



**Aerospace
Systems Division**

APOLLO 15 PSE ANOMALIES

ATM-1062

PAGE 1 OF 28

DATE 15 Nov 1971

This ATM presents the results of the Apollo 15 PSE
Anomalies Investigation.

Prepared by:

L. Hogeboom
L. Hogeboom

D. K. Breseke
D. K. Breseke

Approved by:

W. Tosh
W. Tosh



**Aerospace
Systems Division**

APOLLO 15 PSE ANOMALIES

ATM-1062

PAGE 2 OF

DATE

1.0 INTRODUCTION

All scientific measurements of the Apollo 15 Passive Seismic Experiment are being performed within the requirements of its specification. However, three anomalous conditions have been noted:

1. The initial leveling operation of the horizontal long period seismometers (X and Y) appeared to require an unusual length of time.
2. The magnitude of the calibration pulse applied by command to the vertical long period seismometer (Z) is larger than the value to which it was adjusted during acceptance testing.
3. The temperature variation of the sensor assembly from lunar day to lunar night is within specification but greater than expected.



**Aerospace
Systems Division**

APOLLO 15 PSE ANOMALIES

ATM-1062

PAGE 3 OF

DATE

2.0 LONG PERIOD SEISMOMETER LEVELING

2.1 Anomaly Description

The PSE horizontal long period seismometers (X, Y and Z) are initially leveled by commanding on the leveling motors and observing the seismometer response as displayed in the Control Center at Houston. The Apollo 15 PSE X and Y axes appeared to require an extensive period of time to initially level each axis. Leveling was accomplished by repeated commands using both forced and automatic modes.

2.2 Anomaly Cause

Review of the available data indicates that the problem of extended leveling time was caused by: (1) the method with which the initial leveling was accomplished on the Y axis and (2) either an operational or hardware malfunction on the X axis. To avoid recurrence of the Y problem, a definite pattern should be utilized to complete the leveling operation. The uplink and downlink signal transmission and processing time should be considered in the leveling process.

From the data available for this report, it appears that on two occasions excessive time was required to drive the X axis to its center position. An operational malfunction, that is, motor drive commands logged but not actually reaching the PSE would give the appearance of excessive drive time. The second possibility is that the X axis is a "sticking" seismometer and several drive commands were required to break the boom free.

2.3 Analysis

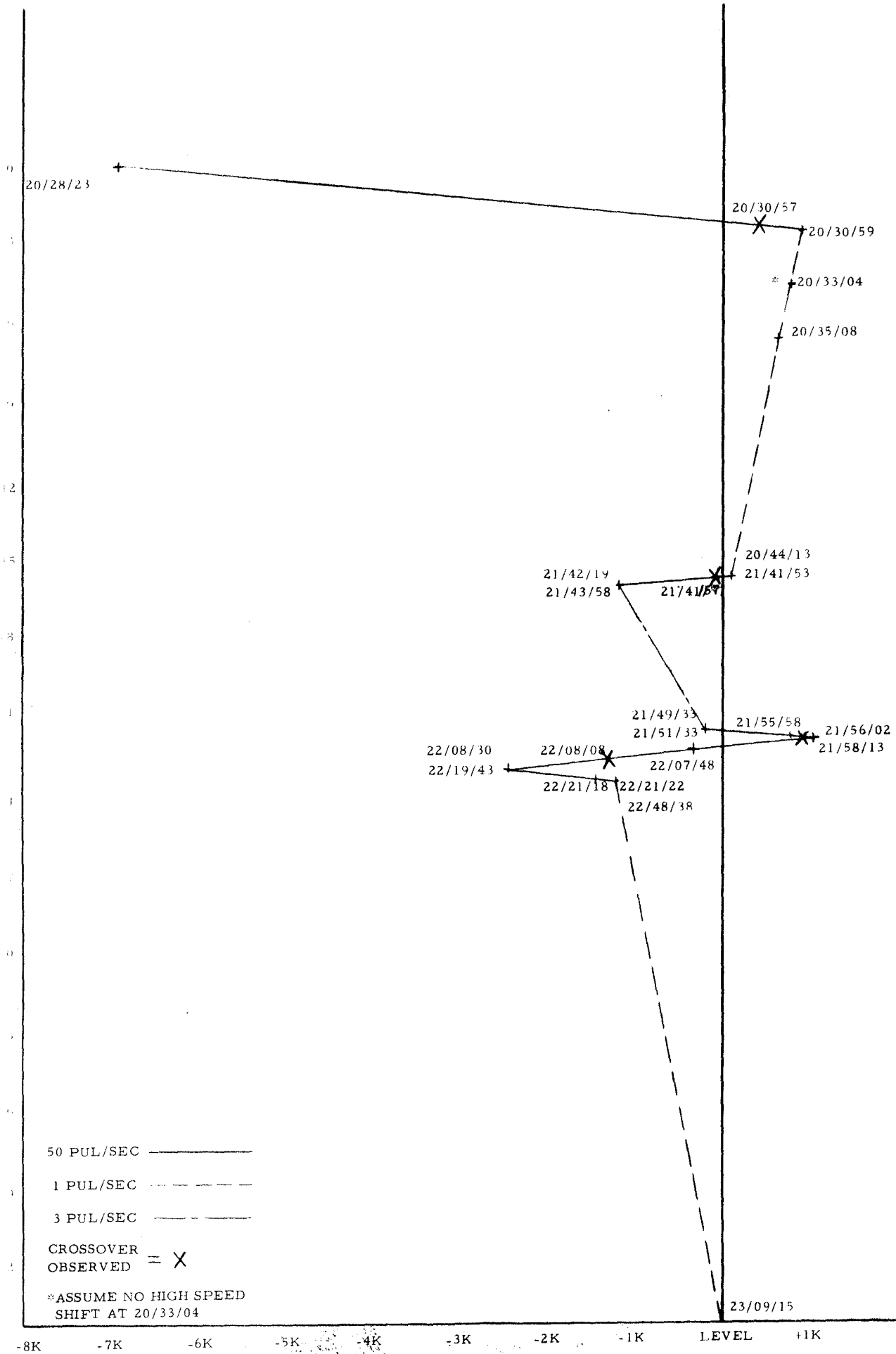
The long period X and Y axis leveling problem was evaluated from mission records and science data chart recordings. These data, plotted on charts representing each of the three axes, were produced by starting from the point at which leveling was achieved and working back in time to the point at which the first command was received. See Figures 2-1, 2-2 and 2-3. At this point the original position of the mass with respect to center can be seen.

