The anomalous condition, that of intermittent oscillations, of the Long Period Vertical seismometer of the Apollo 14 Passive Seismic Experiment and the analysis and testing which was performed in the investigation of the anomaly is described in this report. This performance condition was first described in the Apollo 14 PSE Anomalies Report of Reference 1.

Prepared by: M. Goodkin
M. Goodkin

Prepared by: L. Hogeboom
L. Hogeboom

Prepared by: D. K. Breseke
D. K. Breseke

Approved by: W. Tosh
W. Tosh, Manager
ALSEP Experiments

1.0 INTRODUCTION

The Apollo 14 PSE Long Period Vertical (LPZ) seismometer became unstable, undamped oscillations, shortly after turn on in February, 1971. The oscillatory condition was removed by operating the instrument in a Filter-Out Mode, with a seismometer natural period of 2.2 seconds, rather than a Filter-In mode, with a period of 15 seconds. This mode, Filter-Out, was also preferred because (a) a greater number of lunar seismic events are in the 2.2 second range and (b) correlation can be made more readily with the Apollo 12 PSE which has been operated in the Filter-Out Mode.

After 122 days of operation, oscillations of the LPZ have again occurred: these oscillations are, however, intermittent and in general of a much lower magnitude. The recurrence of the LPZ oscillation was noted by Apollo 14 AISEP SMEAR 48 and 51 resulting in the investigation of this report. The study was conducted to determine what may have caused the LPZ anomalous condition, what might be done to improve the Apollo 14 PSE LPZ behavior, and what might be done to prevent the anomalous condition from occurring in future flights.

2.0 ANOMALY DESCRIPTION

The Filter-In Anomaly, shown in Figure 1, is characteristic of an unstable seismometer. The LPZ Seismic output oscillates with a period of approximately 1 minute with increasing amplitude until a (+) saturation condition is achieved. The LPZ Tidal signal also goes to saturation.

Since 7 June 1971, LPZ anomalous oscillations have occurred several times, in the Filter-Out mode. These oscillations are of varying duration and with varying amplitudes (Figures 2 and 3). The LPZ oscillation occurrences are shown in Figures 4-A, 4-B and 4-C for the time period covered by this analysis. The amplitude variations are shown in the figures: generally, "high-amplitude" describes those oscillations which are readily apparent on the LPZ Tidal output. Random measurements showed that the period of the oscillations varied between 1.9 and 2.4 seconds. In some cases the anomaly continued for only a few minutes; in others, up to several days.

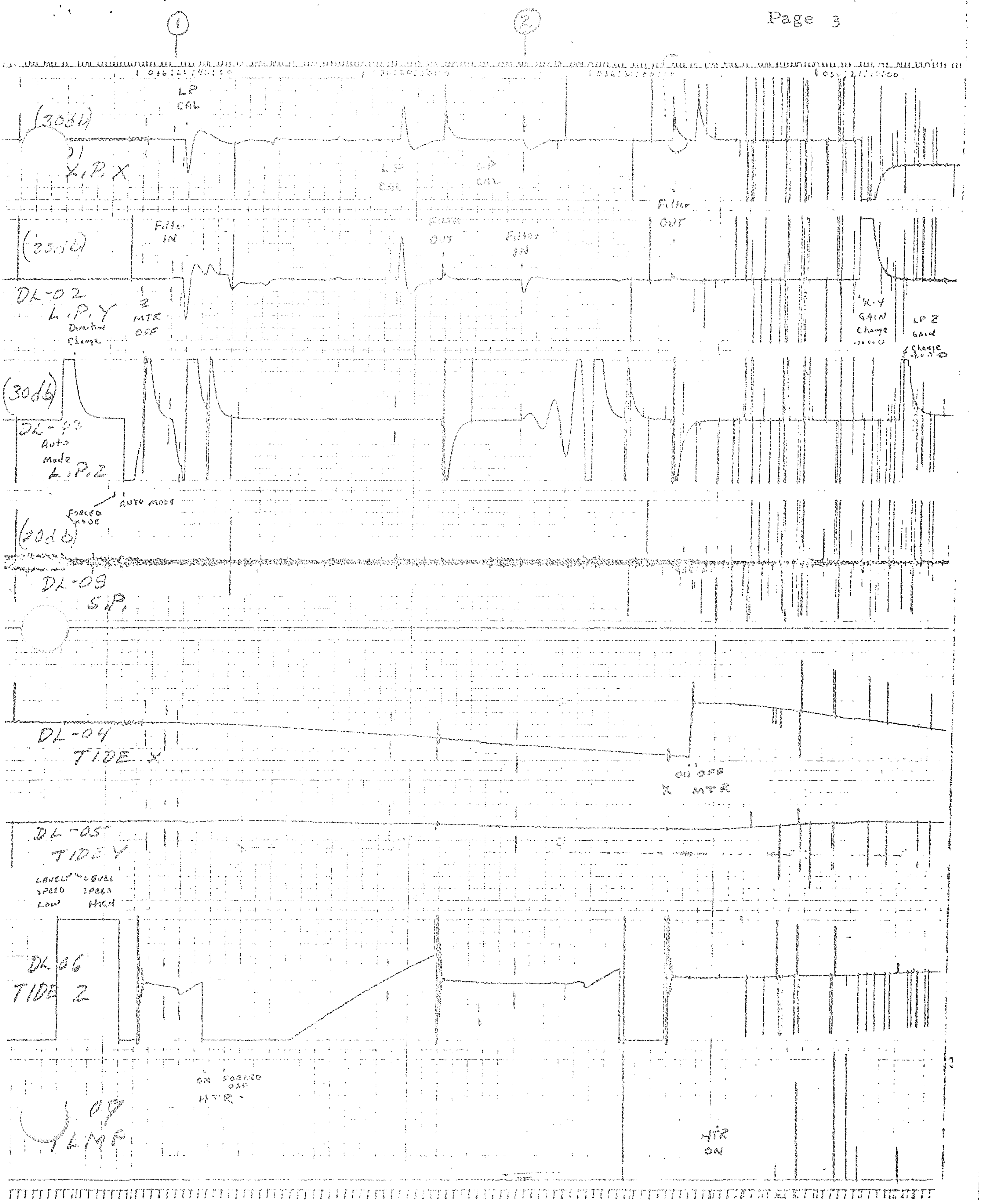

1
2
LP CAL
(30db)
L.P. X
LP CAL
LP CAL
Filter IN
Filter OUT
Filter IN
Filter OUT
DL-02
L.P.Y
Direction Change
Z MTR OFF
X-Y GAIN Change
LP Z GAIN Change
(30db)
DL-03
Auto Mode
L.P.Z
AUTO MODE
FORCED MODE
(20db)
DL-08
S.P.
DL-04
TIDE X
ON OFF
X MTR
DL-05
TIDE Y
LEVEL SPEED LOW
LEVEL SPEED HIGH
DL 06
TIDE Z
ON FORCED OFF
HTR
HTR ON

