TECHNICAL ADVISEMENT MEMORANDUM NO. 106-10

OPERATIONAL RELIABILITY ASSESSMENT OF THE GEOS A SPACECRAFT

PRC D-1056

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To: Program Manager, Geodetic Satellite Physics and Astronomy Programs, Office of Space Science and Applications, NASA Headquarters

From: PRC GEOS Reliability Assessment Team

Subject: Operational Reliability Assessment of the GEOS A Spacecraft

1. Introduction

This TAM presents the results of an operational reliability assessment of the GEOS A spacecraft. The purpose of this assessment was to set up and implement a method to (1) recognize and diagnose possible "in orbit" failures, and (2) provide corrective actions for these possible failures. Diagnostic routines and decision-action procedures were prepared for the various subsystems and are included in section 4. The approach that was used is discussed in section 2. An overall utilization method for the routines and procedures is included in section 3.

2. Approach

An important factor which influenced the approach is the type of data available for the diagnostics. There is, of course, telemetry data, or, more specifically, commutated (pulse amplitude modulation (PAM)) telemetry data. In addition, the telemetry time marker and memory readout are transmitted via the telemetry transmitter. Another source of information will be designated as "experiment response," which includes details on ground reception of Doppler, SECOR, range/range rate (R/RR) transponder, and the optical beacon. It was felt that time constraints prohibited reliance on some of the experiment responses as normal sources of diagnostic data, but that under abnormal conditions they should be given consideration. This matter is discussed further below.

Before proceeding, a few statements regarding the time spans involved in this assessment are in order. Of course, telemetry data is available when the spacecraft is in view of a ground station (the NASA satellite tracking network (STADAN) or the Applied Physics Laboratory (APL), Johns Hopkins University, Howard County, Maryland). Approximately five of the Doppler ground stations are on direct teletype lines to APL, while telephone and/or teletype relay communication is available for the others. A rapid response time with respect to these Doppler ground stations is indicated.

The ground stations associated with the other experiments can detect experiment malfunctions rather rapidly. The maximum detection time is that associated with processing the photographic plates used for optical beacon observations. The time required can be as little as a few hours; however, the plates may not be processed immediately after exposure. The optical beacon, SECOR, and R/RR transponder ground stations are not part of the GEOS operational control loop, primarily because a significant delay is usually involved in analyzing the data (on the order of months). However, specific requests for rapid processing of data samples by GOCC, the GEOS control center at Goddard, would certainly be honored.

The most practical means of monitoring the performance of the experiments is via telemetry when the spacecraft is in view of a STADAN or APL ground station.

Generally, corrective action should be taken as rapidly as possible. If the indication of a malfunction is via telemetry, it would be preferable to issue corrective commands during the same pass of the spacecraft over the controlling ground station. All the STADAN stations, as well as APL, have the capability of issuing commands to GEOS.

In view of the objective of rapidity in making diagnoses and taking corrective action, it was felt that the routines should be somewhat independent, i.e., that any desired routine should be accessible without the necessity of first going through several other routines. The time limitations very obviously make computer applications desirable and this, in turn, makes it desirable that the routines be set up in such a form that they can easily be programmed.

Another factor which influenced the approach is the possibility that the telemetry indication may not be correct, due to a failure in the telemetry subsystem. This possibility creates the potential problem of the observer being deceived. Therefore, means were included where-ever possible for corroborating telemetry data and identifying states of telemetry failure.

The approach consisted of four tasks: (1) relate subsystem failure modes to system operation; (2) evaluate the information available for diagnosis; (3) determine what corrective actions are possible; and (4) set up and implement the procedures. Each of these tasks is discussed below.

a. Relate Subsystem Failure Modes to System Operation

This task consisted of determining the "system" effect of "subsystem" failures. Most of the subsystem failure modes were known from previous assessment work, so that, in general, the task involved determining what equipments are immediately affected by the failure and/or what the long-range effect is (e.g., draining a battery). Since some experiment packages were not assessed, some assumptions based on engineering judgment were made in this area.

b. Evaluate the Information Available for Diagnosis

As mentioned previously, there are two sources of information available: information transmitted via the telemetry transmitter, and experiment response. The only experiment response considered to any extent was Doppler, because it appeared that significant time delay was generally involved with the ground station response of the other experiments.

For the possible failure states from subsection 4.a above, it was determined that most of the needed information was available from telemetry data. This task, then, essentially consisted of specifying what kinds of telemetry indications to look for in order to identify or diagnose the possible failure states.

c. Determine What Corrective Actions are Possible

There are basically four types of corrective actions possible, and these are itemized in Exhibit 1. As can be seen from the exhibit, the number of corrective actions to choose from is fairly limited. The main requirement of this task was, therefore, to ascertain that the corrective action specified for any given circumstance was the best possible.

d. Set Up and Implement the Procedures

This task required "inputs" from the three tasks discussed above in order to provide a timely, systematic method for arriving at the appropriate corrective action. The format utilized for each subsystem was selected on the basis of providing the most efficient procedures for that subsystem. However, each of the formats lends itself to computer programming.

In addition to the subsystem procedures, attention was given to the overall manner in which these procedures could be utilized, and this is discussed in section 3.

3. Overall Utilization Method

The requirements that must be accounted for in the overall utilization method are: (1) the possibility that the telemetry subsystem is in some failure state; (2) the manner and frequency of conducting the procedures for each subsystem; (3) "history" (e.g., care should be taken in switching in a redundant unit if at sometime in the past switching has already been required). The implications of each of these are discussed below. One possible method of overall utilization is included in Exhibit 2.

a. Possibility of Telemetry Failure

Telemetry failure is a distinct possibility, and its importance can be seen when it is considered that the largest amount of information is obtained from PAM data. Since the telemetry subsystem has several easily recognizable failure states (see section 4.e), it would be efficient to determine first if the subsystem is in one of these states.

EXHIBIT 1 - POSSIBLE CORRECTIVE ACTIONS

1. Switch in Redundant Unit	Commands
Oscillator	1a and b
Oscillator Oven	2a and b
Main Converter	3a and b
Memory Unit	13a and b
Memory Converter	30a and b
Boom Squib Fire and 3.9 Volt Zener IN Boom Safe and 4.7 Volt Zener IN	15a and b

2. Switch Power ON/OFF (either singly or in combinations)

On Main Supply	Commands
162 Megacycle On/Off	4a and b
324 Megacycle On/Off	5a and b
972 Megacycle On/Off	6a and b
Telemetry Power On/Off	7a and b
Telemetry Functions On/Off	8a and b
Vector Magnetometer On/Off	9a and b
162 Megacycle Phase Modulation On/Off	19a and b
324 Megacycle Phase Modulation On/Off	20a and b
Telemetry Time Marker On/Off	32a and b

On Transponder Power Supply	Commands
SECOR On/Off	23a and b
SECOR Select On/Off	24a and b
R/RR On/Off	25a and b
R/RR Select On/Off	26a and b
Voltage Sensing Override On/Off	31a and b

EXHIBIT 1 (Continued)

3. Other Switchable Actions	Commands
Solar Power Only On/Off	10a and b
Optical Power Dump	21
Transponder Power Dump	22
Alternate Optical Logic	27 and 28

4. Other Types of Corrective Actions

   a. Special programming for the optical beacon.

   b. Cease to use the optical beacon.

   c. Plan use between the two command logic units.

   d. Send terminal commands.

   e. Send no more commands.

   f. Plan use of equipment on main supply.

   g. Ignore some commutated telemetry data.

EXHIBIT 2 - OVERALL UTILIZATION METHOD

1. Scan telemetry and compare with preset limits to determine if the telemetry subsystem is in one of its possible failure states. Look only for those failure states which are easily identifiable (see Exhibit 12).
2. Is all data usable? (1)
3. Is some data usable?
4. Go to "information lost" mode.
5. Identify those possible subsystem failures (other than telemetry) which will not now be identifiable and correctable due to the requirement of the routine(s) for data that is not usable.
6. Remove these routines from the normal sequence and determine whether to go to "information lost" mode.
7. Should the power supply routines be run?
8. Run the power supply routines.
9. Was any power supply malfunction encountered?
10. Remove any associated routine from the normal sequence and go to next step.
11. Should the thermal control routines be run?
12. Run the thermal control routines.
13. Was any undesirable condition encountered?
14. Remove any associated routine from the normal sequence and go to next step.
15. Should the optical beacon routines be run?
16. Run the optical beacon routines.
17. Was any optical beacon malfunction encountered?
18. Remove any associated routine from the normal sequence and go to the next step.
19. Perform any updating and/or logging required and return to step 1 if desired.