FIG 2-1

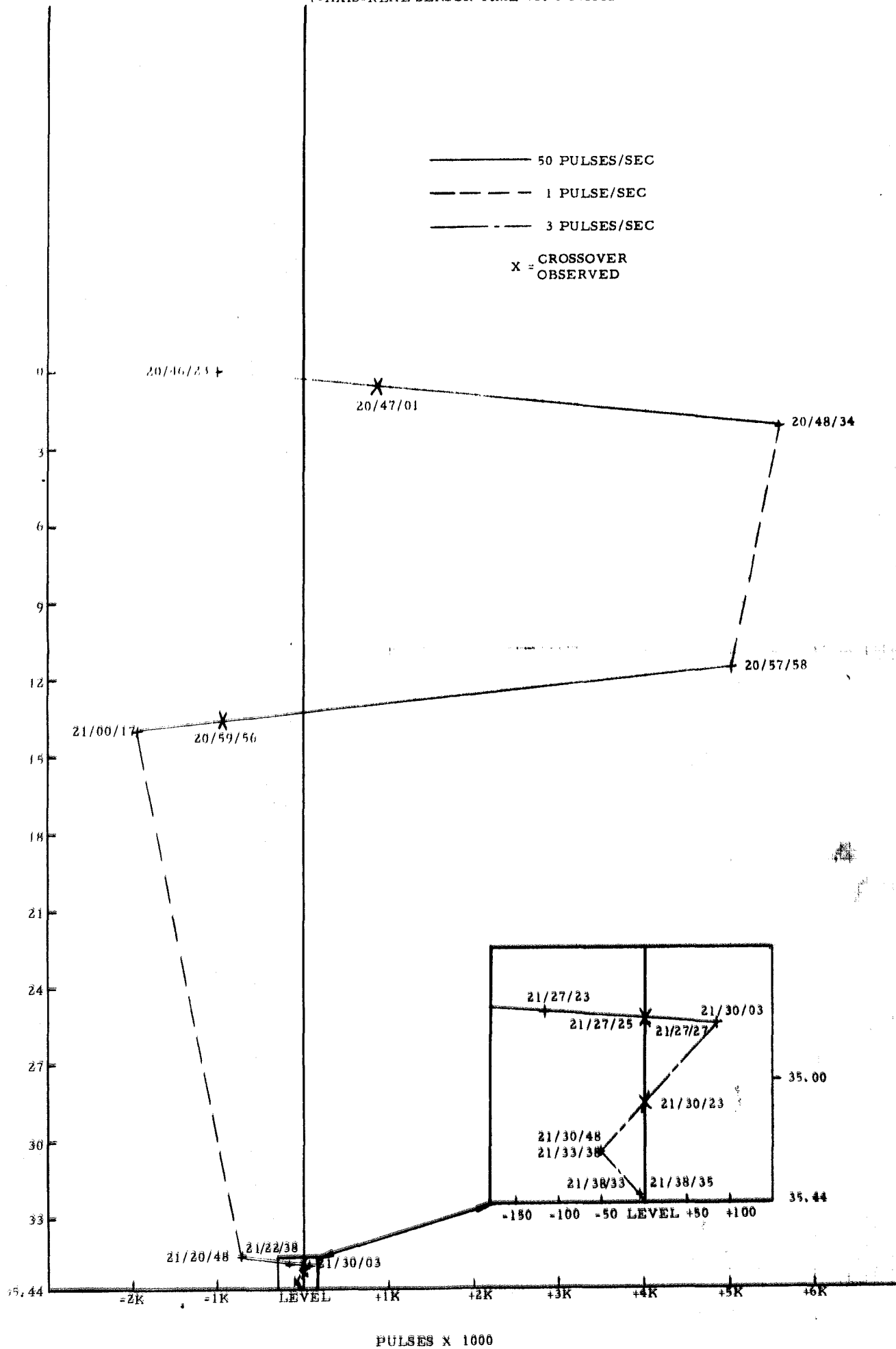
ATM-1062

Page 4

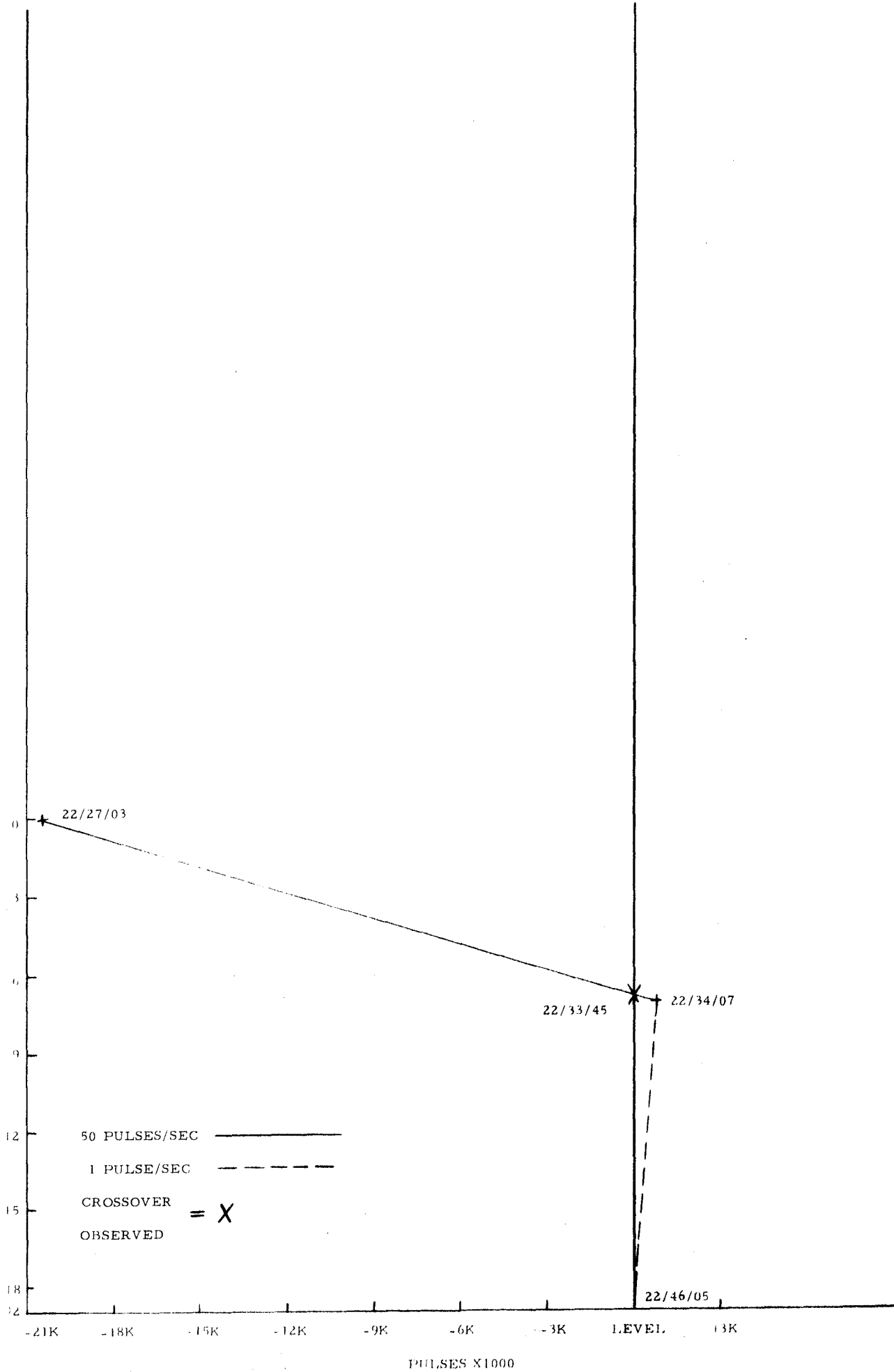
X AXIS-REAL SENSOR TIME VS. POSITION



Y-AXIS-REAL SENSOR TIME VS. POSITION



Z-AXIS - REAL SENSOR TIME VS. POSITION





**Aerospace
Systems Division**

APOLLO 15 PSE ANOMALIES

ATM-1062

PAGE 7 OF

DATE

The diagrams present the logged leveling Motor On time in minutes versus the input pulses which indicate approximate distance in relation to level. The long period Z axis, having no anomaly, was used as a basis for evaluating the long period X and Y axes.

Assuming no operational difficulties Tables 2-1, -2 and -3 indicate the times at the sensor (assuming a total signal processing and transmission time of three seconds for the uplink and six seconds for the downlink) at which commands were received and leveling sequences occurred. Motor speed is noted as 50 pulses per second for forced-mode (high speed) and for course-in (high speed), 3 pulses per second for forced-mode (low speed) and 1 pulse per second for course-out (low speed) and course-in (low speed).

The sequence followed in leveling both the X and the Y seismometers was to drive in auto-mode, coarse sensor-in until crossover occurred and then command the coarse sensor-out. Driving with coarse sensor out resulted in an extended time at low speed, not returning the seismometers to a level condition. Thus, the required time for leveling the Y axis was actually correct and the leveling system, command functions and motor drive functioned as designed.

Two events of the X axis leveling sequence have not been explained. The motor was driven, intermittently from 21/51/33 to 21/56/02 with a leveling position reached momentarily at 21/55/58. This time appears unusually late. The following sequence with level crossover at 22/08/08 similarly appears very late. However, the total sequence of the leveling process, as shown by Figure 2-1, appears to be a normal, continuous pattern.

2.4 Recommendations

On subsequent missions if this leveling procedure is followed, additional time should be allowed for driving in auto, coarse-out; the low speed mode. An alternate method of leveling would be to follow the initial crossover with a motor power off command, drive the seismometer back in high speed, forced mode for a time estimated equal to motor off command transmission time and then complete leveling in the auto mode, course sensor out. This alternate method will result in a shorter motor drive time but will require the transmitting of additional commands.