Figure 1

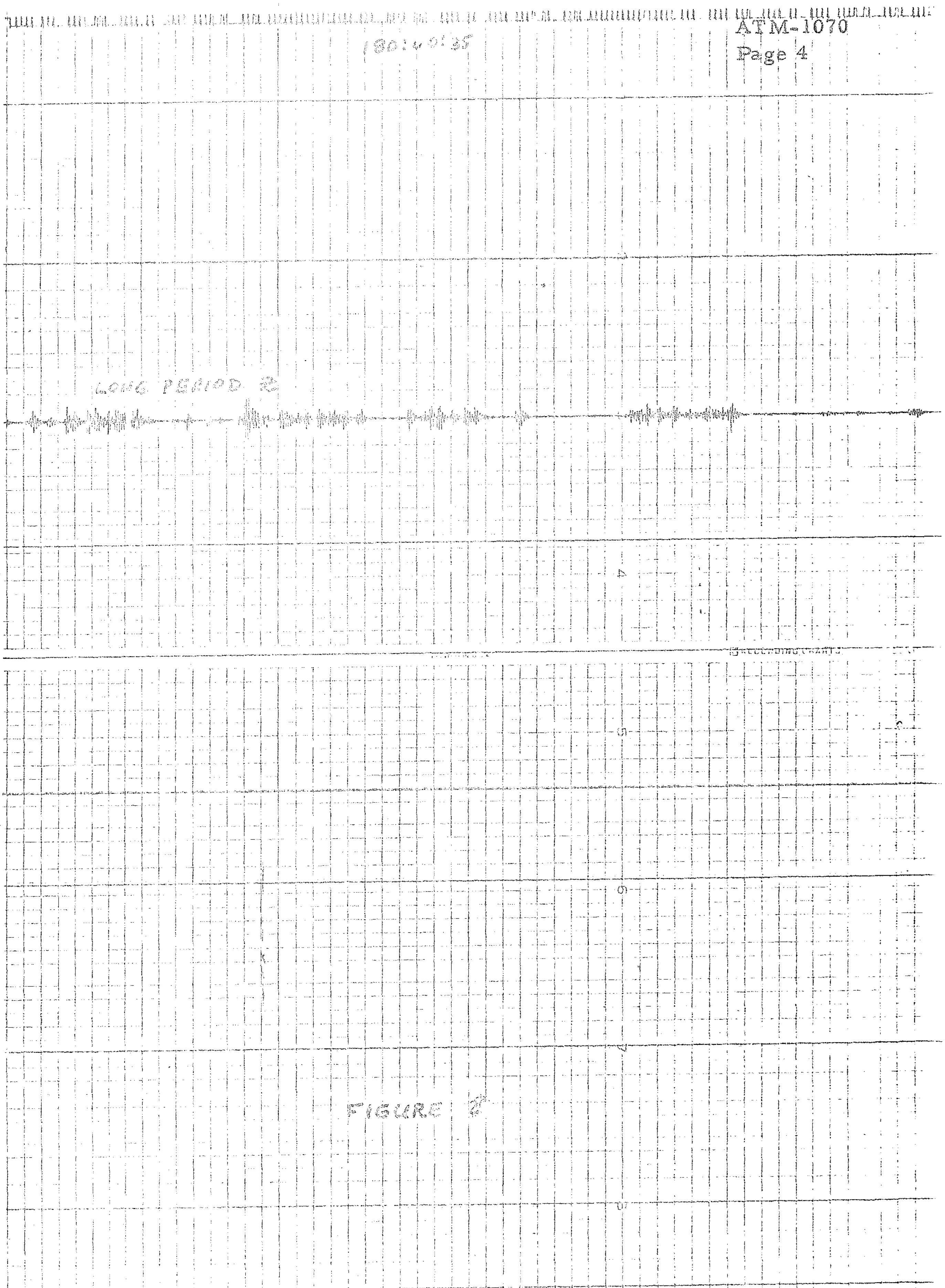


FIGURE 2

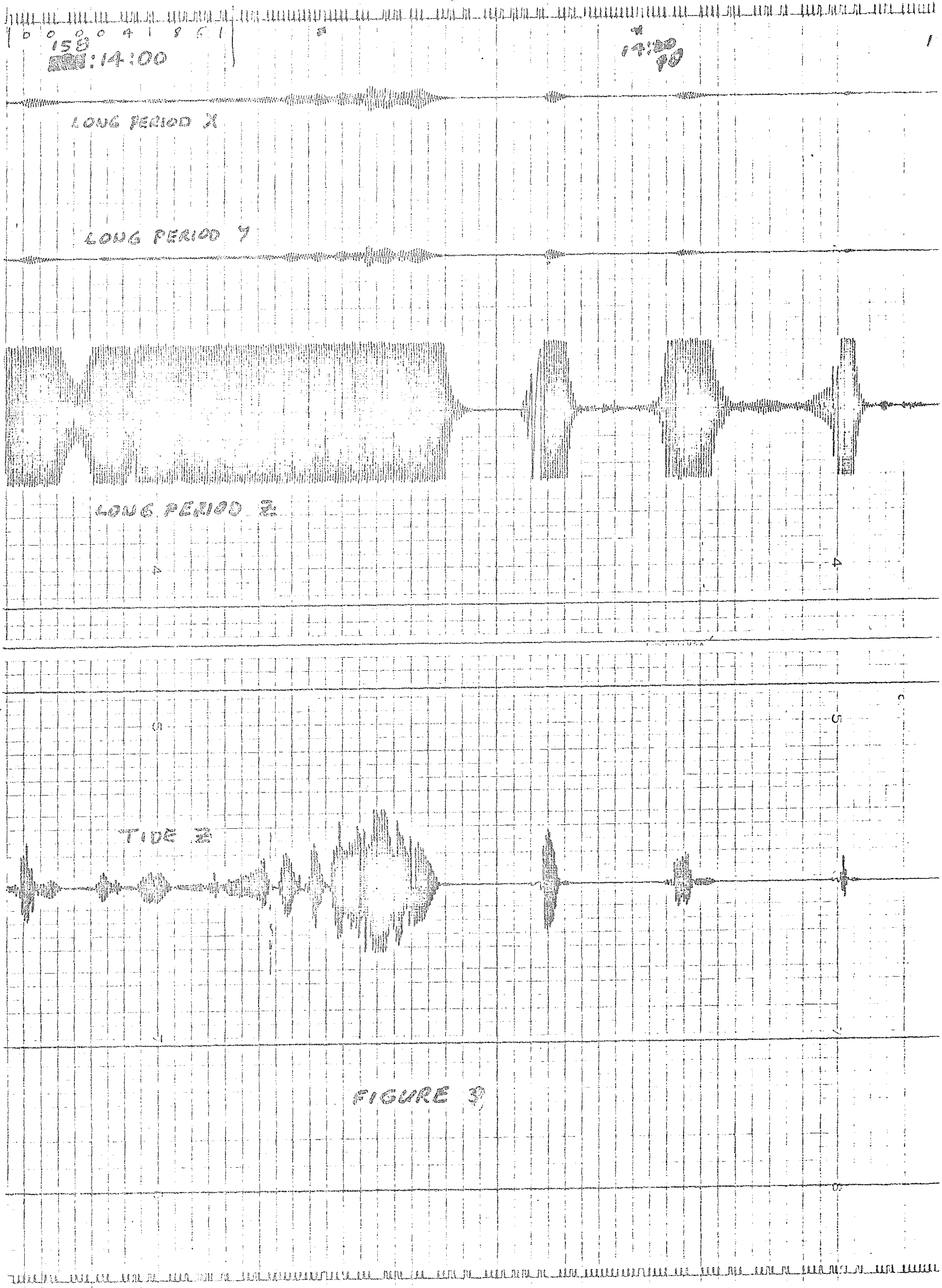

158
[redacted]:14:00
LONG PERIOD X
LONG PERIOD Y
LONG PERIOD Z
TIDE Z

FIGURE 3

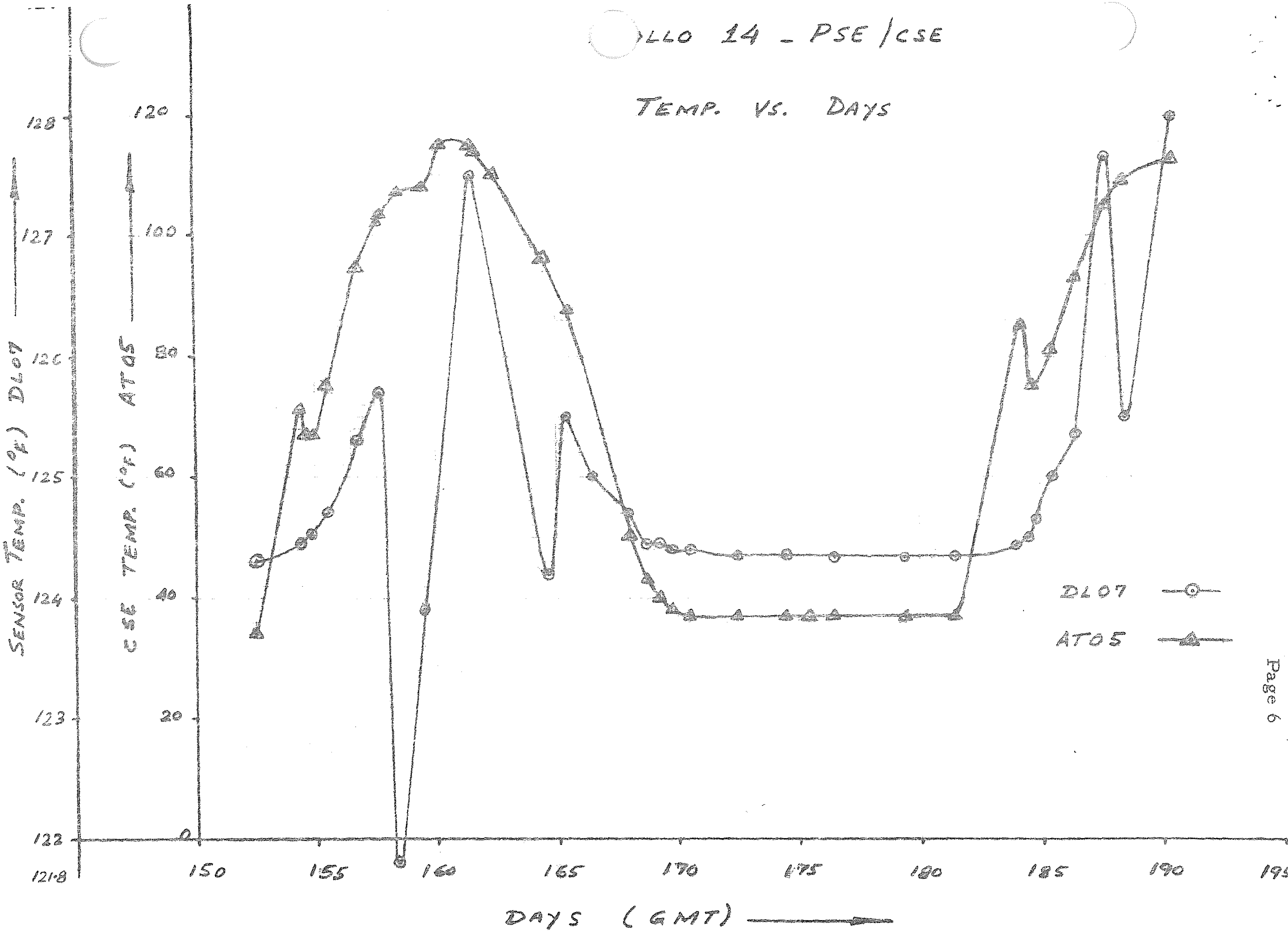

LLO 14 - PSE/CSE
TEMP. VS. DAYS
SENSOR TEMP. (°F) DL07
CSE TEMP. (°F) AT05
DAYS (GMT)
DL07
AT05
128
127
126
125
124
123
122
121.8
120
100
80
60
40
20
0
150
155
160
165
170
175
180
185
190
195

