elongation data in the specification (MIL-C-5651), to produce a total vertical stiffness of 3.25 pounds per inch when supporting 5/6 of the lunar roving vehicle weight. The elastic cord stiffness does not have an appreciable effect on the lateral and fore and aft modes of the lunar roving vehicle. These modes are primarily affected by the length of the pendulum which, in this case, produced a lateral and fore and aft stiffness of less than one pound per inch.

To verify the behavior of the as-delivered elastic cord, laboratory tests were conducted using samples of the elastic cord which were approximately two feet in length. These tests indicated that the stiffness was higher, but still acceptable, than that calculated using the specification data. After the lunar roving vehicle/traverse gravimeter equipment testing was completed, a bounce test with the lunar roving vehicle fully suspended on the elastic cord, was conducted to determine the natural frequency. The measured natural frequency was approximately twice that calculated using the data from the sample tests (0.4 Hz versus 0.18 Hz). As a result of the frequency (stiffness) discrepancy, load-deflection tests of the actual support system were conducted. Load-deflection data were taken at loads equivalent to 5/6 of the total lunar roving vehicle weight. The stiffness characteristics of the elastic cord subsequent to being cycled were significantly different than during the initial load application. Figures A-1 and A-2 are plots of the data from these tests. Measured stiffness of the forward and aft support assemblies were 4.12 and 2.97 pounds per inch, respectively, at the loads corresponding to 5/6 of the lunar roving vehicle weight. At loads corresponding to the full lunar roving vehicle weight, the stiffness was 5.54 pounds per inch and 3.89 pounds per inch for the forward and aft assemblies, respectively. The natural frequency calculated using the full weight stiffness correlates well with the measured, natural frequency of 0.4 hertz while fully suspended.

The increase in vertical stiffness from the original 3.25 pounds per inch to 7.1 (4.12 + 2.97) pounds per inch caused some concern as to the effect of the support system on the lunar roving vehicle/wheel modes. The only six-degree-of-freedom model available in-house was one MIT had used for traverse gravimeter experiment sensitivity studies. Although the model is not a totally accurate representation of the lunar roving vehicle, particularly with regard to lateral and fore and aft stiffnesses of the tires, it is adequate to assess the changes in natural frequencies and mode shapes caused by the elastic cord support system. The mass and stiffness matrices for the lunar roving vehicle, as well as the stiffness matrix for the support system, are shown in figure A-3. Modal analyses were performed with and without the additional stiffness of the support system. Results of these analyses are shown in figure A-4 and indicate insignificant changes in both the natural frequencies and mode shapes.