Note: (1) Y - Yes; N - No.

If so, use of the procedures which require data that is recognized as invalid should be inhibited.

The problem of how to proceed when telemetry data is lost must then be faced. One way to handle this is to establish a dichotomy of operating modes, namely, an "information available" mode and an "information lost" mode. The "information available" mode is covered by the subsystem procedures discussed in subsection 3.b.

The "information lost" mode presents problems of a dynamic nature, since before the fact it cannot be stated with certainty what the characteristics of this mode will be. Some of the possible characteristics are as follows:

- The amount of information that must be lost to constitute the "information lost" mode will depend upon the status of the spacecraft at that time. For example, if some previous failure has rendered the optical beacon useless, the loss of optical beacon data would be of no consequence. Another example is loss of information that is needed to diagnose a failure which has a very low probability of occurrence. Therefore, a great deal of data can be lost with insignificant adverse effects if it applies to situations like those in the examples. On the other hand, if situations like these do not exist, even the loss of a small amount of data will be serious.
- The information can be lost "all at once" (e.g., loss of the transmitter) or in serial fashion (e.g., loss of several single channels nonsimultaneously over a fairly long period).
- In some cases, experiment response could conceivably provide very useful information. To determine what these cases were, one would have to consider any remaining valid telemetry data, along with the experiment response information, and then find the failure states which this information would be useful in diagnosing.

From the above discussion, it can be seen that the result of losing information is uncertainty as to (1) whether a failure might have occurred, or (2) what action to take when it is known that a failure has occurred. Since decision theory provides mathematical methods for minimizing risk in the face of uncertainty, its application might prove useful. The application of decision theory to the case of loss of single telemetry channels is presented in Appendix A.

An application of decision theory to decisions involving the GEOS A redundant command converter was carried out to determine the effect of failure of a single telemetry channel on the decision-action procedures.

It was demonstrated that if corroborating evidence based on data from other nonfailed telemetry channels is utilized, then no significant uncertainty remains with respect to decision making; thus the problem of obtaining incorrect telemetry data on a single channel and therefore taking a wrong action was found to be inconsequential if corroborating evidence from other telemetry channels is utilized. The diagnostic routines and decision-action charts presented in this document reflect the philosophy of seeking corroborative evidence.

The application of decision theory to GEOS operational reliability in the grosser situation where there is substantial loss of telemetry and concomitant increase in uncertainty is expected to yield results which are non-intuitive. This application is presently under consideration.

It appears that the following choices are available as operation methods for the "information lost" mode:

(1) Transmit a set of predetermined terminal commands and then transmit no further commands.

(2) Use decision theory to determine what the terminal commands should be, transmit them, and issue no further commands.

(3) Continue operation and use decision theory to determine all actions.

(4) Do nothing.

(5) Combine some of above as conditions indicate, e.g., use (3) as long as possible and then (1) or (2).

The case of the "information lost" mode is being given detailed study in a continuing effort.

b. Manner and Frequency of Conducting Subsystem Procedures

For the case of no loss or insignificant loss of telemetry information, a suggested method is as follows:

- Utilize the optical beacon electronics routine only when pertinent subcommutator channels, photographs of beacon flashes, and/or memory readout indicate trouble.
- Utilize thermal control routine whenever telemetry data is received.
- Utilize command routine whenever commands are given.

- Utilize power supply routine periodically (for example, daily) and whenever called for by other routines.

Exhibit 2 is a graphic presentation of the overall utilization method.

c. History

This is more or less a "bookkeeping" task. It includes such things as the previously mentioned example of preventing a routine from calling for switching in a redundancy when switching has already been necessary in that redundancy. It should be noted, however, that it might be desirable to switch back to a degraded redundant unit if a more serious degradation was found in the other redundant unit.

4. Subsystem Procedures

a. Power Supply

Since the electrical power subsystem is virtually the heart of the spacecraft electronics and is vital to the system operation, a malfunction of any sort may be indicative of a failure in this subsystem. Therefore, if a malfunction is evidenced in another subsystem and the diagnostics for that subsystem either indicate that the trouble is not in that subsystem or do not provide information to determine the cause of the malfunction, the power supply diagnostics should be carried out.

Because of its importance and the fact that a majority of the commands and telemetry indications are associated either directly or indirectly with the power supply, the scope for this subsystem is greater than for any other. There are 37 procedures, most of them independent; they are listed in Exhibit 3.

Some of the general aspects of the procedures should be noted. The first of these concerns the definition of the "high" or "low" indication specified throughout. It was felt that a numerical value for these indications should not be specified at this time. Therefore, "low" should

EXHIBIT 3 - POWER SUPPLY PROCEDURES

A. <u>Indication</u> - Main Power Supply, Solar Current Low (Commutator (C) 1, Channel (Ch) 4)

<u>Procedure</u>

1. Eclipse?[1]
2. Normal indication, no further action required.
3. Transmit command (Cmd) 10a (solar only on) and go to step 4.
4. Are telemetry and Doppler being received correctly?
5. Telemetry (TM) malfunction on Cl, Ch 4. Apply correction factor if possible; otherwise, ignore this channel henceforth. Transmit Cmd 10b if desired.
6. Indicates malfunction in main solar array. Ascertain that main battery remains unloaded until plans can be formulated to conserve remaining battery power.

B. <u>Indication</u> - Main Power Supply, Battery Current Low (Cl, Ch 5)

<u>Procedure</u>

1. Transmit Cmd 10a (solar only on) when not in eclipse.
2. Does Cl, Ch 5, now indicate normal current?
3. Main battery is defective. Plan further operation of equipment on main supply only in sunlight. Attempt to charge battery if situation warrants.
4. Check main battery voltage (C2, Ch 5) and go to step 5.
5. Is voltage normal?
6. Transmit Cmd 10b (solar only off) and wait for eclipse; then go to step 7.
7. Are telemetry and Doppler being received correctly?
8. TM malfunction on Cl, Ch 5. Apply correction factor if possible; otherwise, ignore this channel henceforth and transmit Cmd 10b if desired.
9. Same as step 3 above.

Note: (1) Y - Yes; N - No.

EXHIBIT 3 (Continued)

C. Indication - Main Power Supply, Battery Current High (Cl, Ch 5)

Procedure

1. If in eclipse, unload main supply and wait until sunlight to perform following procedure. If not in eclipse, go to step 2.

2. Is battery on charge or discharge?[1]

3. Indicates high charge rate. This could come about as a result of high solar array output and light loading. If no other malfunction is indicated, the battery should be kept on charge and additional equipment should be turned on. A safe sequence would be to transmit "solar only on" (Cmd 10a), followed by a turn-on of appropriate equipment, followed by "solar only off" (Cmd 10b).

4. Is main bus voltage low (C2, Ch 4)?

5. Go to procedure Y.

6. Transmit the following commands singly to determine if malfunction is in one of the loads:

   a. 162 MC off (Cmd 4b)

   b. 324 MC off (Cmd 5b)

   c. 972 MC off (Cmd 6b)

   d. Telemetry time marker off (Cmd 32b)

   e. Vector magnetometer off (Cmd 9b)

7. Did current return to normal or is battery on charge?

8. Leave malfunctioning unit off and restore other units as desired.

9. Switch to alternate main converter (Cmd 3a or 3b) and go to step 10.

10. Did current return to normal or is battery on charge?

11. Malfunction in main converter. Continue operation with selected converter and restore other units as desired.

12. Either a high leakage path in wiring harness or a telemetry malfunction on this channel. If indication persists for several orbital periods with no detectable consequences, assume that a telemetry channel malfunction exists. Apply correction factor if possible; otherwise, ignore this channel henceforth. Restore commands as desired.