TABLE 2-1

X AXIS OPERATIONS

| EVENT | EARTH TIME | LUNAR TIME | RUNNING TIME | X | RATE | = | PULSES |
|---------------------|---------------|---------------|-----------------|---|-------|---|----------|
| MOTOR ON HIGH SP. | 20/28/20 | 20/28/23 | | | | | |
| CROSSOVER (+) | 20/31/03 | 20/30/57 | 2:36 | X | 50P/S | = | 7800 (+) |
| SHIFT TO LO SPEED | 20/31/05 | 20/30/59 | 2:05 | X | 1P/S | = | 125 (-) |
| SHIFT TO HI SPEED | 20/33/10 | 20/33/04 | 2:04 | X | 1P/S | = | 124 (-) |
| COURSE OUT | 20/35/05 | 20/35/08 | | | | | |
| X MOTOR OFF | 20/44/10 | 20/44/13 | 9:05 | X | 1P/S | = | 545 (-) |
| X MOTOR ON HI SPEED | 21/41/50 | 21/41/53 | | | | | |
| CROSSOVER (-) | 21/42/03 | 21/41/57 | :26 | X | 50P/S | = | 1300 (-) |
| X MOTOR OFF | 12/42/16 | 21/42/19 | | | | | |
| X MOTOR ON LO SP. | 21/43/55 | 21/43/58 | 5:35 | X | 3P/S | = | 1005 (+) |
| X MOTOR OFF | 12/49/30 | 21/49/33 | | | | | |
| X MOTOR ON HI SP. | 21/51/30 | 21/51/33 | :22 | X | 50P/S | = | 1000 (+) |
| X MOTOR OFF | 21/55/29 | 21/55/32 | | | | | |
| X MOTOR ON HI SP. | 21/55/55 | 21/55/58 | :04 | X | 50P/S | = | 200 (+) |
| CROSSOVER (+) | 21/56/01 | 21/55/58 | | | | | |
| X MOTOR OFF | 12/55/59 | 21/56/02 | | | | | |
| X MOTOR ON HI | 21/58/10 | 21/58/13 | :27 | X | 50P/S | = | 1350 (-) |
| X MOTOR OFF | 22/05/45 | 22/05/48 | | | | | |
| X MOTOR ON HI | 22/07/45 | 22/07/48 | :42 | X | 50P/S | = | 2100 (-) |
| CROSSOVER (-) | 22/08/14 | 22/08/08 | | | | | |
| X MOTOR OFF | 22/08/27 | 22/08/30 | | | | | |
| X MOTOR ON HI | 22/19/40 | 22/19/43 | :20 | X | 50P/S | = | 1000 (+) |
| X MOTOR OFF | 22/20/00 | 22/20/03 | | | | | |
| X MOTOR ON HI | 22/21/15 | 22/21/18 | :04 | X | 50P/S | = | 200 (+) |
| X MOTOR OFF | 22/21/19 | 22/21/22 | | | | | |
| X MOTOR ON AUTO | 22/48/35 | 22/48/38 | 20:37 | X | 1P/S | = | 1237 (+) |
| X TIDE ON SCALE | 23/09/21 | 23/09/15 | | | | | |

TABLE 2-2

Y AXIS OPERATIONS

| EVENT | EARTH TIME | LUNAR TIME | RUNNING TIME | X | RATE | = | PULSES |
|----------------------|---------------|---------------|-----------------|---|--------|---|-----------|
| Y MOTOR ON - H. S. | 20/46/20 | 20/46/23 | | | | | |
| CROSSOVER (+) | 20/47/07 | 20/47/01 | > 2:11 | X | 50P/S | = | 6.550 (+) |
| LO SPEED | 20/48/40 | 20/48/34 | | | | | |
| COURSE OUT | 20/53/50 | 20/53/53 | > 9:24 | X | 1P/S | = | 564 (-) |
| (-) DIR. H. S. M. M. | 20/57/55 | 20/57/58 | | | | | |
| CROSSOVER (-) | 21/00/02 | 20/59/56 | > 2:19 | X | 50 | = | 6.950 (-) |
| AUTO MODE | 21/00/14 | 21/00/17 | | | | | |
| (+) DIR. | 21/19/35 | 21/19/38 | > 20:31 | X | 1P/S | = | 1,231 (+) |
| Y MOTOR OFF | 21/20/45 | 21/20/48 | | | | | |
| Y MOTOR ON M. M. | 21/22/35 | 21/22/38 | > :12 | X | 500P/S | = | 600 (+) |
| Y MOTOR OFF | 21/26/45 | 21/26/48 | | | | | |
| Y MOTOR ON | 21/27/20 | 21/27/23 | > :04 | X | 50P/S | = | 200 (+) |
| CROSSOVER (+) | 21/27/31 | 21/27/25 | | | | | |
| Y MOTOR OFF | 21/27/24 | 21/27/27 | | | | | |
| DIR. LO SP. | | | | | | | |
| Y MOTOR ON | 21/30/00 | 21/30/03 | > :45 | X | 3P/S | = | 135 (-) |
| CROSSOVER (-) | 21/30/29 | 21/30/23 | | | | | |
| Y MOTOR OFF | 21/30/45 | 21/30/48 | | | | | |
| (+) DIR. LO SP. | | | | | | | |
| Y MOTOR ON | 21/33/35 | 21/33/38 | > :16 | X | 3P/S | = | 48 (+) |
| Y MOTOR OFF | 21/36/30 | 21/36/33 | | | | | |
| (+) DIR. LO SP. | 21/38/30 | 21/38/33 | > :02 | X | 1P/S | = | 2 (+) |
| Y TIDE ON SCALE | 21/38/41 | 21/38/35 | | | | | |

TABLE 2-3

Z AXIS OPERATIONS

| EVENT | EARTH TIME | LUNAR TIME | RUNNING TIME | X | RATE | = | PULSES |
|-----------------|---------------|---------------|-----------------|---|-------|---|------------|
| Z MOTOR ON | 22/27/00 | 22/27/03 | 7:04 | X | 50P/S | = | 21,200 (+) |
| CROSSOVER (+) | 22/33/51 | 22/33/45 | | | | | |
| AUTO MODE | 22/34/04 | 22/34/07 | 11:58 | X | 1P/S | = | 718 (-) |
| Z TIDE ON SCALE | 22/46/11 | 22/46/05 | | | | | |



**Aerospace
Systems Division**

APOLLO 15 PSE ANOMALIES

ATM-1062

PAGE 11 OF

DATE

A more detailed analysis of the data recorded during the X axis leveling sequence should be performed. This analysis hopefully will establish whether or not the X motor was actually driving in response to each command logged. A high speed recording of the sequence is required for analysis so that the X motor drive pulses can be verified on the response of the Short Period Seismometer (SPZ). The SPZ record was unusually noisy during the leveling operations, due to the presence of the crew, making interpretation of the motor pulses difficult.

If it is determined that the Apollo 15 LPX seismometer performed as a "sticky" instrument during initial leveling, recommendations for this condition must be considered. The point at which the anomaly occurred is off-level to an extreme that is not an area of normal operation: it is not anticipated that further Apollo 15 LPX operations will be performed in this area. However, should the X axes be driven to this point by transient commands (leveling mode and power), repeated motor commands should be used to free the seismometer.

The leveling operation of subsequent instruments has been verified in test: no further action is required on the units.

3.0 LPZ CALIBRATION PULSE

3.1 Anomaly Description

The long period vertical seismometer calibration pulse, used to determine the instrument's response (parameters of feedback, natural period and damping), is larger than normal. The degree of increase, estimated to be a factor of 5, is constant over the 4 amplifier gain settings. Instrument response can be determined from the larger calibration pulse but requires additional data processing.

3.2 Anomaly Cause

Failure modes of the calibration circuit were analyzed by both lab model tests and examination of the circuit schematics and physical layout. The fault has been isolated to an open resistor.

3.3 Analysis

The LPZ calibration pulse, +2.5V, is generated within the PSE CSE, attenuated in the calibration circuit network (attenuated to correspond with the LPZ output amplifier gain) and is applied to the seismometer feedback coil. The response of the seismometer to the calibration pulse is seen through the normal science data output circuit. These related circuits are shown in the sketch of Figure 3-1 (reference schematics 234376, 234541, 234616 and 234385).

Areas considered for the cause of the anomaly were:

1. The portion of the feedback loop associated with the calibration pulse.
2. The LPZ output circuitry.
3. The calibration circuit located in the CSE.
4. The calibration circuit located in the sensor.