Figure 4A-1

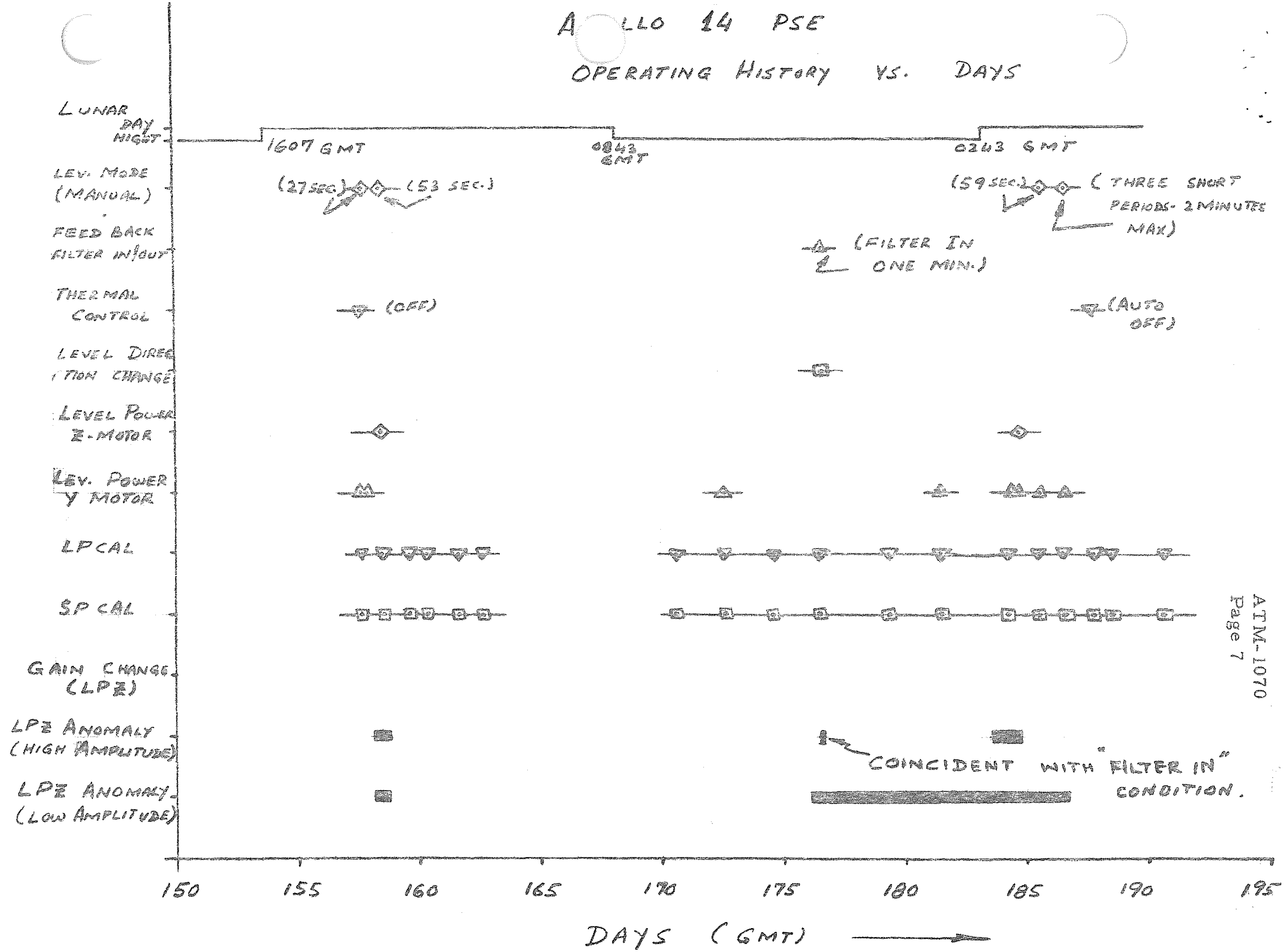

APOLLO 14 PSE
OPERATING HISTORY VS. DAYS
LUNAR DAY NIGHT
1607 GMT
0843 GMT
0243 GMT
LEV. MODE (MANUAL)
(27 SEC.)
(53 SEC.)
(59 SEC.)
(THREE SHORT PERIODS- 2 MINUTES MAX)
FEED BACK FILTER IN/OUT
(FILTER IN ONE MIN.)
THERMAL CONTROL
(OFF)
(AUTO OFF)
LEVEL DIRECTION CHANGE
LEVEL POWER Z-MOTOR
LEV. POWER Y MOTOR
LP CAL
SP CAL
GAIN CHANGE (LPZ)
LPZ ANOMALY (HIGH AMPLITUDE)
COINCIDENT WITH "FILTER IN" CONDITION.
LPZ ANOMALY (LOW AMPLITUDE)
150
155
160
165
170
175
180
185
190
195
DAYS (GMT)