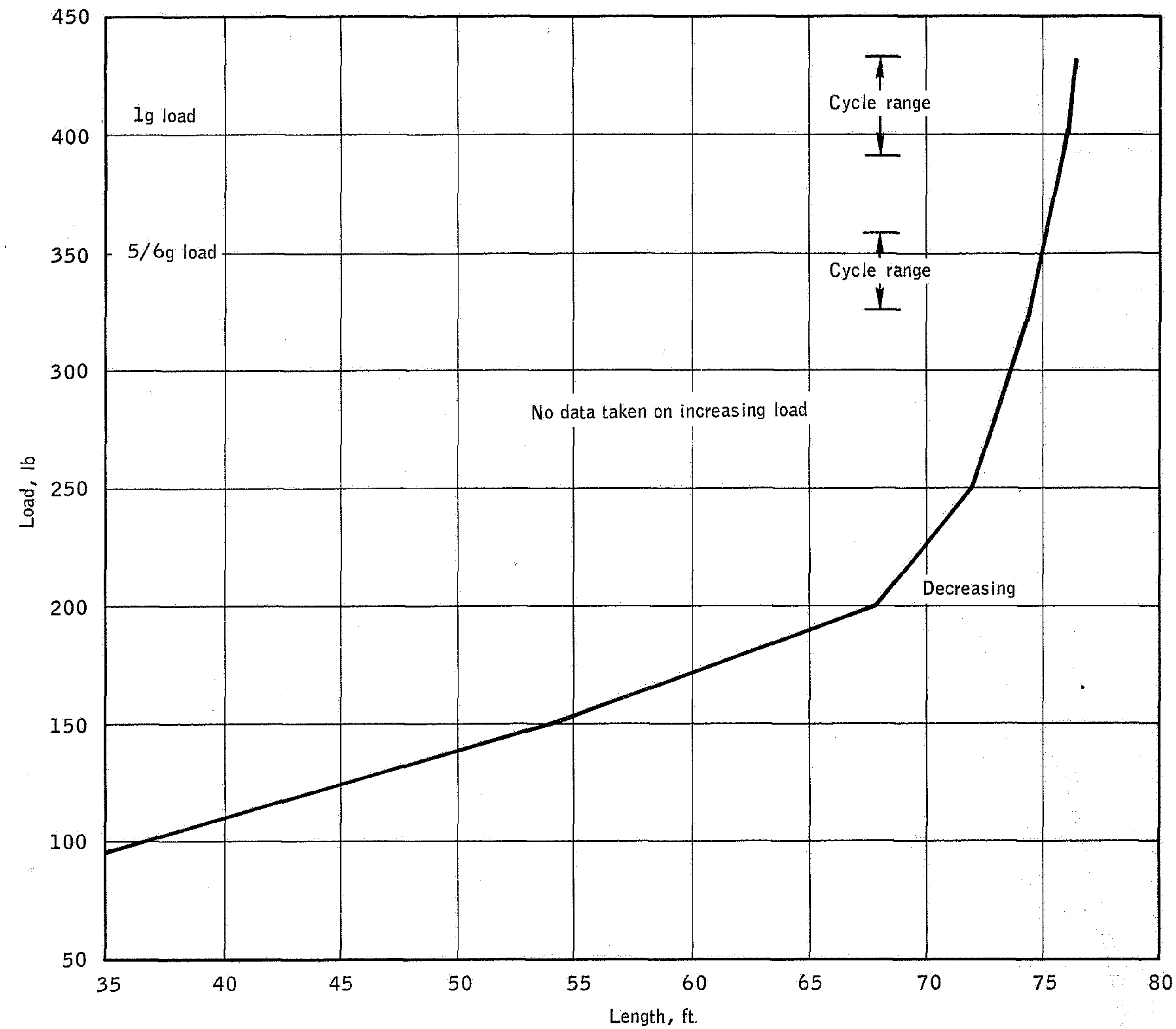


Figure A-1.- Lunar roving vehicle forward suspension cable.