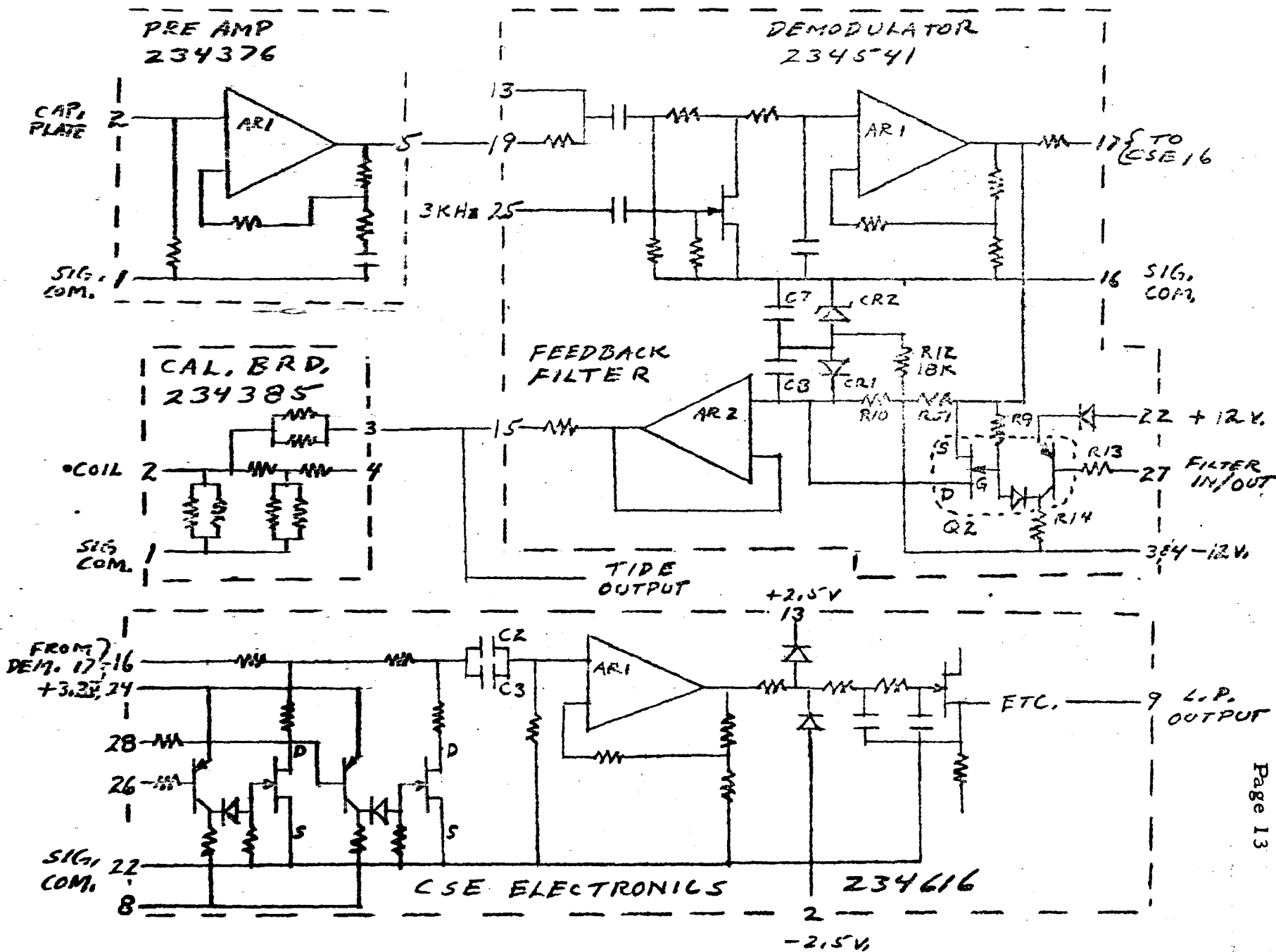


FIGURE 3-1

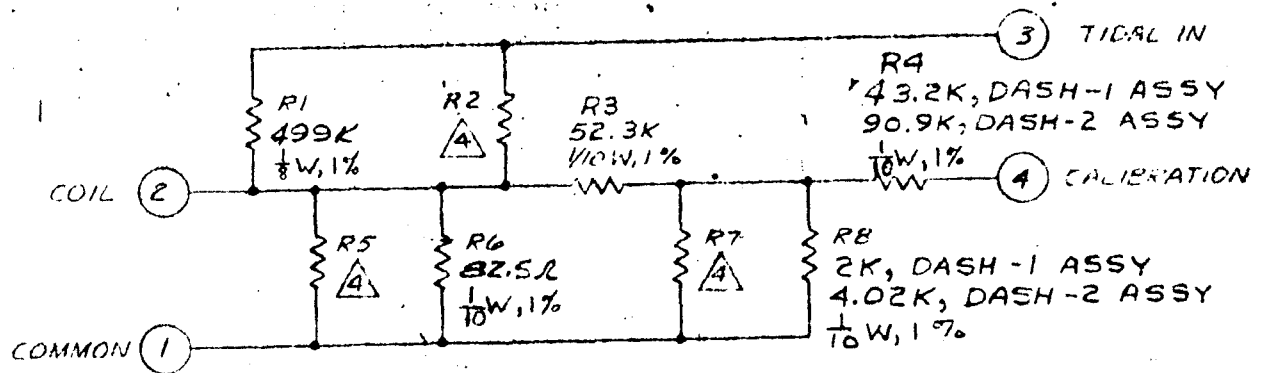
Items (1) and (2) were eliminated as the source of the anomaly based on the apparent proper response (feedback, gain, natural period and damping) of the LPZ seismometer to activity simultaneously detected by the horizontal seismometers. The attenuator network of the calibration circuit located within the CSE was also eliminated since the anomaly existed at all LPZ gain setting. The remaining section of the circuit is shown in Figure 3-2, which shows both the schematic and the physical layout of the circuit.

Analysis of the calibration circuit of Figure 3-2 shows:

1. A change in the circuit of R_1 , R_2 , R_3 , R_5 or R_6 would affect the LPZ feedback and/or damping.
2. An open in R_7 , a trim resistor of 12K in sensor SN 01, would increase the magnitude of the cal pulse by a factor of approximately 1.2 (the divider ratio of the R_7 R_8 combination to the total R_7 R_8 R_4 combination changes from $\frac{1.7}{44.9}$ to $\frac{2.0}{45.2}$).
3. An open in R_8 would increase the magnitude of the cal pulse by a factor of approximately 5.7 ($\frac{1.7}{44.9}$ to $\frac{12}{55.2}$).
4. A short in R_4 would increase the magnitude of the cal pulse by a factor of approximately 26.4 ($\frac{1.7}{44.9}$ to 1) neglecting the change in loading of the CSE output circuit.

Significant points in the normal assembly and test sequence of the LPZ calibration circuit are:

1. Pre-ATP T-13069
 - Base Line Impedance Test
 - Test to determine proper value of trim resistor, R_7
 - Install trim resistor.



SCHEMATIC

TRIM VALUES APOLLO 15
 $R2 = 2.4 \text{ MEG.}$
 $R5 = 820 \text{ OHM}$
 $R7 = 12 \text{ K OHM}$