Figure 4A-2

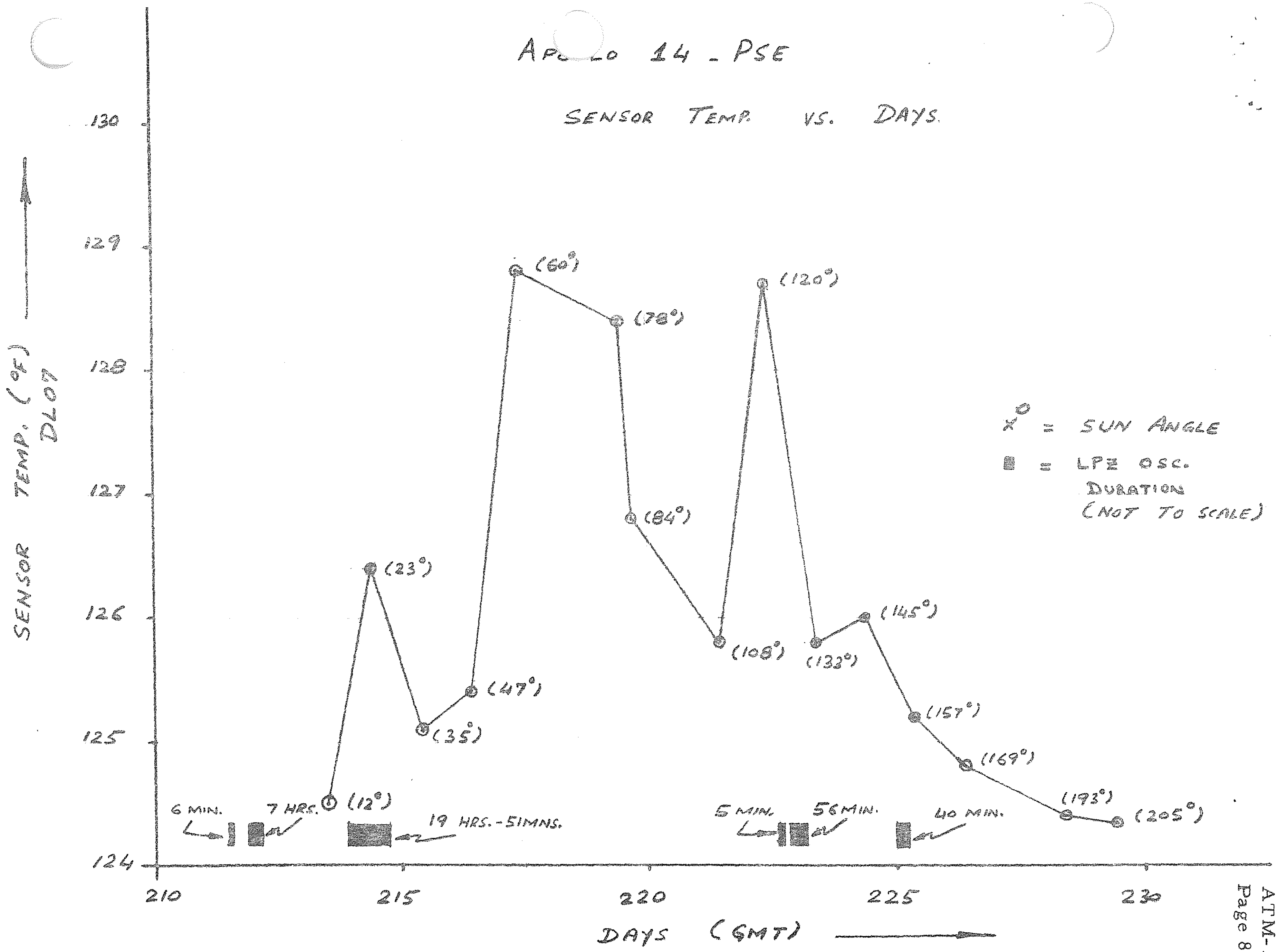

AP LO 14 - PSE
SENSOR TEMP. VS. DAYS.
SENSOR TEMP. (°F) DL07
130
129
128
127
126
125
124
210
215
220
225
230
DAYS (GMT)
(12°)
(23°)
(35°)
(47°)
(60°)
(78°)
(84°)
(108°)
(120°)
(133°)
(145°)
(157°)
(169°)
(193°)
(205°)
6 MIN.
7 HRS.
19 HRS. - 51MNS.
5 MIN.
56MIN.
40 MIN.
x° = SUN ANGLE
= LPE OSC. DURATION (NOT TO SCALE)

Figure 4B

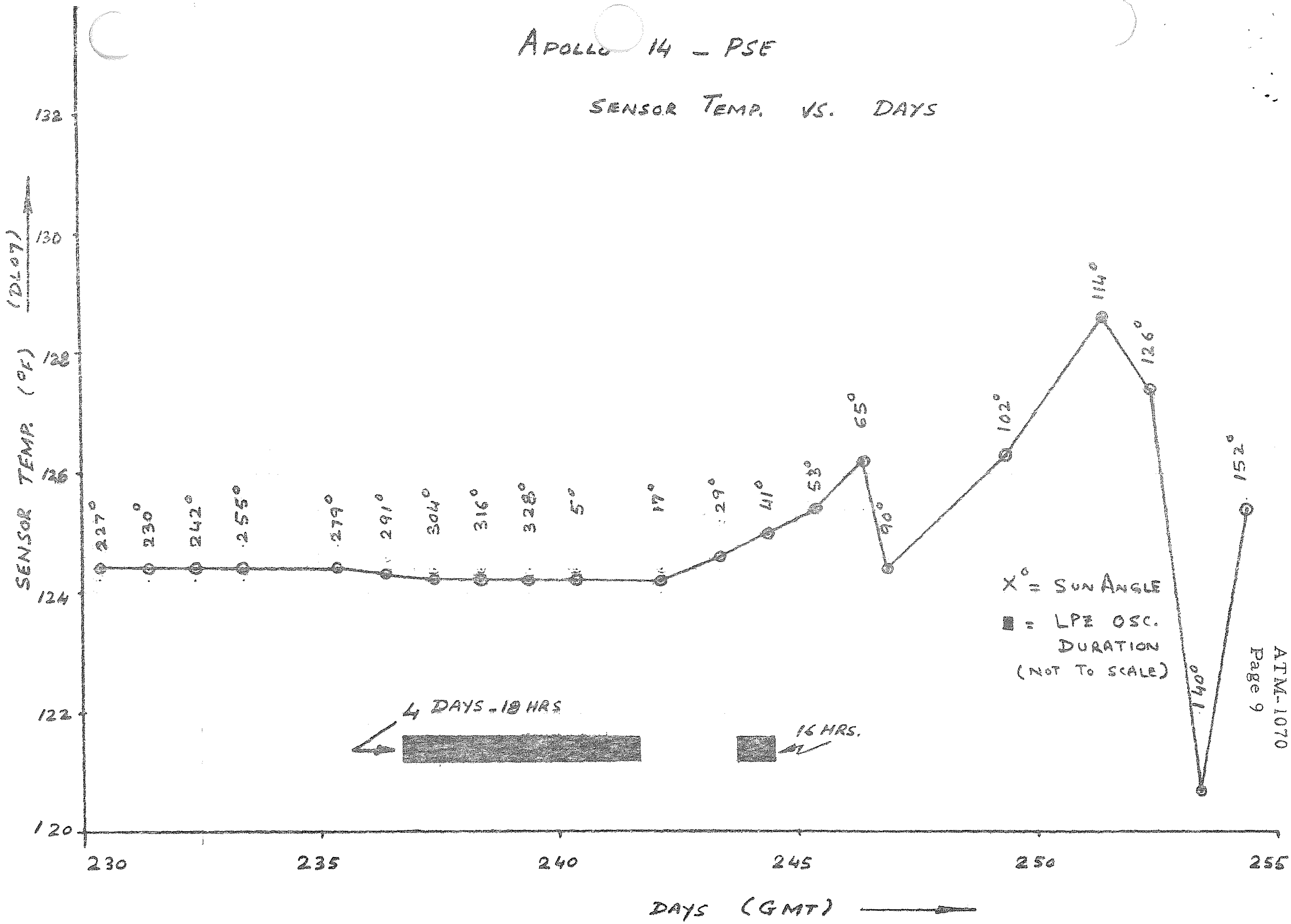

APOLLO 14 - PSE
SENSOR TEMP. VS. DAYS
SENSOR TEMP. (°F) (DL07)
132
130
128
126
124
122
120
230
235
240
245
250
255
DAYS (GMT)
227°
230°
242°
255°
279°
291°
304°
316°
328°
5°
17°
29°
41°
53°
65°
90°
102°
114°
126°
140°
152°
X° = SUN ANGLE
= LPE OSC. DURATION (NOT TO SCALE)
4 DAYS - 18 HRS
16 HRS.