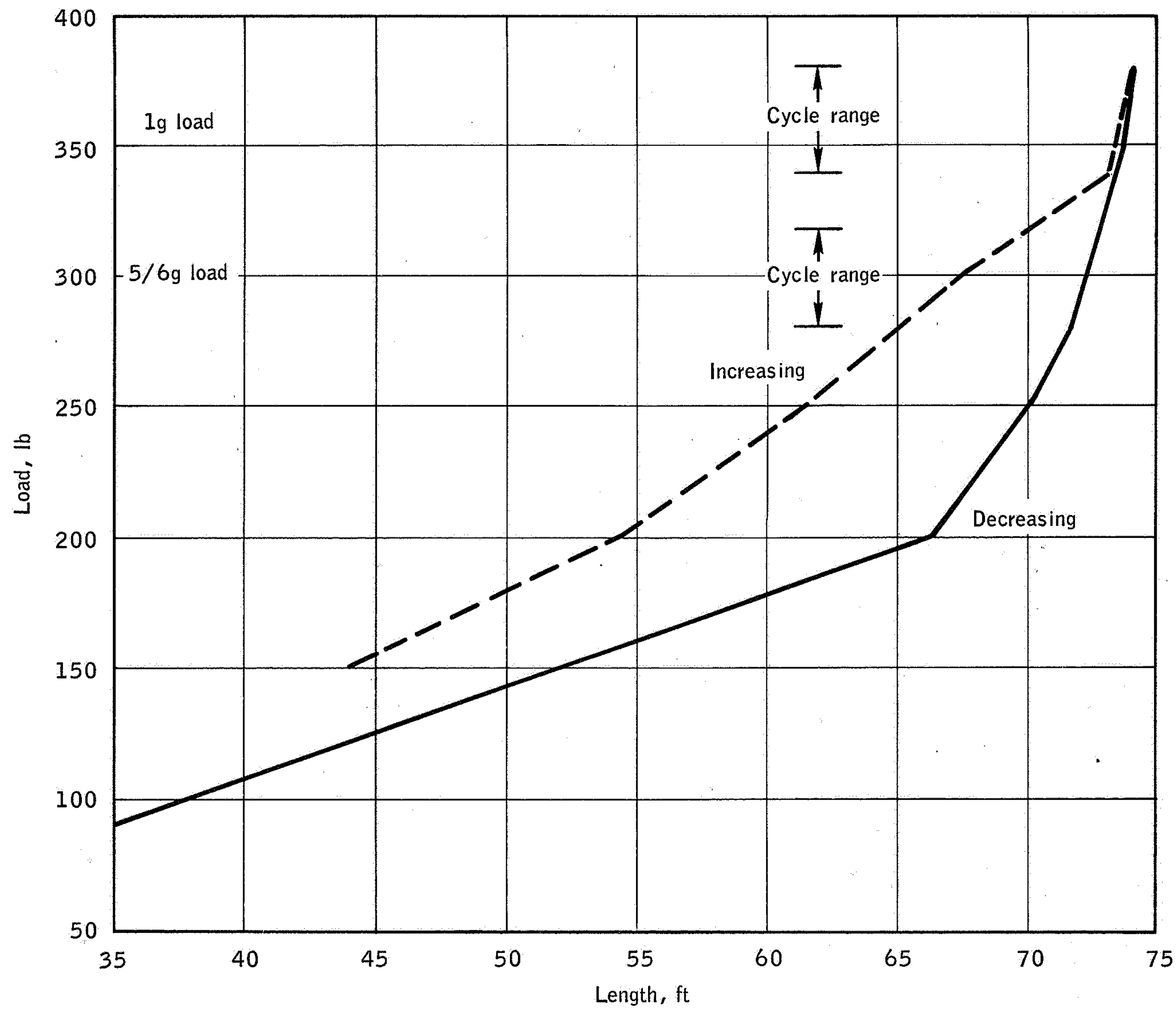


Figure A-2.- Lunar roving vehicle aft suspension cable.

Degrees of freedom		1	2	3	4	5	6
(K) = Lunar roving vehicle	1	1772	0	0	0	-1648	0
	2	0	1772	0	1648	0	-1551
	3	0	0	1772	0	1551	0
	4	0	1648	0	17 499	0	-1440
	5	-1648	0	1551	0	27 865	0
	6	0	-1551	0	-1440	0	29 061

Units: pounds, feet, and radians

Degrees of freedom		1	2	3	4	5	6
(M) = Lunar roving vehicle	1	21.8	0	0	0	0	0
	2	0	21.8	0	0	0	0
	3	0	0	21.8	0	0	0
	4	0	0	0	61.6	0	0
	5	0	0	0	0	282	0
	6	0	0	0	0	0	208

Units: slugs, and feet

Degrees of freedom

1. Fore and aft
2. Lateral
3. Vertical
4. Roll
5. Pitch
6. Yaw

Degrees of freedom		1	2	3	4	5	6
(K) = Support system	1	0	0	0	0	0	0
	2	0	0	0	0	0	0
	3	0	0	84	0	-25.95	0
	4	0	0	0	204.4	0	0
	5	0	0	-25.95	0	795.5	0
	6	0	0	0	0	0	0

Units: pounds, feet, and radians

Figure A-3.- Mass and stiffness matrices for the lunar roving vehicle and support system.

Analytical model without support system, mode no.; freq, Hz	Analytical model with support system, mode no.; freq, Hz
1. 1.232 (roll and lateral)	1. 1.255
2. 1.296 (roll, lateral and yaw)	2. 1.297
3. 1.435 (fore and aft, and bounce and pitch)	3. 1.454
4. 1.745 (fore and aft, and bounce)	4. 1.761
5. 1.905 (lateral, roll and yaw)	5. 1.906
6. 2.736 (fore and aft, and bounce and pitch)	6. 2.750

Mode shapes

Degrees of freedom/mode		1	2	3	4	5	6
Fore and aft	1	0.1857-16 0.1620-16	-0.6636-16 -0.2108-16	-0.9289-01 -0.8829-01	0.1468+00 0.1384+00	-0.3585-15 -0.5031-15	0.1253+00 0.1376+00
Lateral	2	0.4617-01 0.4550-01	-0.5095-01 -0.5136-01	0 0	-0.1522-14 0	-0.2028+00 -0.2029+00	0 0
Vertical	3	0.2807-16 0.2534-16	0.1004-15 0.3103-16	0.8742-01 0.9013-01	0.1560+00 0.1628+00	0.3234-14 0.1810-14	-0.1179+00 -0.1060+00
Roll	4	0.1236+00 0.1237+00	0.2071-01 0.2032-01	0.6950-17 0.3297-17	0.2524-15 0.5683-16	0.2294-01 0.2260-01	0.5083-15 0.2353-14
Pitch	5	0 0	0 0	0.4783-01 0.4812-01	0.3406-08 -0.3949-02	0 0	0.3547-01 0.3486-01
Yaw	6	-0.7702-02 -0.7524-02	0.6640-01 0.6640-01	0.2522-16 0.1182-16	0.1860-15 0.9565-16	-0.1843-01 -0.1849-01	-0.3939-15 -0.1893-14