DASH-1 = LPZ
 DASH-2 = LPX5Y

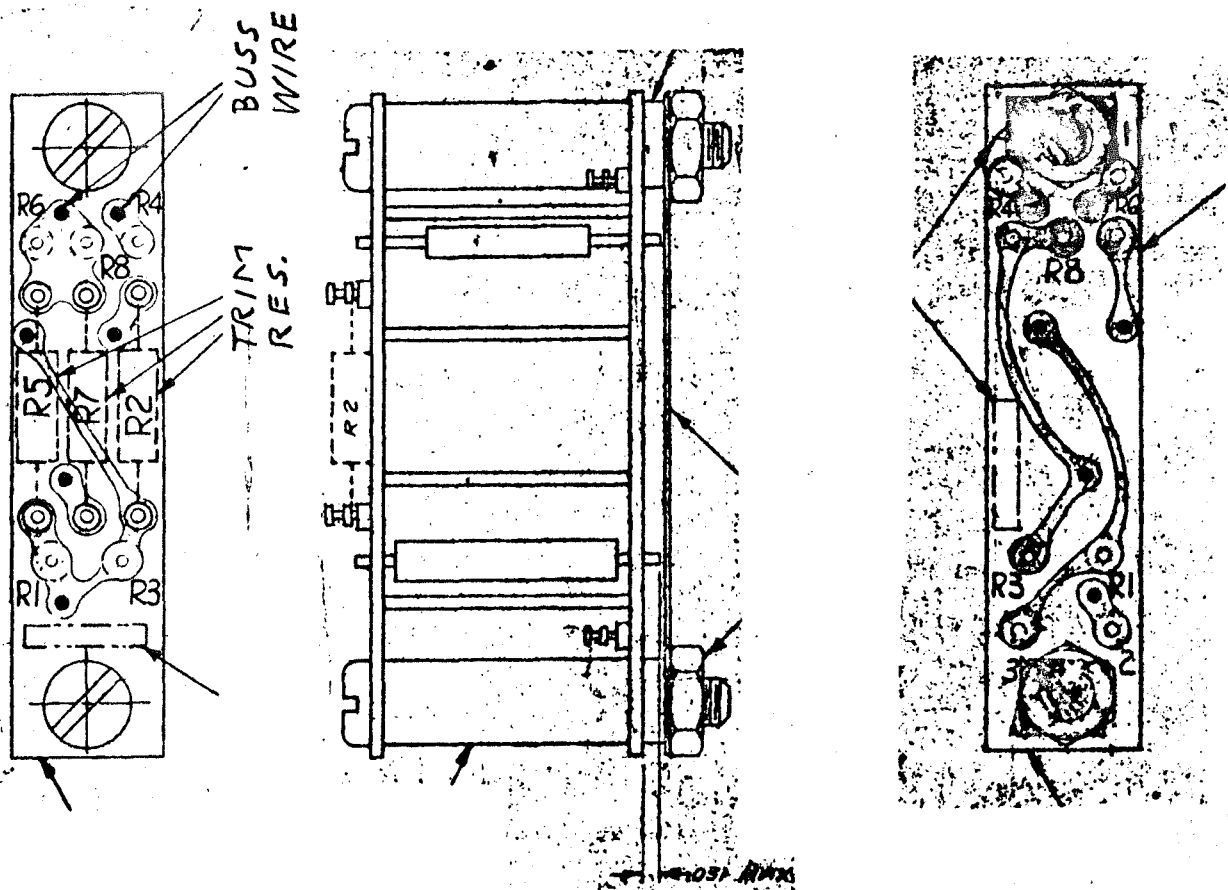


FIGURE 3.2



**Aerospace
Systems Division**

APOLLO 15 PSE ANOMALIES

ATM 1062

PAGE 16 OF

DATE

2. ATP 2338848

- . Impedance test of sensor connectors after vibration

3. PIA 2333019

- . Verify cal circuit up to and including R_4

Examination of the documentation of sensor SN 01 indicates that the impedance test of the Pre-ATP was repeated due to rework of other sensor subsystems. At this test there is an increase in calibration circuit impedance over previous tests (Nominal 45K to 50K). Comparing these results with the analysis of the calibration circuit would indicate a probable open in R_8 resistor. An open in R_8 would produce an impedance of 55.2K.

3.4 Recommendations

No correction action can be implemented by command of the Apollo 15 sensor SN01, nor is any required since the fault does not degrade the science data. The test data of sensor SN08 has been reviewed and the ATP impedance test verifies proper resistor values. The SN08 calibration performance will be verified during thermal characterization by variation to the test procedure. Sensor SN03, in process, will also be verified by performing a calibration pulse test during the ATP.



**Aerospace
Systems Division**

APOLLO 15 PSE ANOMALIES

ATM-1062

PAGE 17 OF

DATE

4.0 SENSOR THERMAL CONTROL

4.1 Anomaly Description

During the first lunar cycle following deployment, the PSE sensor temperature ranged from 128.3°F at lunar noon to 113.3°F at lunar night. The thermal control specification for the sensor temperature is:

Design Requirement = $T \pm 18^{\circ}\text{F}$

Design Goal = $T \pm 0.36^{\circ}\text{F}$

Where T is the set point temperature, approximately 125°F. This control is achieved by: (1) a proportional heater within the sensor, and (2) thermal insulation from the lunar environment by the thermal shroud. Performance of the instrument of Apollo 14 indicated that temperature control of $T + 4.0^{\circ}\text{F}$ to $T - 1^{\circ}\text{F}$ is nominal.

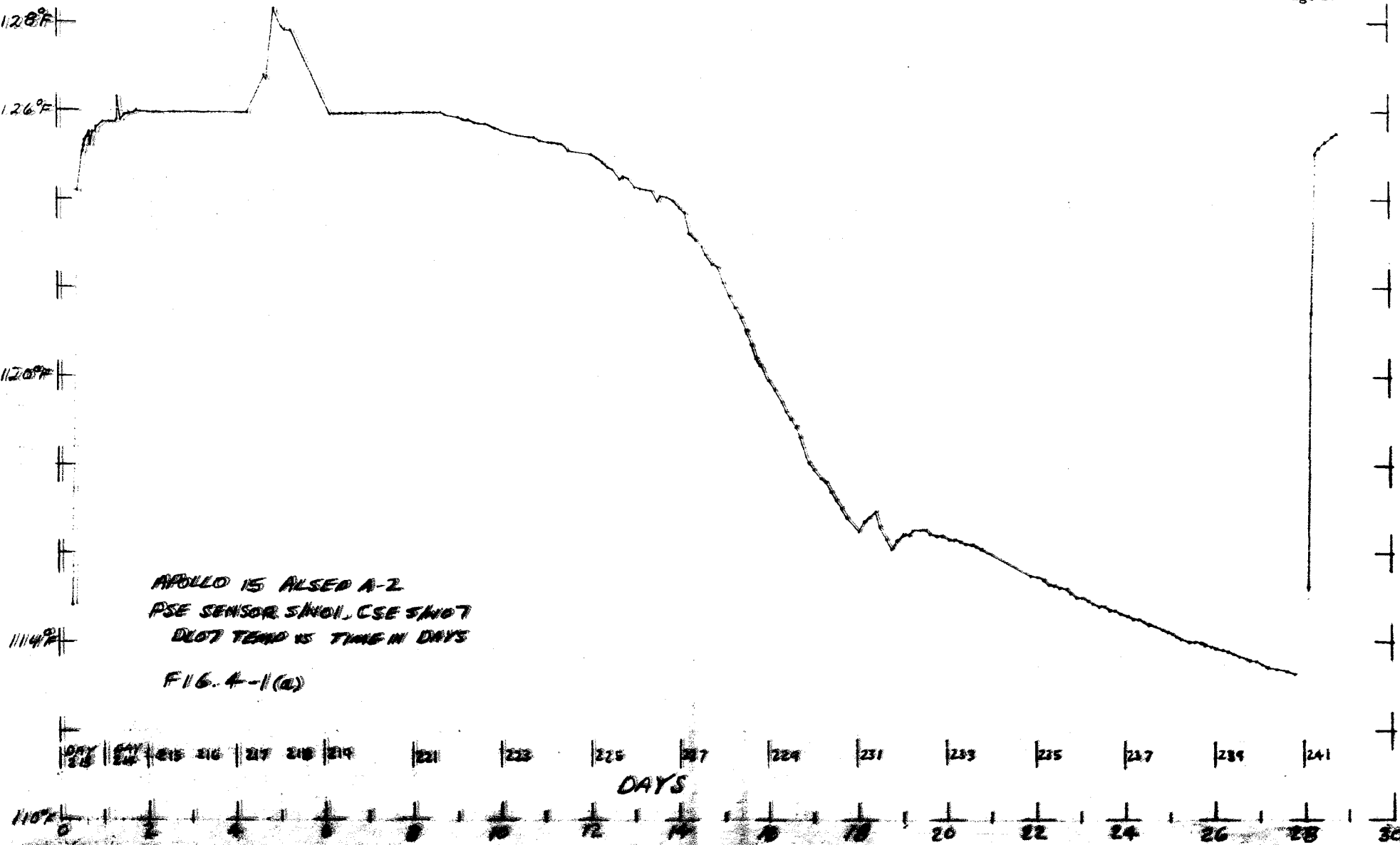
The Apollo 15 SN01 sensor temperature during the second lunar day, plotted on Figure 4-1, reached a high of 133.1°F. This variation from the first lunar day is attributed to the solar eclipse of day 1.