Note: (1) C - Charge; D - Discharge.

EXHIBIT 3 (Continued)

Rationale

Indication is that battery current is high, but it is not known if this is charge or discharge or if the spacecraft is in eclipse or sunlight. If the battery is excessively discharging and the spacecraft is in eclipse, a safe action would be to shut off all main supply loads and wait until sunlight in order to isolate the fault.

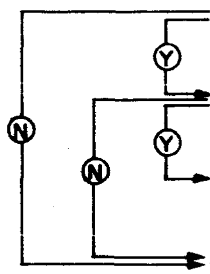
If the fault is not a dead short but is of such magnitude that is could be compensated for by removal of loads, then the battery, if it is discharging in sunlight, will revert to a charging condition after the appropriate amount of load is removed.

The rest of the procedure is to determine if a faulty load is present and, if so, isolate it, to determine if the battery is at fault, and to determine if a fault in the wiring harness is present. If none of these determinations is positive after several orbits, then it can reasonably be assumed that there is a malfunction in the telemetry subsystem.

EXHIBIT 3 (Continued)

D. Indication - Main Converter, Input Current Low (Cl, Ch 6)

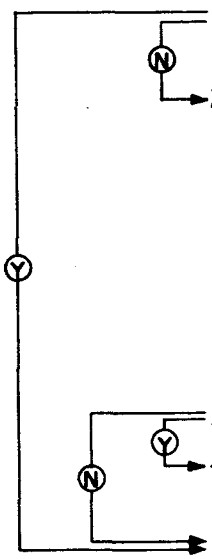
Procedure



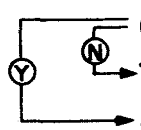
1. Are main converter +21-volt (v) current (Cl, Ch 24) and main converter -32v current (Cl, Ch 25) normal?
2. Are telemetry, Doppler, and vector magnetometers normal?
3. TM malfunction on Cl, Ch 6. Apply correction factor if possible; otherwise, ignore this channel henceforth.
4. Main converter malfunction. Switch to alternate converter (Cmd 3a or 3b).

E. Indication - Main Converter, Input Current High (Cl, Ch 6)

Procedure



1. Are telemetry, Doppler, and vector magnetometers normal?
2. Transmit the following commands singly to determine if the malfunction is in one of the loads:
   a. 162 megacycle (MC) off (Cmd 4b)
   b. 324 MC off (Cmd 5b)
   c. 972 MC off (Cmd 6b)
   d. Telemetry time marker off (Cmd 32b)
   e. Vector magnetometer off (Cmd 9b)
3. Was malfunction isolated?
4. Leave malfunctioning unit off and restore others as desired.
5. Switch to alternate converter (Cmd 3a or 3b) and go to step 6.



6. Is indicated current still too high?
7. Malfunction was in converter.
8. This indicates that the malfunction is in telemetry. Turn off all telemetry equipment (Cmd 7b) and restore operation to original converter if desired. Determine whether the malfunction was only in Cl, Ch 6, and if it should be corrected or ignored, or whether the malfunction is such that it can cause damage, in which case telemetry should remain off henceforth.

EXHIBIT 3 (Continued)

F. Indication - Command Converter, Input Current Low (C1, Ch 7)

Procedure

1. Check the following channels:

   a. Command converter +21v current (C1, Ch 26)

   b. Command converter +21v voltage (C2, Ch 26)

   c. Command converter +4.0v voltage (C2, Ch 27)

   d. Command converter -10.7v voltage (C2, Ch 28)

   e. Receiver 1, automatic gain control (AGC) (C1, Ch 27)

   f. Receiver 2, AGC (C1, Ch 28)

2. Is all of this information normal?

3. TM malfunction on C1, Ch 7. Apply correction factor if possible; otherwise, ignore this channel henceforth.

4. Issue terminal commands.

5. Were terminal commands executed?

6. No further action available.

7. Decide whether terminal commands should remain in effect henceforth.

G. Indication - Command Converter, Input Current High (C1, Ch 7)

Procedure

Same as procedure F above.

EXHIBIT 3 (Continued)

H. Indication - Transponder Power Supply, Solar Current Low (Cl, Ch 8)

Procedure

1. Eclipse?

2. Normal indication. No further action required.

3. Transmit the following commands to remove all loads:

   a. 3.9v command zener to alternate position (Cmd 15a or 15b)

   b. Transponder power dump off (Cmd $22a_1$)

   c. SECOR off (Cmd 23b)

   d. R/RR transponder off (Cmd 25b)

   e. Voltage sensing switch override off (Cmd 31b)

4. Check transponder battery charge rate (Cl, Ch 9)

5. Is charge rate normal?

6. TM malfunction on Cl, Ch 8. Apply correction factor if possible; otherwise, ignore this channel henceforth.

7. Indicates malfunction in transponder solar array. Plan further operation to conserve remaining battery power.

EXHIBIT 3 (Continued)

I. Indication - Transponder Power Supply, Solar Current High (C1, Ch 8)

Procedure

1. Transmit the following commands to remove all loads:

   a. 3.9v command zener to alternate position (Cmd 15a or 15b)

   b. Transponder power dump off (Cmd $22a_1$)

   c. SECOR off (Cmd 23b)

   d. R/RR transponder off (Cmd 25b)

   e. Voltage sensing switch override off (Cmd 31b)

2. Does current return to normal?

3. Indicates load short but not in battery. Reapply loads singly until fault is isolated. Operate without malfunctioning unit henceforth and restore other loads as desired.

4. Is battery charge rate high (C1, Ch 9)?

5. Turn on power dumps (Cmd $22b_2$) and go to step 6.

6. Does solar current return to normal?

7. Proceed normally and restore loads as desired.

8. Transmit commands to apply the following loads and go to step 9:

   a. SECOR on (Cmd 23a and 24a)

   b. R/RR transponder (Cmd 25a)

   c. Voltage sensing switch (Cmd 31a)

9. Does current return to normal?

10. Remain in this load condition until eclipse and proceed with normal eclipse mode operation.

11. No further action. If the transponders function normally, proceed with normal operation.

12. Indicates either a harness short or malfunction on this telemetry channel.

EXHIBIT 3 (Continued)

J. Indication - Transponder Power Supply, Battery Current High (C1, Ch 9)

Procedure

1. Check battery temperature (C2, Ch 8).

2. Is temperature high?

3. Utilize power dump (Cmd $22b_2$).

4. Is battery on charge or discharge?

5. Utilize power dump (Cmd $22b_2$) and go to step 6.

6. Does current return to normal?

7. Proceed normally in this mode.

8. Transmit the following commands to apply all loads and go to step 9:
   a. SECOR on (Cmd 23a)
   b. R/RR transponder on (Cmd 25a)
   c. 3.9v command zener (Cmd 15a)
   d. Voltage sensing switch (Cmd 31a)

9. Does charge rate return to normal?

10. Continue with maximum loading until eclipse operation and then proceed normally.

11. No further action available. Assume telemetry error and proceed normally. Periodically check battery temperature. Restore loads as desired.

12. Transmit the following commands to remove all loads and go to step 13:
    a. SECOR off (Cmd 23b)
    b. R/RR transponder off (Cmd 25b)
    c. Voltage sensing switch (Cmd 31b)
    d. Power dumps off (Cmd $22b_1$)
    e. 3.9v command zener to alternate position (Cmd 15a or 15b)

13. Does current return to normal?

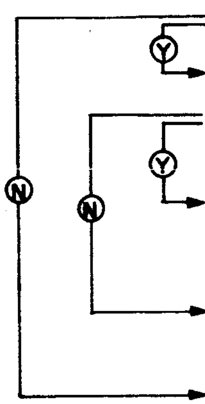
14. Indicates load short. Reapply loads singly until fault is isolated. Operate without malfunctioning unit henceforth and restore other loads as desired.

15. If subsystem appears to function correctly, assume telemetry malfunction on this channel and proceed normally. Restore loads as desired.