Figure 4C

3.0 ANOMALY CAUSE

The analysis and testing conducted on flight hardware and the engineering model indicates that two failures have occurred: no single point failure could be established which would duplicate the observed results for both the Filter-In and Filter-Out conditions. The first, the undamped oscillations occurring in the Filter-In mode, have been attributed to a mechanical problem: the second, the intermittent, lower magnitude-oscillations of the Filter-Out mode, are due to an electrical problem. Both conditions have been reproduced in test.

A mechanical malfunction of identical characteristics was temporarily reproduced during in-process testing of flight sensor SN/08; however, the completion of assembly eliminated the problem without positive identification of the specific cause. It is believed that the most significant adjustment made was securing the position of the thermal compensation bar. The mechanical instability also recurred in the LPZ engineering model and was operated in this mode for considerable time; however, a single mechanical cause of the instability was not established.

While the LPZ of the engineering model was mechanically unstable, a number of electronic malfunctions were simulated. When a forward path gain increase of 1.5 or more was induced, the LPZ output strongly resembled the Filter-Out lunar anomaly. This experiment is described in the Appendix, Test IV. This type of electronic gain change could be due to a feedback resistance change in either the Pre-amplifier or the Demodulator. A second potential cause is a phase shift in the Demodulator or the Feedback Filter. Test X simulated this type of failure and produced results similar to the anomaly.

An examination of the data recorded during an interval in which the anomaly occurred, can be made to determine if a gain change is apparent on the LPZ. This would resolve the uncertainty of the cause, i.e., a gain change or a phase shift.

4.0 ANALYSIS

4.1 TEMPERATURE RELATIONSHIP TO ANOMALY

Due to the coincidence of sensor temperature gradients and the LPZ oscillations on 2 August 1971, the possibility was considered that a relationship might exist between these two parameters. Temperature vs time curves were plotted and the LPZ oscillation occurrences were noted, reference Figures 4A, B and C.

There is no apparent correlation between the sensor temperature and the outbreak or continuation of the anomaly. The LPZ oscillations started when the temperature was as low as 123°F (day 158, 7 June 1971) and as high as 126°F (day 222). Continuation of the oscillations occurred with the temperature as low as 121°F (day 158) and as high as 126.5°F (day 214).

There is also no apparent relationship between temperature transitions and the anomaly occurrence. On day 158, the oscillations started when the temperature was dropping sharply. On days 176 and 236, however, the temperature was stable at the beginning of anomalous output, and on days 243 and 213, the temperature was rising.

The measurement of temperature within the PSE sensor is at a point approximately half way up the inside wall of the case. Temperature gradients within the sensor occur with the lunar cycle: the range of the sensor base temperature is estimated to be 75 to 135°F.

4.2 OPERATING EVENTS RELATIONSHIP TO ANOMALY

The occurrence of the LPZ anomaly was compared to that of other normal operating events and modes. Except for the Filter-In condition, it is apparent from Figure 4A that the operating events and the anomaly are not related. There appears to be no correlation between an operating event and the start, the continuation, or the termination of oscillations.

4.3 LPZ STABILITY ANALYSIS

4.3.1 Mechanical Assembly

Laboratory experience has shown that the seismometer mechanical assembly will become unstable with misalignment of any one of several sub-assemblies. Conditions similar to the Apollo 14 anomaly were observed on a flight model, sensor SN08, and on the engineering model. Sensor SN08 was in assembly and test during the anomaly investigation.

During in-process testing of sensor SN08, inadequate seating of the thermal compensation bar set screw caused an LPZ instability. During resolution of this problem several alignment adjustments were made and at one time the Apollo 14 Filter-In anomaly was reproduced. The definition of misalignments required to produce this condition are not known. It was observed that the seismometer characteristics could be changed by commanded leveling operations. An attempt was made to also duplicate the anomalous mechanical behavior using an engineering model of the LPZ assembly. The anomalous behavior was successfully duplicated while adjustments were being made in the area of the thermal compensator bar. Unfortunately, this anomaly did not occur during one of the controlled experiments; therefore, the specific cause was not determined.

The thermal compensator bar supports the flexure mount of the LPZ boom and affords thermal correction for expansion and contraction of the LaCoste Spring. A set screw located in the thermal bar and under the flexure mounting bar clamps the thermal bar to a spring attached to the platform. This assembly allows vertical movement of the thermal bar while restricting the horizontal movement. Vertical movement of the bar corrects mass position and has very minor effect on the period of the seismometer. Horizontal movement of the bar has little affect on mass position but does cause a change of period and possibly seismometer instability.