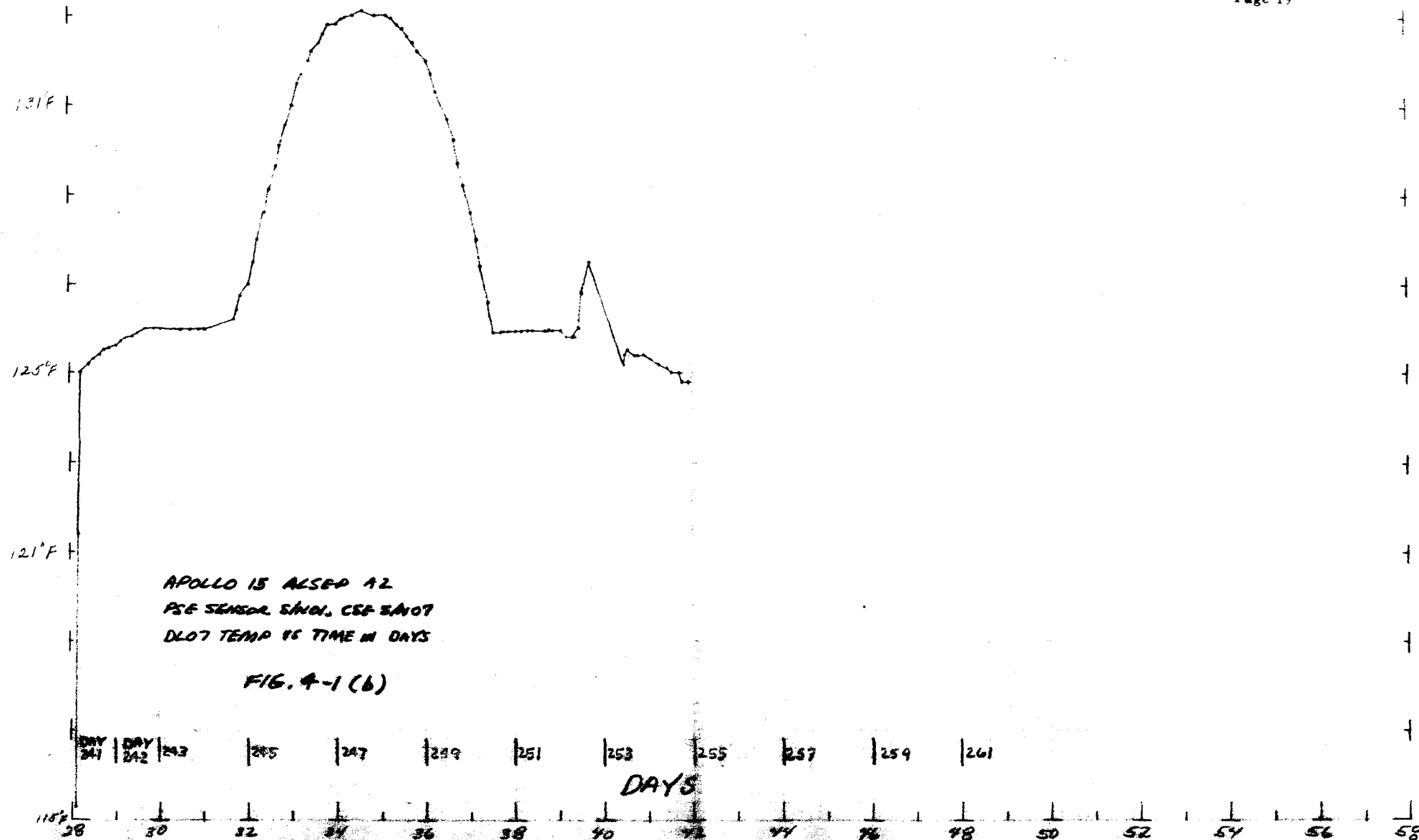
4.2 Anomaly Cause

Potential causes of the anomaly are:

- o A discrepant heater controller which does not reduce the heat sufficiently in daytime and does not supply adequate heat at night.
- o Inadequate insulation from the lunar environment allowing heat leaks to and from the sensor during day and night.

Item 1 was eliminated by verifying the proper change in ALSEP reserve power at the time of commanding the heater off. The daytime measurement indicated a negligible power change, or that the heater was not supplying excessive heat; and the night measurement indicated a power change on the order of 5w, the maximum rating of the proportional heater.







**Aerospace
Systems Division**

APOLLO 15 PSE ANOMALIES

ATM-1062

PAGE 20 OF

DATE

The deployment of the thermal shroud on the lunar surface is shown in the photographs of Figures 4-2, -3 and -4. From the photographs it appears that:

- o The shroud is not extended over the full 5 ft. diameter thus reducing the length of the lunar soil conduction path to the sensor base.
- o Tunneling exists introducing radiation heat leak paths.
- o The shroud edges are lifted off the surface by the deployment tabs which were not properly extended.

The cause of the anomaly has thus been identified as heat leaks attributable to the thermal shroud deployment.

4.3 Analysis

The control range of the proportional heater of sensor SN01 (of Apollo 15) as measured in acceptance tests is (reference Figure 4-5):

- o Maximum power of 4.8 watts at a temperature of 124.2°F.
- o Minimum power of 0.0 watts at a temperature of 125.9°F.

Analysis of the lunar performance data of Figure 4-1 confirms the limits of the control range. On day 213, at approximately 1000 hours the sharp rise in temperature decreased as the proportional heater started reduction of the full heater power. This break point occurred at approximately 124.2°F. The lower limit was again noted on day 227 at 0000 hour when the controller could no longer provide the additional heat required and the rate of temperature drop increased. The break point in the temperature rise on the second lunar day is not well defined by the data plotted. The upper limit of the control range on the moon is approximately 126°F, the sensor temperature at which a smooth transition in temperature can not be maintained by the controller. This is shown at four points on Figure 4-1; days 217, 219, 244 and 250.



**Aerospace
Systems Division**

APOLLO 15 PSE ANOMALIES

NO.

REV. NO.

ATM-1062

PAGE 21 OF

DATE

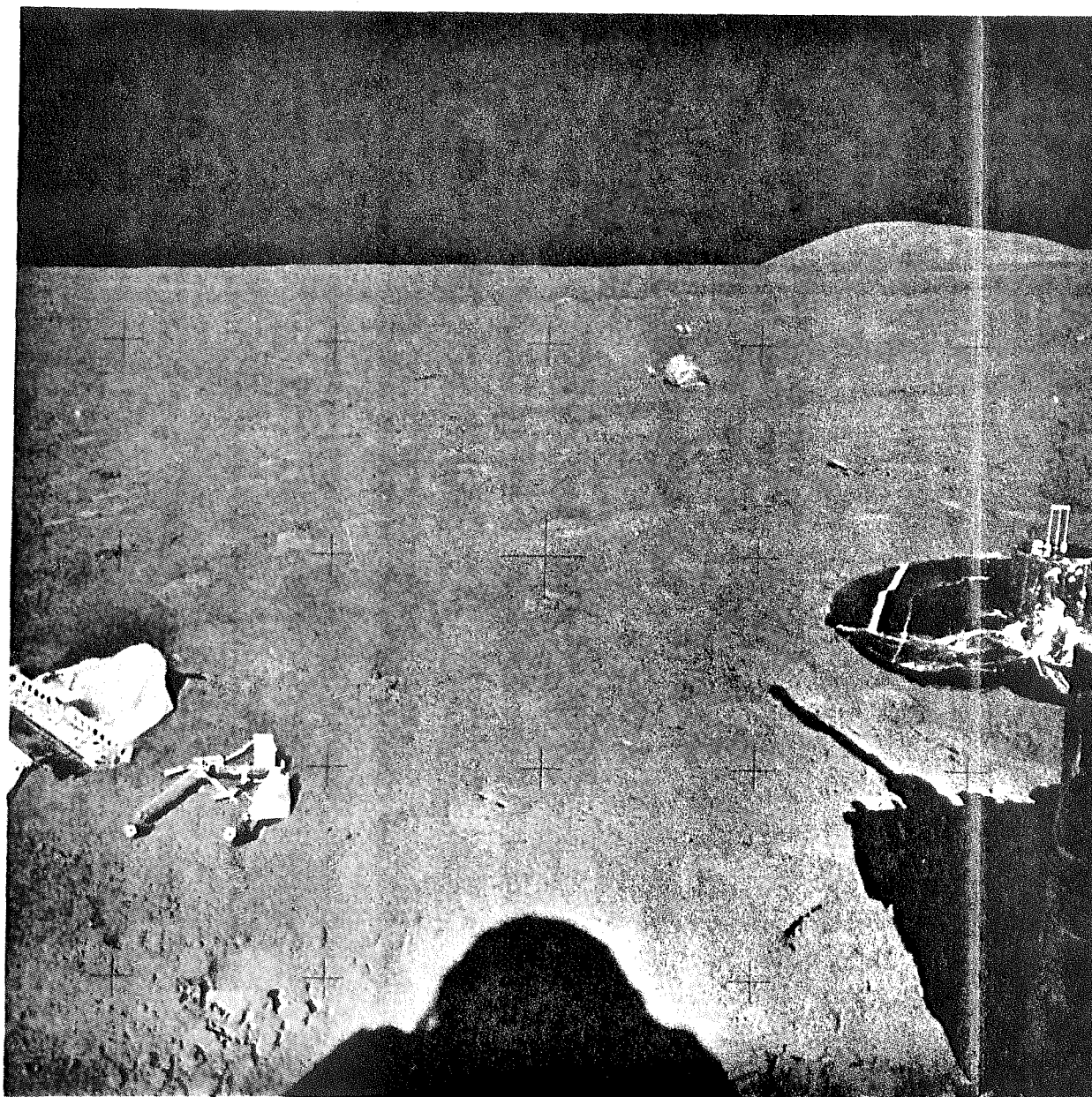


Figure 4-2
Apollo 15 PSE Shroud



**Aerospace
Systems Division**

APOLLO 15 PSE ANOMALIES

NO.