EXHIBIT 3 (Continued)

K. Indication - Optical Power Supply, Battery Temperature High (Cl, Ch 16)

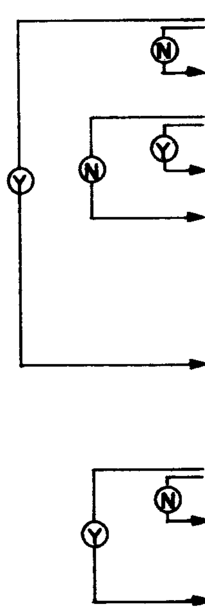
Procedure



1. Is optical battery charge rate high (Cl, Ch 19)?
2. Utilize power dump (Cmd $21b_2$) and go to step 3.
3. Does charge rate remain high (including eclipse periods)?
4. TM malfunction on Cl, Ch 16. Apply correction factor if possible; otherwise, ignore this channel henceforth. Restore power dump if desired.
5. Proceed normally with power dump in position $21b_2$ until situation warrants change.
6. Unless battery has heated up due to general temperature rise of the spacecraft, this indicates telemetry malfunction on Cl, Ch 16.

L. Indication - Optical Power Supply, Battery Current Low (Cl, Ch 19)

Procedure



1. Eclipse?
2. Turn off power dump (Cmd $21a_1$) and go to step 3.
3. Does current return to normal?
4. Proceed with normal operation.
5. Check current during flash sequence. If current is low during flash sequence, the telemetry sense resistor is open. Discontinue use of beacon until operation plan can be formulated.
6. Switch to AOL operation by Cmd 27a and note battery discharge (Cl, Ch 18; subcommutator Ch 1, 4, and 8). Go to step 7.
7. Did the beacon flash?
8. Battery charge circuit is open. Discontinue further optical beacon operation.
9. TM malfunction on Cl, Ch 19. Apply correction factor if possible; otherwise, ignore this channel henceforth. Return to normal beacon operation if desired.

EXHIBIT 3 (Continued)

M. Indication - Optical Power Supply, Battery Current High (Cl, Ch 19)

Procedure

1. Eclipse?
2. Check battery temperature (Cl, Ch 16) and go to step 3.
3. Is temperature high?
4. Utilize power dump (Cmd $21b_2$) and go to step 5.
5. Is current still high?
6. TM error on Cl, Ch 19. Apply correction factor if possible; otherwise, ignore this channel henceforth. Restore power dump if desired.
7. Proceed with normal operation with power dump in $21b_2$ position until situation warrants change.
8. Is optical bus voltage (C2, Ch 18) high?
9. TM error on Cl, Ch 19. Apply correction factor if possible; otherwise, ignore this channel henceforth.
10. Go back to step 4.
11. Switch to alternate memory converter (Cmd 30a or 30b) and go to step 12.
12. Is current still high?
13. Malfunction was in converter.
14. Turn power dump off (Cmd $21a_1$) and go to step 15.
15. Is current still high?
16. Proceed normally with power dump in position $21a_1$ until situation warrants change. Restore use to original converter if desired.
17. Switch to alternate memory (Cmd 13a or 13b) and go to step 18.
18. Is current still high?
19. Malfunction in memory. Continue operation with selected memory and restore other commands if desired.
20. If beacon is functioning normally, assume telemetry malfunction on Cl, Ch 19, and proceed normally or attribute condition to high leakage path.

EXHIBIT 3 (Continued)

N. <u>Indication</u> - Memory Converter, Input Current Low (C1, Ch 20)

<u>Procedure</u>

1. Check the following channels:

   a. Memory converter +10.7 voltage (C1, Ch 21)

   b. Memory converter +4.0 voltage (C1, Ch 22)

   c. Memory converter -10.7 voltage (C1, Ch 23)

2. Is this information normal?

3. TM malfunction on C1, Ch 20. Apply correction factor if possible; otherwise, ignore this channel henceforth.

4. Switch to alternate memory converter (Cmd 30a or 30b) and go to step 5.

5. Are indications normal?

6. Malfunction was in memory converter.

7. Switch to alternate optical logic (AOL) operation and restore original converter if desired.

O. <u>Indication</u> - Memory Converter, Input Current High (C1, Ch 20)

<u>Procedure</u>

1. Switch to alternate memory converter (Cmd 30a or 30b).

2. Is reading normal?

3. Malfunction was in memory converter.

4. Switch to alternate memory unit (Cmd 13a or 13b) and go to step 5.

5. Is input current still high?

6. Malfunction was in memory unit. Continue use with selected memory unit and restore converter if desired.

7. Check the following channels:

   a. Memory converter +10.7 voltage (C1, Ch 21)

   b. Memory converter +4.0 voltage (C1, Ch 22)

   c. Memory converter -10.7 voltage (C1, Ch 23)

8. Is this information normal?

9. TM malfunction on C1, Ch 20. Apply correction factor if possible; otherwise, ignore this channel henceforth and restore commands if desired.

10. Switch to AOL operation.

EXHIBIT 3 (Continued)

P. Indication - Memory Converter, +10.7v Low (Cl, Ch 21)

Procedure

1. Select alternate memory converter (Cmd 30a or 30b).
2. Is voltage still low?
3. Malfunction in memory converter.
4. Select alternate memory unit (Cmd 13a or 13b) and go to step 5.
5. Is voltage still low?
6. Malfunction in memory. Restore original converter if desired.
7. Check operation of optical beacon and go to step 8.
8. Is beacon operating correctly?
9. TM malfunction on Cl, Ch 21. Apply correction factor if possible; otherwise, ignore this channel henceforth. Restore converter and memory unit if desired.
10. Switch to AOL operation.

Q. Indication - Memory Converter, +4.0v Low (Cl, Ch 22)

Procedure

Same as procedure P above.

R. Indication - Memory Converter, -10.7v Low (Cl, Ch 23)

Procedure

Same as procedure P above.

EXHIBIT 3 (Continued)

S. Indication - Main Converter, +21v Current Low (C1, Ch 24)

Procedure

1. Check for normal operation of telemetry commutators and vector magnetometer. Are there indications of malfunction or erratic operation?

2. TM malfunction on C1, Ch 24. Apply correction factor if possible; otherwise, ignore this channel henceforth.

3. Switch to alternate main converter (Cmd 3a or 3b) and go to step 4.

4. Is current normal now?

5. Malfunction in main converter.

6. Send telemetry on and off commands (Cmds 8a and 8b) to test for relay contact closure, and go to step 7.

7. Is current normal now?

8. Fault was in Cmd 8 relay contacts. Proceed with normal operation. Restore original converter if desired.

9. If malfunction indications are associated with the vector magnetometer, discontinue further operations with it (Cmd 9b). If malfunctions are associated with telemetry, continue telemetry operations to the extent possible and until more serious symptoms occur.

T. Indication - Main Converter, +21v Current High (C1, Ch 24)

Procedure

1. Switch to alternate main converter (Cmd 3a or 3b).

2. Is reading normal?

3. Malfunction was in main converter.

4. Switch off vector magnetometer (Cmd 9b) and go to step 5.

5. Is reading normal?

6. Malfunction in vector magnetometer. Restore original main converter if desired.

7. Switch off telemetry functions (Cmd 8b) and decide whether they should remain off henceforth.

EXHIBIT 3 (Continued)

U. Indication - Main Converter, -32v Current Low (Cl, Ch 25)

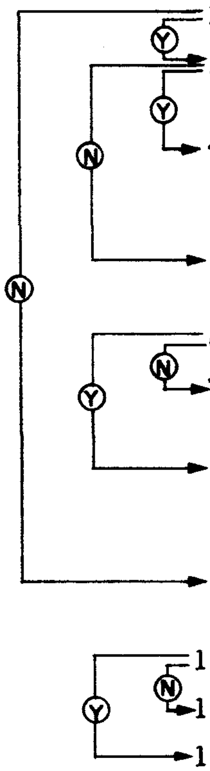
Procedure

1. Transmit the following commands singly to determine if the malfunction is in one of the loads:

   a. 162 MC off (Cmd 4b)

   b. 324 MC off (Cmd 5b)

   c. 972 MC off (Cmd 6b)



2. Did the current reading decrease with each command?

3. Does telemetry show signs of malfunction or erractic operation?

4. Telemetry at fault. Continue telemetry operation to the extent possible and until more serious symptons appear.

5. Switch to alternate main converter (Cmd 3a or 3b) and go to step 6.

6. Does current still read low?

7. Malfunction in main converter. Restore Doppler as desired.

8. Telemetry malfunction on Cl, Ch 25. Apply correction factor if possible; otherwise, ignore this channel henceforth. Restore Doppler and converter if desired.