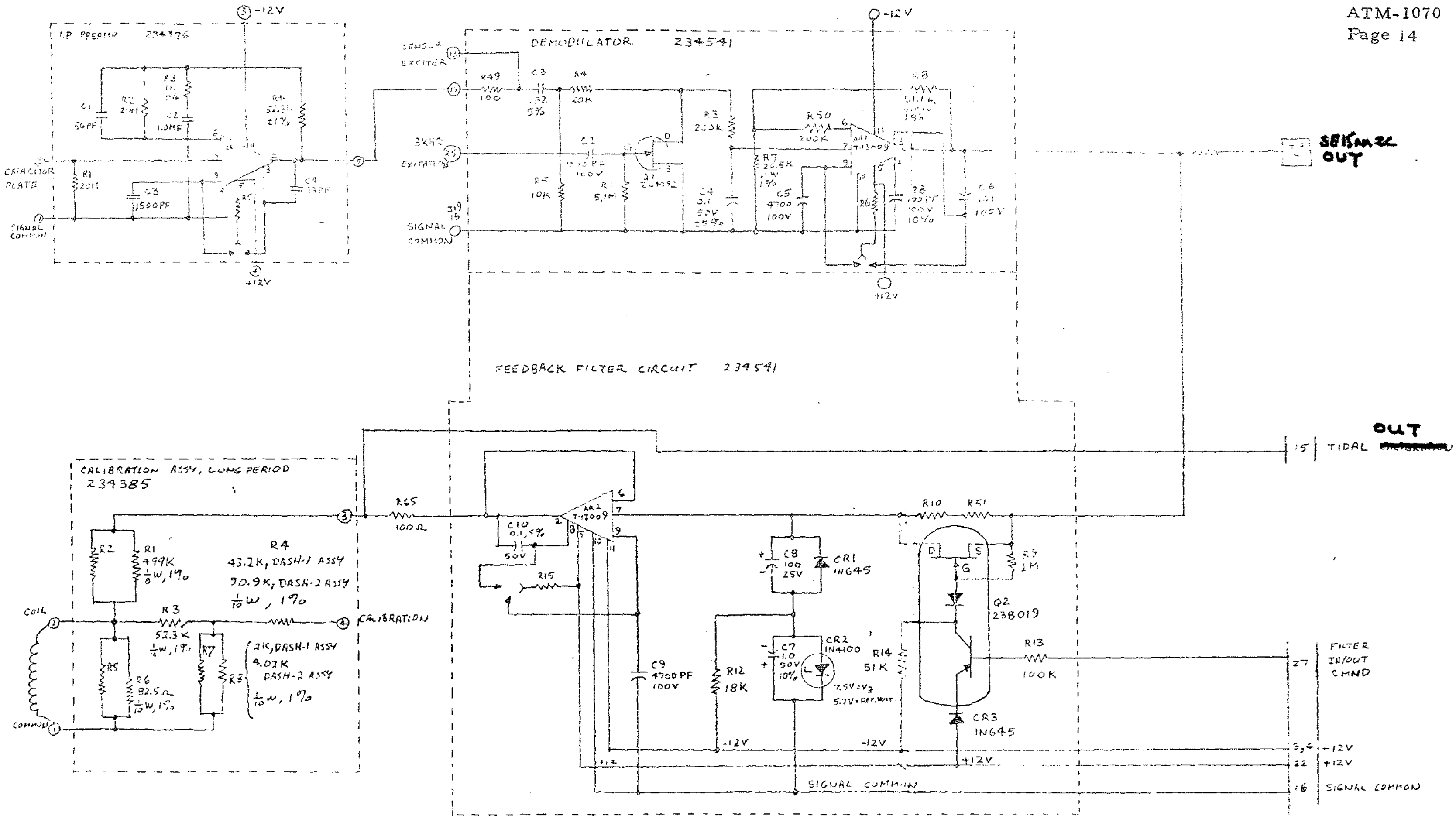
The amount of thermal bar movement considered is extremely small. The horizontal movement that caused the change of period in the SN 08 sensor could not be visibly detected even when observed under a 40 power microscope. However, when the flexure mounting bar was removed and the set screw in the thermal bar was reseated on the platform spring and the flexure bar installed, the period variations in SN 08 ceased and the performance of the LPZ was normal.

4.3.2 LPZ Feedback Analysis

The LPZ seismometer consists of an electro-mechanical feedback loop followed by attenuator, amplifier, and filter circuits. Generally, the stability of a feedback loop is a function of the loop gain and phase. If the loop gain or phase cross certain boundaries, the system will become unstable. For normal operating conditions, the LPZ loop can be approximated by a linear model. Linear analyses have been performed by S. N. Thanos (Ref. 2) and Sutton and Latham (Ref. 3).

From the LPZ schematic of Figure 5, it can be seen that a gain change can result from a faulty component or connection in the preamplifier, the demodulator, or the feedback coil attenuator network and that a phase shift can be caused by a malfunction in the demodulator filter or the feedback filter.

A number of experiments were performed in an effort to isolate an electronic component or connection failure that would duplicate the Filter-Out mode anomalous behavior of the Apollo 14 PSE LPZ system. The experiments and their results are described in the Appendix. Test IV, increased gain, and Test X, phase shift, resulted in malfunctions similar to the Apollo 14 anomaly. Of the two tests, the gain change gave a much closer match to the anomaly. The gain change test results have an oscillation period equal to the normal filter-out period of the system and show rapid amplitude variations. Both of these conditions were characteristic of the lunar anomaly.



LPE FEEDBACK LOOP

FIGURE 5

5.0 RECOMMENDATIONS

The gain change theory should be further tested by analyzing normal seismic outputs during a period of anomalous activity. Above "normal" amplitude would support a change in gain. The relationship to "normal" would have to be determined by the PI.

Commanding the LPZ drive assembly may reduce the anomalous behavior of the Apollo 14 PSE as demonstrated on the PSE SN08 mechanical anomaly. However, this action will not affect the LPZ electronics anomaly.

No modifications in design, manufacture or test are recommended for future LPZ assemblies.

APPENDIX

ENGINEERING MODEL EXPERIMENTS*

1.0 TEST I:

Series resistance in series between Preamp output (Pin 5) and Demodulator input (Pin 19).

1.1 PROCEDURE:

- Insert resistor decade box between preamp and demodulator.
- Vary Resistance of decade box, 3 minutes at each value, by the following increments:

  0-10K Ω, 1 K Ω increments

  10K-60K Ω, 5K Ω increments

  60K-100K Ω, 10K Ω increments
- Mark strip chart at each resistance change

1.2 RESULTS: Run 10/6/71

No significant oscillations

* All tests were performed in the Filter-In mode except where explicitly stated othewise, and with a mechanically unstable assembly except where stated otherwise.

APPENDIX

2.0 TEST II

Reduced value of Demodulator Filter resistor, R_3

2.1 PROCEDURE

- Place resistor decade box in parallel with R_3.
- Vary resistance of decade box, a few minutes at each value, by the following decrements:

  1MΩ - 100K Ω, 100K Ω decrements

  100 KΩ - 20K Ω, 20 K Ω decrements
- Mark strip chart at each resistance change.

2.2 RESULTS: Run 10/7/71

No significant oscillations sustained at any resistance value. Oscillations occurred during transition times of large resistance changes.

3.0 TEST III:

Increased resistance to base of Filter Mode switch control transistor.