REV. NO.

ATM-1062

PAGE 22 OF

DATE

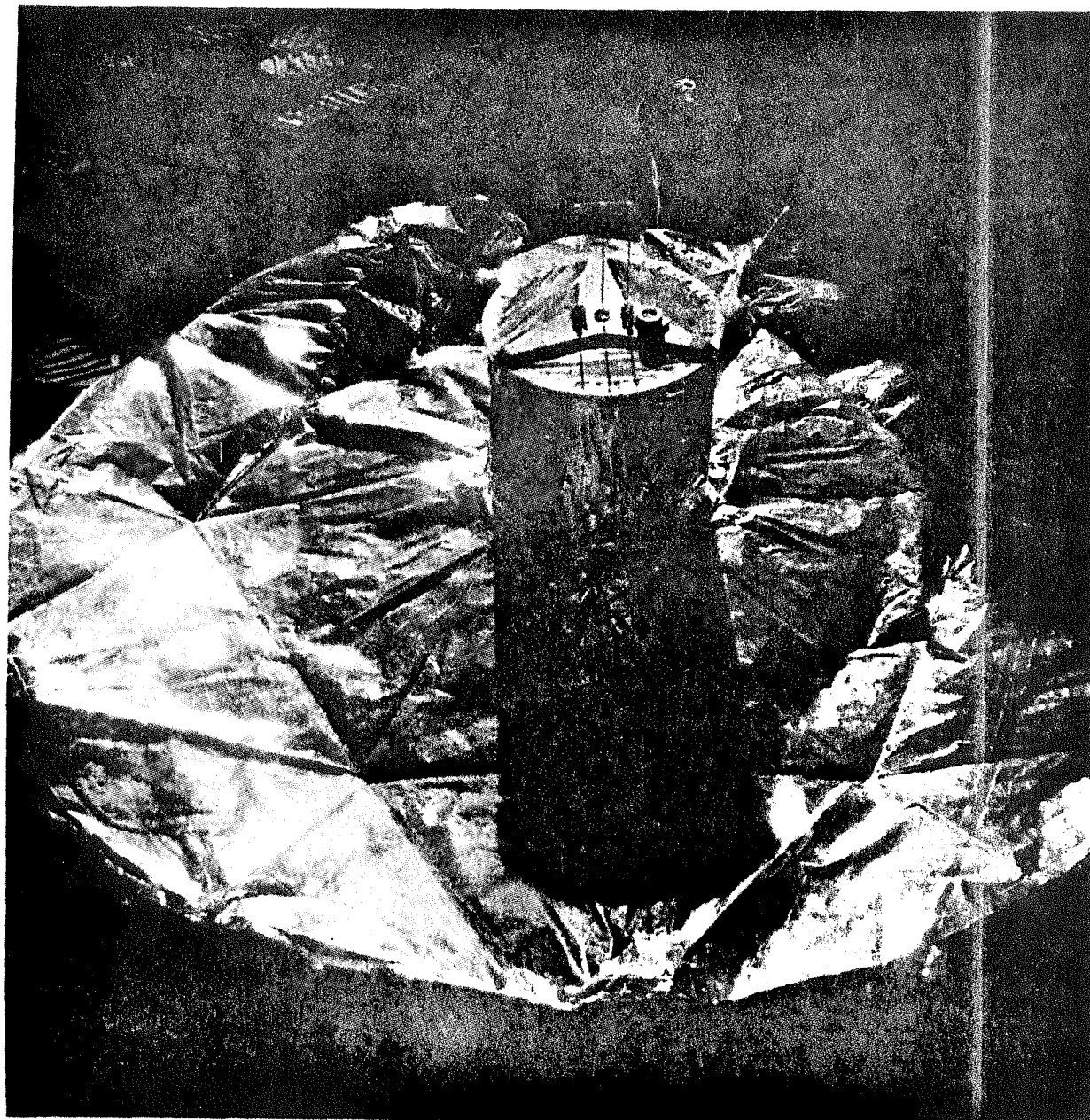


Figure 4-3
Apollo 15 PSE Shroud



**Aerospace
Systems Division**

APOLLO 15 PSE ANOMALIES

NO.

REV. NO.

ATM-1062

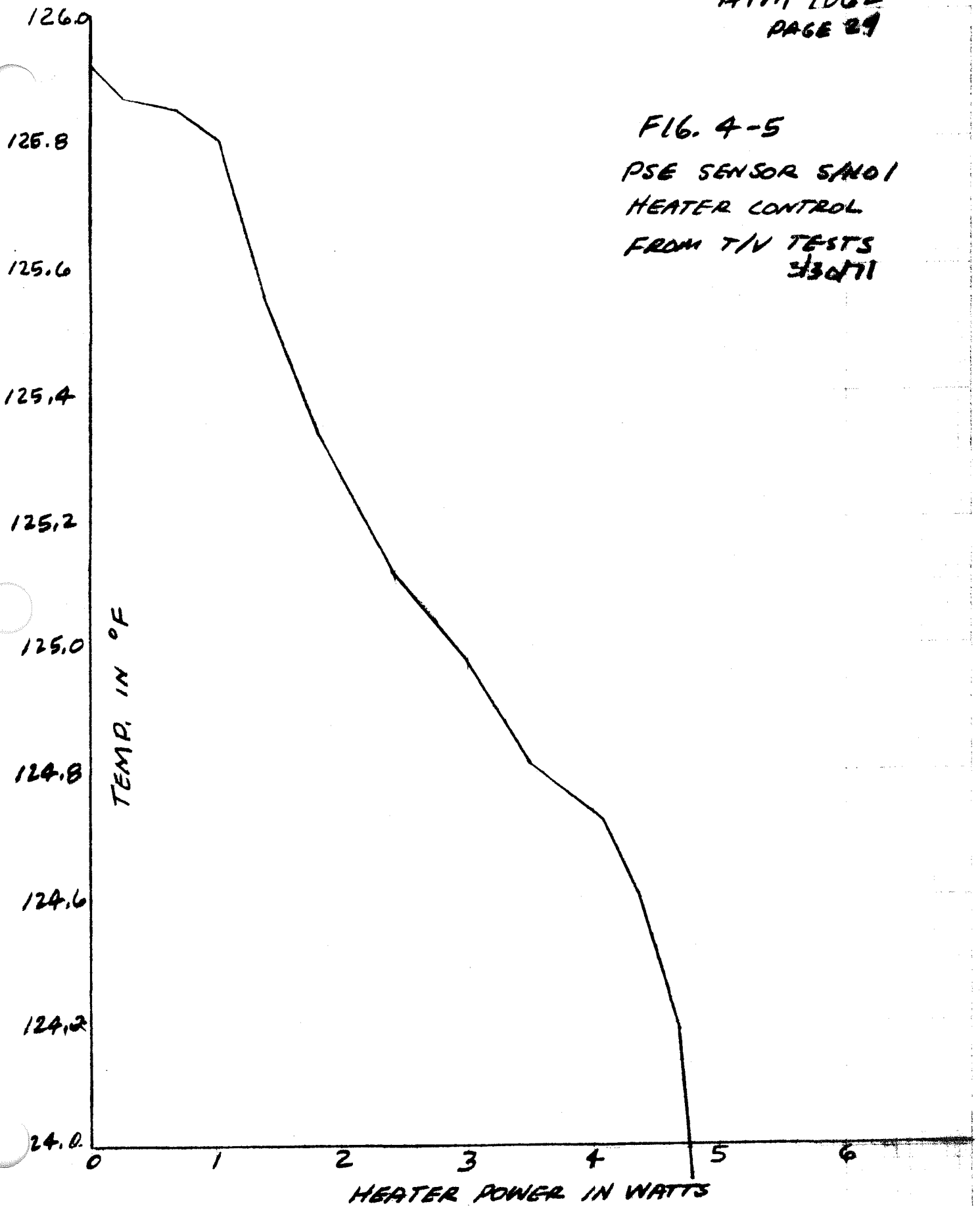
PAGE 23 OF

DATE



Figure 4-4
Apollo 15 PSE Shroud

FIG. 4-5
PSE SENSOR SMO1
HEATER CONTROL
FROM T/V TESTS
3/30/71





**Aerospace
Systems Division**

APOLLO 15 PSE ANOMALIES

ATM-1062

PAGE 25 OF

DATE

As a result of decrease in sensor temperature during lunar night, the effect of using a leveling motor as a heat source to supplement the present heater was considered. The technique of supplying additional heat to the PSE sensor by operation of a leveling motor continuously during lunar night was first used on the Apollo 12 sensor, which contained a 2.5 watt proportional heater.