9. Turn on only the Doppler unit(s) which did not cause a current decrease when switched off, and go to step 10.

10. Does this Doppler unit(s) function normally?

11. Discontinue further Doppler operations with this unit(s).

12. TM malfunction on Cl, Ch 25. Apply correction factor, if possible; otherwise, ignore this channel henceforth. Restore Doppler if desired.

EXHIBIT 3 (Continued)

V. Indication - Main Converter, -32v Current High (C1, Ch25)

Procedure

1. Transmit the following commands singly to determine if the malfunction is in one of the loads:

   a. 162 MC off (Cmd 4b)

   b. 324 MC off (Cmd 5b)

   c. 972 MC off (Cmd 6b)

   The malfunction may be isolated through a process of elimination by comparing -32v current with the sum of current for the two pertinent completely unfailed Doppler units which are turned on in each case.

2. Was the malfunction isolated?

3. Leave malfunctioning unit off and restore others as desired.

4. Switch to alternate main converter (Cmd 3a or 3b) and go to step 5.

5. Is reading normal?

6. Malfunction in main converter. Restore Doppler if desired.

7. Turn the Doppler units back on singly, look for signs of malfunction, and go to step 8.

8. Is Doppler functioning normally?

9. TM malfunction on C1, Ch 25. Apply correction factor if possible; otherwise, ignore this channel henceforth. Restore Doppler and converter if desired.

10. Turn off telemetry system (Cmd 7b).

11. Is Doppler functioning normally?

12. Malfunction in telemetry. Decide whether to operate without telemetry.

13. Malfunction in Doppler. Operate only with those frequencies which show no malfunction. Restore converter and telemetry if desired.

EXHIBIT 3 (Continued)

W. Indication - Command Converter, +21v Current Low (Cl, Ch 26)

Procedure

1. Check +21v voltage (C2, Ch 26) and command converter input current (Cl, Ch 7).

2. Is command converter input voltage high and/or has input current decreased?

3. Telemetry malfunction on Cl, Ch 26. Apply correction factor if possible; otherwise, ignore this channel henceforth.

4. Send terminal commands and go to step 5.

5. Were terminal commands executed?

6. No further action available.

7. Send no further commands if possible, and continue to take available telemetry and experimental data.

X. Indication - Command Converter, +21v Current High (Cl, Ch 26)

Procedure

1. Check +21v voltage (C2, Ch 26) and converter input current (Cl, Ch 7).

2. Is command converter input voltage low and/or has input current increased?

3. Telemetry malfunction on Cl, Ch 26. Apply correction factor if possible; otherwise, ignore this channel henceforth.

4. Send terminal commands and go to step 5.

5. Were terminal commands executed?

6. No further action available.

7. Send no further commands if possible, and continue to take available telemetry and experimental data.

EXHIBIT 3 (Continued)

Y. Indication - Main Power Supply, Bus Voltage Low (C2, Ch 4)

Procedure

1. Switch to alternate main converter (Cmd 3a or 3b).
2. Does voltage return to normal?
3. Malfunction in main converter.
4. Eclipse?
5. Transmit "solar only off" (Cmd 10b) and go to step 6.
6. Does voltage return to normal?
7. Proceed with normal operation. Restore converter if desired.
8. Transmit "solar only on" (Cmd 10a) and go to step 9.
9. Does voltage return to normal?
10. Schedule sun operation only for further use. Restore converter if desired.
11. Transmit the following commands singly to determine if the malfunction is in one of the loads:
    a. 162 MC off (Cmd 4b)
    b. 324 MC off (Cmd 5b)
    c. 972 MC off (Cmd 6b)
    d. Telemetry time marker off (Cmd 32b)
    e. Vector magnetometer off (Cmd 9b)
12. Was malfunction isolated?
13. Leave malfunctioning unit off and restore others if desired.
14. Has telemetry or Doppler shown any signs of malfunction or erratic operation?
15. Is main converter -32v voltage low?
16. Either a high leakage path in wiring harness or a telemetry malfunction on this channel. If indication persists for several orbital periods with no detectable consequences, assume that a telemetry channel malfunction exists. Apply correction factor if possible; otherwise, ignore this channel henceforth. Restore commands as desired.
17. No further telemetry operation possible. Restore other commands as desired.

EXHIBIT 3 (Continued)

Z. Indication - Main Power Supply, Battery Voltage Low(1) (C2, Ch 5)

Procedure

1. Transmit solar only on (Cmd 10a) and wait until not in eclipse to go to step 2.
2. Is voltage still low?
3. Go to procedure Y.
4. Transmit solar only off (Cmd 10b) and go to step 5.
5. Did battery charge?
6. Proceed with normal operation.
7. No further action. Schedule sun operation only.

AA. Indication - Main Power Supply, Battery Temperature High (C2, Ch 6)

Procedure

1. Check main battery current (C1, Ch 5).
2. Is current high?
3. Go to procedure C.
4. Unless battery has heated up due to general temperature rise of spacecraft, this indicates telemetry malfunction on C2, Ch 6.

Note: (1) Low voltage may be considered as any value $\leq$ 8.4v. 100 percent depth of discharge for these cells is 1.0v, and 8.4v is equivalent to 1.05v per cell for eight cells.

EXHIBIT 3 (Continued)

BB. Indication - Command Converter, Input Voltage Low (C2, Ch 7)

Procedure

1. Transmit terminal commands.
2. Were terminal commands executed?
3. No further action available.
4. Did the voltage rise?
5. The terminal commands caused enough unloading for the voltage to rise. Careful use of the command subsystem might be possible. Turning off SECOR and the R/RR transponder and using the transponder power supply to drive the command converter might be considered.
6. Leave terminal commands in effect.

CC. Indication - Transponder Power Supply, Battery Temperature High (C2, Ch 8)

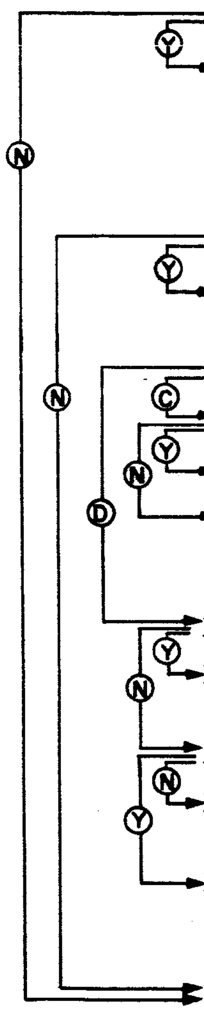
Procedure

1. Check transponder battery current (Cl, Ch 9).
2. Is current high?
3. Go to procedure J.
4. Unless battery has heated up due to general temperature rise of spacecraft, this indicates telemetry malfunction on C2, Ch 8.

EXHIBIT 3 (Continued)

DD. Indication - Transponder Power Supply; Bus Voltage Low (C2, Ch 9)

Procedure



1. Transmit the following commands to remove loads:
   a. Power dump off (Cmd $22a_1$)
   b. SECOR off (Cmd 23b)
   c. R/RR transponder off (Cmd 25b)
2. Is voltage still low?
3. Transmit the following commands and go to step 4:
   a. 3.9v command zener to other position (Cmd 15a or 15b)
   b. Voltage sensing switch override off (Cmd 31b)
4. Is voltage still low?
5. Check the transponder battery current (Cl, Ch 9) and go to step 6.
6. Is battery on charge or discharge?
7. Is current high?
8. Indicates defective battery. No further action available.
9. Unless abnormal operation is noted in the future, this would indicate a telemetry malfunction on C2, Ch 9. Restore loads as desired.
10. Is current high?
11. Indicates random short or uncalibrated telemetry resistor.
12. Does solar current (Cl, Ch 8) equal the battery current?
13. Indicates random short on the transponder bus. No further action available.
14. Telemetry malfunction on C2, Ch 9. Apply correction factor if possible; otherwise, ignore this channel henceforth. Restore loads as desired.
15. Malfunction located. Proceed without malfunctioning unit and restore others if desired.