Note:

Upper number is without support system.
Lower number is with support system.

Figure A-4.- Dynamic characteristics of the lunar roving vehicle with and without the support system.

CONCLUSIONS

A support system to simulate the lunar gravity environment for the lunar roving vehicle/traverse gravimenter equipment test was designed and built and had insignificant affect on the dynamic characteristics of the lunar roving vehicle. The maximum increase in any of the six lunar roving vehicle/wheel natural frequencies was less than 2 percent.

APPENDIX B

TEST OUTLINE

The following outline states the types of test operations and the order in which they were performed:

1.0 Baseline measurements

1.1 With a fully configured lunar roving vehicle resting on safety blocks, 3 normal-gravity mode and 3 bypass-mode measurements were recorded.

1.2 With the lunar roving vehicle suspended in the simulated lunar gravity environment, 3 normal-gravity mode and 2 bypass-mode measurements were recorded.

NOTE

Subsequent data indicated that this gravimeter required a periodic re-establishment of the baseline. Eventually, baseline measurements were taken before and after each new series of operations.

2.0 The surface electrical properties receiver/recorder was turned on and four successive normal-gravity mode measurements were recorded.

3.0 The ground-controlled television assembly camera color wheel was cycled on and off in the following manner (test step 7).

3.1 With the ground-controlled television assembly on, a normal-gravity mode measurement was initiated and the ground-controlled television assembly was turned off 90 seconds into the measurement cycle.

3.2 With the ground-controlled television assembly off, a normal-gravity mode measurement was initiated and the ground-controlled television assembly was turned on 90 seconds into the measurement cycle.

3.3 Items 3.1 and 3.2 were repeated.

3.4 A normal-gravity mode measurement was initiated and 90 seconds later, the ground-controlled television assembly was turned on for 20 seconds and then off.

3.5 Item 3.4 was repeated.

3.6 After external sources of vibration were shutdown, this series of ground-controlled television assembly commands was repeated.

4.0 The ground-controlled television assembly azimuth operations were performed as follows (test step 8):

4.1 A normal-gravity mode measurement was initiated and 90 seconds into the measurement cycle, the camera was panned right from the forward position until the mechanical stop was reached.

4.2 The procedure was repeated with the camera panning to the left.

4.3 Items 4.1 and 4.2 were repeated.

4.4 The camera was positioned 45° from the left stop and panned into the stop during a normal-gravity mode measurement cycle. This item was repeated.

4.5 The camera was panned twice from right to left stops in 10-second increments, then panned twice in the opposite direction.

4.6 The camera was panned twice from left to right stops in 10-second increments during two bypass-mode measurements (test step 8.8).

4.7 Upon completion of the azimuth operations, two bypass-mode measurements and one normal gravity mode measurement were made to verify the baseline.

5.0 The ground-controlled television assembly elevation motions were checked approximately 140 seconds after initiating each normal gravity mode measurement as follows (test step 9):

5.1 The camera was commanded up from the -45° position (test step 9.1).

5.2 The camera was commanded down from the +85° position.

5.3 The camera was commanded up from 0° elevation to +85°.

5.4 The camera was commanded down from +85° to 0°.

5.5 The camera was commanded down from 0° to -45°.

5.6 The camera was commanded up in 10-second increments from -45° to +85° (test step 9.6).

5.7 The camera was commanded down in 10-second increments (test step 9.7).

5.8 A series of three normal-gravity mode and one bypass-mode measurement was recorded to check the baseline mode.

5.9 Items 5.6 and 5.7 were repeated in the bypass mode.

6.0 Zoom and iris commands were accomplished during both the normal-gravity mode and bypass-mode measurement cycles (test step 10).