3.1 PROCEDURE:

- Insert resistor decade box in series between the Filter Mode Switch base resistor, R_{13} (pin 27) and Filter Mode command manual switch.
- Vary resistance of decade box, a few minutes at each value, by the following increments:

  0-8KΩ, 2 KΩ increments

  8KΩ - 98KΩ, 10 KΩ increments

  98KΩ - 998KΩ, 100 KΩ increments

- Mark strip chart at each resistance change.

3.2 RESULTS: Test run 10/6/71

No significant oscillations.

3.3 TEST MODIFICATION: Higher resistance

3.4 RESULT OF TEST MODIFICATION:

Oscillations occurred when resistance was between 2MΩ and 3MΩ. At higher resistance normal Filter-Out operation was observed.

APPENDIX

4.0 TEST IV:

Forward path gain change.

4.1 PROCEDURE:

- Place resistor decade box in parallel with the Demodulator amplifier feedback resistor, R_7.
- Vary resistance of decade box by the following decrements:

  100KΩ - 10KΩ, 10KΩ decrements, 2 min. at each value

  10KΩ - 1KΩ, 1KΩ decrements, 3 min. at each value

- Repeat resistance value where oscillations occur. Command system to Filter-In mode, then back to Filter-Out mode after one minute.
- Mark strip chart at each resistance change and at each command.

4.2 RESULTS: Test run 10/7/71

- Significant oscillations first noted at 9 K.
- Oscillations quite noticeable at 8K.
- At fixed resistance, oscillations varied in amplitude. Frequency about normal for Filter-Out mode.
- With both LPZ Seismic and LPZ Tidal at same sensitivity, oscillations were slightly greater amplitude on Tidal output.
- When commanded to Filter-In mode, oscillations quickly built up to saturation. After a few cycles, the LPZ Seismic output went to (+) saturation and remained there. The low level oscillations returned after the system was commanded back to the Filter-Out mode.

APPENDIX

5.0 TEST V: Increased value of Preamp feedback capacitor, C_2

5.1 PROCEDURE:

- Place capacitor decade box in parallel with the Preamplifier feedback capacitor, C_2.
- Vary capacitance of decade box, 60 to 80 seconds at each value by the following increments:

  1 μf - 10 μf, 1 μ increments

5.2 RESULT:

No significant oscillations

6.0 TEST VI: Leakage of Preamp feedback capacitor, C_2 at 3KHz:

At 3KHz:

$$X_c = \frac{1}{2\pi f C_2} = \frac{1}{2\ (3x10^3)\ 1X10^{-6})} \approx 40\ \Omega$$

A Filter-In Natural Period:

$$X_c = \frac{1}{2\pi f C_2} = \frac{1}{2\ (1/6)\ (1 \times 10^{-6})} \approx 10^6\ \Omega$$

If capacitor C_2 had large leakage or was shorted out of the circuit, the signal amplifications at the preamp would be the same at all frequencies, instead of being greatly reduced at the LPZ natural period. The worst case should be a short across the capacitor.

6.1 PROCEDURE:

Short out the preamp feedback capacitor, C_2.

6.2 RESULT: Test run 10/8/71

No significant oscillations; however, a (+) drift was observed on LPZ Seismic Data.

APPENDIX

7.0 TEST VII: Reduced current to calibration board, feedback resistor network.

7.1 PROCEDURE:

- Insert resistance decade box in series between pin 3 of Calibration Board and pin 25 of Z Board.
- Vary resistance of decade box by the following increments:

  0 - 100 KΩ, 10K Ω increments, 40 sec. each value

  100KΩ - 1M Ω, 100 KΩ increments, 1 min. each value

  1MΩ - 2M Ω, 1M Ω increment, 2 min. at 2 MΩ.

- Mark strip chart at each change

7.2 RESULTS: Test run 10/11/71

No significant oscillations up to 1MΩ.
Low level oscillations, fairly constant amplitude, at 2MΩ.

8.0 TEST VIII: Reduced resistance in parallel with feedback coil.

8.1 PROCEDURE:

- Place resistor decade box in parallel with R_5 of Calibration Board.
- Vary resistance of decade box by the following decrements:

  10K Ω - 1K Ω, 1K Ω decrements, 40 sec. each value

  1K Ω - 100 Ω, 100 Ω decrements, 40 sec. each value

  100 Ω - 20 Ω, 20 Ω decrements, 60 sec. each value

- Mark strip chart at each resistance change.

8.2 RESULTS: Test run 10/11/71

Very small oscillation.
LPZ output drifted (+).

9.0 TEST IX:

Mechanical adjustment of natural period of LPZ mechanical assembly to achieve a stable condition.

9.1 PROCEDURE:

Shorten the LPZ period by turning the period adjustment screw by the following procedure:

Turn screw "in" 1/2 turn.
Check for stability in Filter-In mode.
Repeat until the stability is sufficient to perform a natural period measurement.

9.3 RESULTS: Test run 10/15/71

- 3 full revolutions of screw were required to change from the original unstable condition to a stable condition.
- The natural period at which stability was achieved was 4.7 seconds.

10.0 TEST X:

Feedback filter corner point change.

NOTE: This test was run prior to tests I through IX and was performed with a stable mechanical assembly.

10.1 PROCEDURE:

Command LPZ system to Filter-In mode.
Place resistor decade box in parallel with filter resistors, R_{10} and R_{51}.
Slowly increase resistance from 0 Ω (simulating Filter-Out mode) until significant oscillation occurs. Continue increasing resistance, slowly until oscillation stops (lower limit of Filter-In mode stability).
Mark strip chart at each resistance change.
Starting at about 1 M Ω, slowly decrease resistance until the system passes completely through unstable region.
Mark strip chart at each resistance change.

10.2 RESULTS: Test run 8/13/71

At specific resistance values the LPZ output resembled the Apollo 14 anomalous Filter-Out condition (i.e. low level, varying amplitude oscillations); however, the Apollo 14 oscillations had a normal Filter-Out period (approximately 2.5 seconds) and the oscillations produced in the lab model had a period normal for the Filter-In condition (approximately 6 seconds).

LPZ ANOMALY - APOLLO 14 PSE

REFERENCES:

1. ATM-1001, PSE Anomalies ALSEP 4, 12 April 1971.

2. Thanos, S. N., "Feedback-Controlled Seismometer Theory", Lamont Geological Observatory of Columbia University, March 30, 1966.

3. Sutton, G. H. and Latham, G. V., "Analysis of a Feedback-Controlled Seismometer," Journal of Geophysical Research, Vol. 69, No. 18, September 15, 1964, pp. 3865-3882.