EXHIBIT 3 (Continued)

EE. Indication - Optical Power Supply, Battery (Bus) Voltage Low (C2, Ch 18, subcommutator Ch 8)

Procedure

1. Switch to alternate memory converter (Cmd 30a or 30b).
2. Is voltage still low?
3. Malfunction in converter.
4. Turn power dump off (Cmd $21a_1$) and go to step 5.
5. Is voltage still low?
6. Proceed with normal operation with power dump in this position until conditions warrant otherwise. Restore converter if desired.
7. Check battery current (C1, Ch 9) and go to step 8.
8. Is battery on charge or discharge?
9. Is current high?
10. Indicates defective battery.
11. Telemetry malfunction on C2, Ch 18, subcommutator Ch 8. Apply correction factor if possible; otherwise, ignore this channel henceforth. Restore commands as desired.
12. Eclipse?
13. Indicates defective battery.
14. Is current high?
15. Indicates random short. Determine if normal operation can be continued or if AOL can be used.
16. If operation has been normal, this would indicate a telemetry malfunction on C2, Ch 18, subcommutator Ch 8. Apply correction factor if possible; otherwise, ignore this channel henceforth. Restore commands as desired.

EXHIBIT 3 (Continued)

FF. Indication - SECOR Regulator, Output Voltage Low (C2, Ch 19)

Procedure

1. Transmit "R/RR transponder off" (Cmd 25b).

2. Did voltage return to normal?

3. Malfunction in R/RR transponder.

4. Transmit "voltage sensing switch override off" (Cmd 31a) and go to step 5.

5. Did voltage return to normal?

6. Malfunction in override switch. Restore R/RR transponder if desired.

7. Turn off power dump (Cmd $21a_1$) and go to step 8.

8. Did voltage return to normal?

9. Proceed with normal operation with power dump in this position until conditions warrant otherwise. Restore R/RR transponder and override switch if desired.

10. Transmit "SECOR off" (Cmd 23b) and go to step 11.

11. Did voltage return to normal?

12. Discontinue SECOR operation. Restore other commands if desired.

13. If SECOR shows no sign of malfunction, a telemetry malfunction on C2, Ch 19, is indicated. Restore commands as indicated.

EXHIBIT 3 (Continued)

GG. Indication - SECOR Regulator, Output Voltage High (C2, Ch 19)

Procedure

A failure of some sort is indicated in the SECOR regulator, probably a short in the series transistor. Given that the voltage is high, an attempt should be made to load the transponder bus so that the bus voltage drops to a usable range for SECOR. This additional loading may be provided by turning on the power dumps (Cmd $22b_2$), turning on the R/RR transponder, and sending Command 15a. These commands may be sent in whatever combination achieves the desired result of holding input voltage to SECOR near 12 volts. If this attempt fails, discontinue SECOR operation.

EXHIBIT 3 (Continued)

HH. Indication - Main Converter, -32 Volts Low (C2, Ch 25)

Procedure

1. Transmit the following commands singly to determine if the malfunction is in one of the loads:

   a. 162 MC off (Cmd 4b)

   b. 324 MC off (Cmd 5b)

   c. 972 MC off (Cmd 6b)

2. Was malfunction isolated?

3. Leave malfunctioning unit off and restore others as desired.

4. Switch to alternate main converter (Cmd 3a or 3b) and go to step 5.

5. Is voltage still low?

6. Malfunction was in main converter. Restore Doppler as desired.

7. Turn on the Doppler units singly and look for signs of malfunction and for signs of telemetry malfunction; then go to step 8.

8. Was any malfunction noted?

9. Telemetry malfunction on C2, Ch 25. Apply correction factor if possible; otherwise, ignore this channel henceforth. Restore Doppler and converter if desired.

10. Turn off telemetry (Cmd 7b) and operate without it henceforth. Restore other units if desired.

II. Indication - Command Converter, +21v Voltage Low (C2, Ch 26)

Procedure

Go to procedures W and X.

JJ. Indication - Command Converter, +4v Voltage Low (C2, Ch 27)

Procedure

Go to procedure F.

KK. Indication - Command Converter, -10.7v Voltage Low (C2, Ch 28)

Procedure

Go to procedure F.

be construed to mean any indication below the normal lower bound (including zero) and "high" any indication above the normal upper bound.

The second of these concerns the "terminal commands." It is not specified what these include, but they should consist of those commands necessary to place the spacecraft in its desired final state. They are utilized in these procedures when there is a distinct possibility that a condition exists which may render the command subsystem useless.

Finally, in some cases, the "safe" actions are called for before any diagnosis is undertaken. These cases include those in which serious damage might be done immediately or over the period of the next orbit if the spacecraft were to go out of range before the diagnostic was completed. Examples of this would be calling first for terminal commands or unloading a battery and then proceeding with the diagnosis.

b. Optical Beacon and Associated Electronics

The following are three "quick actions" which can be taken to correct the effects of malfunctions in the optical beacon. The Alternate Optical Logic (AOL) will be discussed later.

(1) "Switch memories" (i.e., switch in a redundant memory and control unit) - Command 13a or 13b. Note that the memory which is switched in will not operate until it has been loaded from the ground.

(2) "Switch oscillators" (i.e., switch in a redundant 5-megacycle oscillator as the memory timing source) - Command 1a or 1b.

(3) "Switch oscillator oven heaters" (i.e., switch in a redundant heater unit which controls the temperature of the oven in which the oscillators are located) - Command 2a or 2b.

Exhibit 4 presents the procedures to be followed in attempting to overcome any indicated malfunctions.

EXHIBIT 4 - OPTICAL BEACON AND ASSOCIATED ELECTRONICS PROCEDURES

A. Indication

Indication may be:

a. All 5 flash sequences inhibited.

b. All 7 flash sequences inhibited.

c. The inability to read memory after loading.

d. Presence of memory readout in place of normal telemetry at all times.

e. Extraneous flashing.

Procedure

1. Switch to alternate memory (Cmd 13a or 13b).
2. Is operation correct now?
3. Memory malfunction.
4. Double memory malfunction. Determine whether to use special programming or the AOL.

EXHIBIT 4 (Continued

B. Indication - **Flash Intensity Low During Flashing**

Procedure

1. Is flash intensity low for all lamps?
2. Is + and - ramp normal for this lamp?
3. Either lamp is defective or telemetry flash intensity link is defective. Check via photographs.
4. Switch to alternate memory unit and go to step 5.
5. Is operation normal now?
6. Malfunction in memory unit.
7. Omit this lamp from future programming. Malfunction in optical beacon lamp assembly (or both memory units have a malfunction in the same section of lamp selection equipment; this can be checked by attempting to flash this lamp via the AOL. If lamp operates with AOL, decide whether to omit this lamp from future programming or operate with AOL.).
8. Switch to alternate memory unit and see if flashes occur; then go to step 9.
9. Did flash sequence occur?
10. Malfunction in memory unit.
11. Go back to other memory unit and select alternate oscillator; then go to step 12.
12. Did flash sequence occur?
13. Malfunction in oscillator.
14. Attempt flash sequence with AOL and go to step 15.
15. Did flash sequence occur?
16. Continue use with AOL.
17. Flash capability is gone.

EXHIBIT 4 (Continued)

C. Indication - Continuous Flashing

Procedure

1. Is flashing continuous in only one lamp?
2. Optical beacon malfunction.
3. Switch to alternate memory unit (Cmd 13a or 13b) and go to step 4.
4. Is continuous flashing still present?
5. Optical beacon malfunction.
6. Memory malfunction.

D. Indication - Memory Readout Shows Incorrect Flash Count

Procedure

1. Call for check of recent beacon photographs.
2. Switch to alternate memory unit (Cmd 13a or 13b).
3. Call for check of photographs of beacon flashes occurring after memory switch.
4. Compare results of the two photo checks.
5. Do photos indicate that system is operating properly?
6. Memory malfunction.
7. Optical beacon failure.