Based on the need for increased heat the heater power for Apollo 14 and subsequent flight models was raised to approximately 5.0 watts. The heater and associated circuits, documented on schematics 2341608, 2344708, 234541, 234702, and 234621-2, are sketched in Figure 4-6. With this heater power increase a current limiter was incorporated to limit the larger turn-on transient resulting from the reduced heater element resistance. The current limiter controls the total current to the sensor heater and three leveling motors but not sensor functional power. It was recognized that if the full 5.0 watts was required for the heater, the leveling motors would not have sufficient power to rotate, requiring the heater be turned off during leveling sequences. Though specifically incorporated for limiting turn-on transients, long term operation of the current limiter functioning in a limiting mode is an acceptable operation. The critical area of the limiter in long term operation is the junction temperature of the regulator transistors: if junction temperature were allowed to increase, beyond the rating of the transistor, a further increase in current and possibly "runaway" condition could result. To prevent excessive temperature rise in these transistors a heat sink system was added to conduct the heat to the base of the sensor and thus the heat contributed by the regulator transistors becomes part of the total heater system. The dissipation of a single transistor was calculated to be 631 milliwatts and its junction temperature, when the regulator is supplying 5 watts, to be 76°C (based on data derived from an engineering model tested in thermal-vacuum, shown on Figure 4-7).

When the motor load current is added to that of the heater in a "full on" auto operation, the current limiter will be supplying its maximum output, dissipating a maximum of 1.244 watts, in each of the regulator transistors. This increase in power will result in the junction temperature rising to 106.5°C, which is 93.5° below its operating limit. The additional stress on the transistor

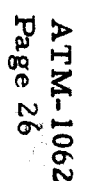
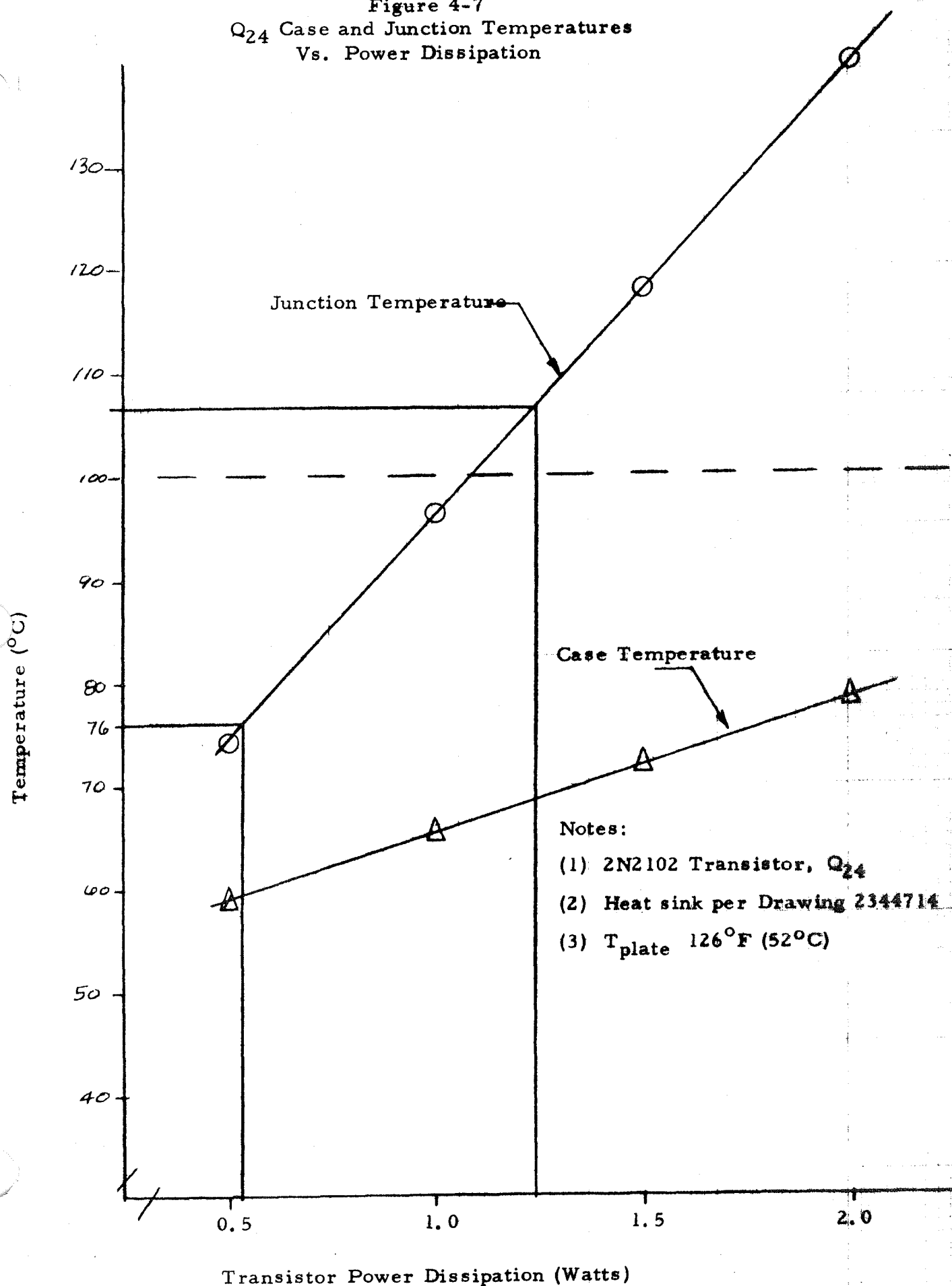


Figure 4-7
Q₂₄ Case and Junction Temperatures
Vs. Power Dissipation





**Aerospace
Systems Division**

APOLLO 15 PSE ANOMALIES

ATM-1062

PAGE 28 OF 28

DATE

as a result of the 30.5° temperature rise is considered to be within safe operating limits of the 2N2102 transistor. The total current will be reduced by the proportional control as the sensor temperature increases and the transistor temperature will assume a value based on the new power requirements.

In addition to increasing the power dissipation in the sensor through motor turn-on, the CSE power will be increased. An 82.5Ω current limiting resistor, in series with the motor, located on the motor control board in the CSE will increase the power dissipated by a maximum of 0.825 watts.

This steady state analysis does not consider transient conditions that will exist until the thermal system stabilizes.

4.4 Recommendations

To preclude thermal control anomalies on subsequent missions, ALSEP deployment training exercises should emphasize the importance of proper PSE shroud deployment definition.

To improve the thermal control of the Apollo 15 PSE sensor, commands should be transmitted to obtain the following status:

- o During lunar day, the uncage circuit should be maintained in an "Uncaged" state (a reduction of approximately 0.1 watts); the calibration circuits maintained in an "Off" state (a reduction of approximately 0.05 watts), and the heater maintained in a "Forced Off" state (a reduction of approximately 0.1 watt from the "Auto Off" state).
- o During lunar night the heater should be maintained in "Auto-On", the LPZ centering motor should be maintained in an "On" state, (a potential of 2.9 watts) and the leveling mode in "Auto". If the sensor temperature falls below 124.2°F , the uncage calibration circuits may be used for additional heat.

The use of the LPZ motor as a heat source can only be considered if the science data is not degraded by intermittent leveling.