7.0 Ninety seconds after initiating a gravity measurement, the camera was commanded in 10-second bursts in azimuth alternating with 10-second bursts in elevation. Azimuth travel was maintained between 0° and 90° at all times (test step 11).

7.1 Ninety seconds after initiated a gravity measurement, the camera was commanded in 10-second bursts in azimuth in conjunction with 10-second bursts in elevation.

7.2 Item 7.1 was repeated while performing zoom commands also.

7.3 Item 7.1 was repeated, but the camera commands were started immediately after initiation of the gravity measurement.

7.4 A series of 3 normal-mode gravity and 2 bypass-mode baseline measurements was taken.

8.0 Ground-controlled television assembly on/off test in the bypass mode were repeated (test step 21).

NOTE

A review of the data indicated that the normal-gravity mode in this gravimeter appeared to be noisier than anticipated. Since this could have influenced the greater than one sigma deviation recorded for the ground-controlled television assembly elevation operations, steps 4.0 and 5.0 were repeated while operating the gravimeter in the bypass mode. This would eliminate the effect of the phase-lock-loop circuitry on the measurements.

8.1 A series of four normal-gravity mode and five bypass-mode measurements were recorded to establish a baseline.

8.2 The ground-controlled television assembly on/off testing in the bypass mode was performed.

9.0 The azimuth test was initiated, but lunar roving vehicle shock mounted dampers were locked (test step 22).

9.1 Lunar roving vehicle dampers were unlocked and a series of six bypass measurements were recorded to reestablish the baseline.

9.2 The azimuth tests were repeated in the bypass mode.

10.0 The elevation tests were run in the following manner (test step 23).

10.1 A series of eight bypass-mode measurements was recorded to establish a baseline.

10.2 The elevation tests were repeated in the bypass mode.

11.0 Further elevation tests were performed to determine the effects of moving the camera through a +15° to -15° area where most of the pans would occur (test step 24).

11.1 A bypass-mode measurement was initiated and 90 seconds later, the ground-controlled television assembly began driving in elevation to -15° then to +15° maintaining 0° azimuth. This test was repeated until the end of the measurement cycle.

11.2 Item 11.1 was repeated.

11.3 Item 11.1 was repeated twice with azimuth at +90°.

11.4 Item 11.1 was repeated twice with azimuth at +180°.

11.5 Item 11.1 was repeated twice with azimuth at -270°.

11.6 Two bypass-mode baseline measurements were recorded.

12.0 A bypass-mode measurement was initiated and 90 seconds later, removal of a collection bag from the aft pallet was simulated by disconnecting a collection bag strap (test step 25).

12.1 Item 12.0 was repeated.

12.2 Four bypass-mode baseline measurements were recorded.

13.0 The ground-controlled television assembly was exercised through approximately twenty-five different motions while data were evaluated for worse case lunar roving vehicle dynamics. The three worse case television operations were selected and were repeatedly initiated at the beginning and end of the gravimeter counting cycle when the instrument was believed to be most susceptible to vibration-induced errors. At least 5 measurements in the normal-gravity mode and 5 measurements in bypass mode were made for every case, varying the initiation points by one second each time (test step 27).

13.1 Five normal-gravity mode and 5 bypass-mode measurements were recorded to establish a baseline (test step 28).

13.2 A gravity measurement was initiated with the ground-controlled television assembly azimuth at 0°. After a delay about 86 seconds, elevation was commanded to -15° then back to zero. About 70 seconds later, the command sequence was repeated (test step 29.0).

13.3 Three bypass-mode and 4 normal-gravity mode measurements were recorded for baseline data.

13.4 While maintaining the ground-controlled television assembly azimuth at zero degrees and elevation at -45°, a gravity measurement was initiated. After a delay of about 81 seconds, elevation up was commanded for five seconds, then stopped, and returned to -45°. About 70 seconds later, the command sequence was repeated (test step 29.1).

13.5 Two bypass-mode baseline measurements were recorded.

13.6 While the ground-controlled television assembly azimuth was maintained at 90° and the elevation five seconds travel time down from +85°, a gravity measurement was initiated. After a delay of about 86 seconds and elevation commanded up to the stop, the elevation was returned down for 5 seconds. About 70 seconds later, the command sequence was repeated (test step 29.2).

14.0 A gravity measurement was initiated and 86 seconds later, the lunar roving vehicle was bumped in the Lunar Module Pilot seat area. This was performed once during a bypass-mode measurement and twice during a normal-gravity mode measurement.