EXHIBIT 4 (Continued)

E. Indication

Indication may be:

a. Memory readout shows improper data word (1-59) contents.

b. Programmed flashes do not occur.

c. Inability to read memory after loading.

d. Inability to verify injected load.

e. Flash sequences out of time reference.

Procedure

1. Switch to alternate memory unit (Cmd 13a or 13b).
2. Is operation normal now?
3. Memory malfunction.
4. Switch to alternate oscillator (Cmd 1a or 1b).
5. Is operation normal now?
6. Oscillator malfunction. Go back to original memory unit if desired.
7. Switch to alternate oven (Cmd 2a or 2b).
8. Is operation normal now?
9. Oven malfunction. Go back to original memory unit and oscillator if desired.
10. Double failure of memories, oscillators, or ovens.

If all attempts to correct the improper operation are unsucessful, the failure is located either in the optical beacon, the optical power supply, or the interface between the optical beacon electronics and the AOL (which is the backup system for the memory and control unit). If the failure is in the optical beacon, no corrective action is possible, except that future memory programming might be able to minimize the effects of the failure. If the failure is in the power supply, the procedures for that subsystem should provide the necessary corrective action. If the failure is in the interface, the AOL can probably still be used as a backup system.[1] The decision as to whether to employ the AOL should be based on the degree of severity of the improper operation as compared with the limitations of the AOL. For example, if the failure effect is the loss of all memory-commanded flash capability, then the AOL would have to be used; but if only one flash assembly is lost, proper programming might be preferable to use of the AOL. The AOL can only serve optical beacon ground stations which have mutual visibility of the spacecraft with one of the STADAN stations or APL.

If the discovery of improper operation has resulted in the switching in of a redundant memory and control unit, and a failure in this unit is discovered, the decision as to what action is to be taken should be based on the relative value to be gained from use of the two degraded memory and control units and the AOL.

Indications of improper operation of the optical beacon experiment can be found via the following:

- Telemetry subcommutator channels which monitor the flash assembly operation and flash intensity. (Continuous flashing, extraneous flashing, absent flash sequences, inoperative flash assemblies, etc., can be discovered from this source.)

[1]Only four of the 30 applicable failure effects involve loss of the AOL.

- Inspection of photographs taken of flash sequences by ground cameras. (Absent flash sequences, flash sequences which are out of time reference, and sequences having low intensity can be discovered from this source.)
- Incorrect number in the flash count word during the memory preload readout. (Absent flash sequences and extraneous flash sequences can be discovered from this source.)
- Incorrect numbers in the 59 data words during the memory readout. (Memory data handling errors resulting in many failure effects can be discovered from this source.)
- Inability to properly load memory.
- Inability to read or verify memory after loading.
- Presence of memory readout in place of normal telemetry at all times.

c. Thermal Control Subsystem

(1) Analysis Inputs

The inputs that are available for a thermal analysis are telemetry data from commutator 1, commutator 2, and telltale register 3. The telemetry data from the commutators represent temperatures measured by thermistors, while the telltale register provides indication of the state of battery thermostats. Exhibit 5 shows the location of the components which are monitored by the telemetry data.

(2) Analysis Outputs

The primary objective of this analysis is to provide a method by which certain telemetry data may be monitored, and thus to provide a means of ameliorating critical thermal conditions if they should arise. Since the equipment being monitored is

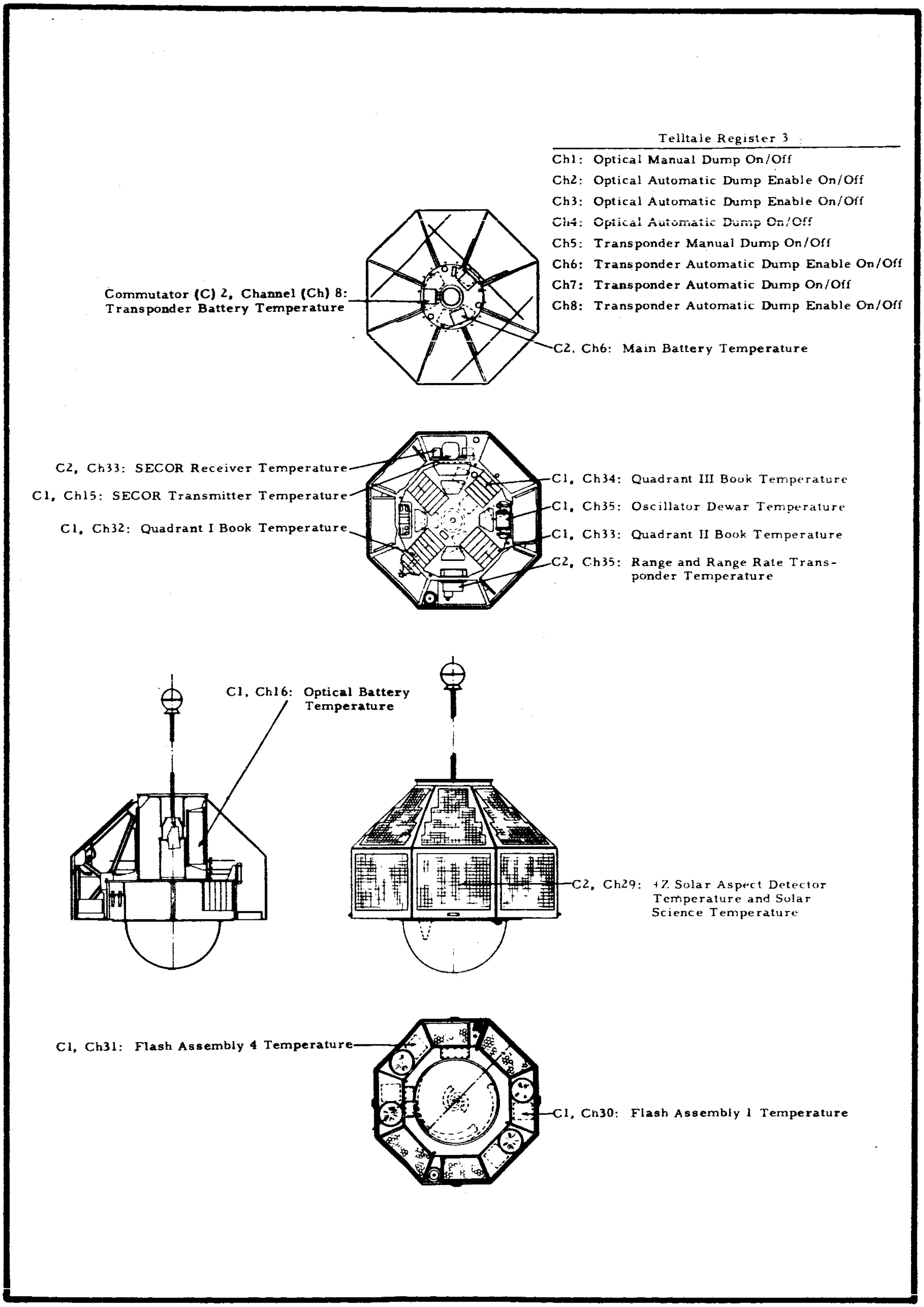


EXHIBIT 5 - LOCATION OF THERMAL CONTROL INDICATORS FOR TELEMETRY

electronic in nature, most failures will occur in an abrupt manner in comparison to the 24-second time period between temperature readings for one channel. The abruptness is even more acute when one considers that telemetry is generally monitored only over APL. The maximum telemetry read-out time is approximately 20 minutes out of each orbit.

The cause of these failures may be (1) nonadjustment to circuit or environmental conditions, (2) random-type failure, or (3) wearout through use. The first type of failure will, for the most part, be taken care of in preliminary engineering work.

The purpose of this analysis will then be to determine what equipment to turn "off" that normally would be "on," or vice versa, to achieve a thermal condition that will not further degrade the spacecraft electronic systems. Exhibit 6 illustrates the basic philosophy that has been taken to arrive at the diagnostic routine. It shows that there is an operating "upper temperature limit" at which parts in a component cannot be expected to perform within circuit-defined specifications. There is an "expected operating upper temperature limit" which may be determined by calculations and tests simulating operation of the spacecraft in view of solar radiation. And, in like manner, there is an "expected operating upper temperature limit" which may be determined by calculations and tests simulating operation of the spacecraft in eclipse of solar radiation. There is a "lower temperature limit" at which certain parts will not function within specification; thus, the components containing these parts must be kept above this temperature. There are also a pair of "expected operating lower temperature limits" corresponding to the sun and eclipse conditions. It may be pointed out that the relationship between "upper temperature limit" and "expected operating upper temperature limit" is, in fact, a measure of the margin of safety of the design.

The thermal stress is a function of the time rate of change of temperature. Therefore, the time rate of change of temperature of

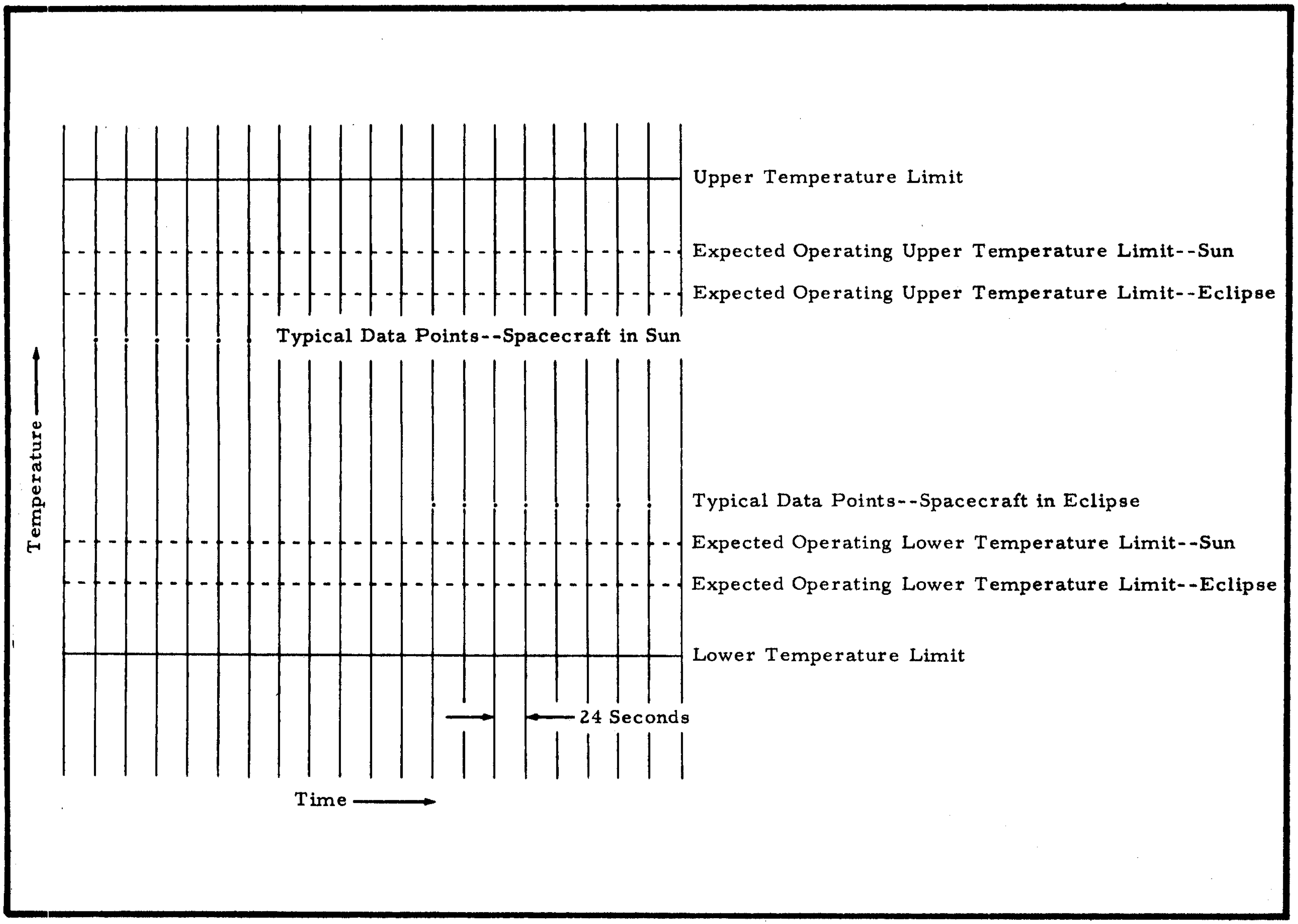


EXHIBIT 6 - TEMPERATURE-TIME PROFILE

each temperature telemetry point will be monitored and, if this value should exceed a predetermined maximum value, an indication of impending trouble will be signaled. The maximum value of the time rate of change of temperature for each temperature point can be determined from thermal stress considerations for all parts in the spacecraft. Transient thermal testing and/or analytical modeling will be required to determine these values. In addition, the expected temperature (T_n) for n multiples of an orbital period will be estimated by the equation $T_i + (dT/dt)n\Delta t = T_n$, where t is equal to elapsed time, T is temperature, and T_i is the most recent temperature reading. The value of T in this extrapolation is the average temperature recorded during a single pass per telemetry point. Variations in temperature during a given pass are expected to be small. It is suggested that n take on integer values from 1 to 10.

Exhibit 7 represents a format for recording the pertinent limiting values of temperature and time rate of change of temperature for the pertinent subcommutator channels. PRC, at present, is not in a position to specify these values. Considerations of current design and part life-time are involved in setting such values. Furthermore, it is necessary to relate the monitored temperatures with the temperatures of all critical parts in the spacecraft under steady-state and transient conditions. Thus, exercise of a computerized thermal analytical model and/or thermal vacuum tests are required to establish these relationships.

Exhibit 8 presents a list of the telltale telemetry points associated with thermal control.

Exhibit 9 is a tabular presentation of the diagnostic routine.

The decision-action chart shown in Exhibit 10 provides remedies, where they exist, based on the results of the diagnostic routine. The decision-action chart provides a remedy for abnormal temperature conditions for certain components that can be controlled from the ground.

d. Command Subsystem

The command subsystem consists of two redundant receivers, two redundant logic units, and a matrix. Since the receivers

EXHIBIT 7 - TEMPERATURE VALUES FOR SUBCOMMUTATOR CHANNELS

Table of Values

Channel		Column 1 Upper Temperature Limit	Column 2 Expected Operating Upper Temperature Limit-- Sun	Column 3 Expected Operating Upper Temperature Limit-- Eclipse	Column 4 Expected Operating Lower Temperature Limit-- Sun	Column 5 Expected Operating Lower Temperature Limit-- Eclipse	Column 6 Lower Temperature Limit	Column 7 Maximum dT/dt
Commutator 1								
15	Range Transponder (SECOR) Transmitter Temperature							
16	Optical Battery Temperature							
30	Flash Assembly 1 Temperature							
31	Flash Assembly 4 Temperature							
32	Quadrant I Book Temperature							
33	Quadrant II Book Temperature							
34	Quadrant III Book Temperature							
35	Oscillator Dewar Temperature							
Commutator 2								
6	Main Battery Temperature							
8	Transponder Battery Temperature							
29	+ Z Solar Aspect Detector Temperature and Solar Science Temperature							
33	SECOR Receiver Temperature							
35	Range and Range Rate Transponder Temperature							

EXHIBIT 8 - TELLTALE TEMPERATURE CHANNELS

Telltale Register 3, Commutator 1, Channel 29

Telltale Number	Telltale Indication	
	High	Low
1	Optical Manual Dump OFF	Optical Manual Dump ON
2	Optical Automatic Dump Enable OFF	Optical Automatic Dump Enable ON
3	Optical Automatic Dump Enable OFF	Optical Automatic Dump Enable ON
4	Optical Automatic Dump OFF	Optical Automatic Dump ON
5	Transponder Manual Dump OFF	Transponder Manual Dump ON
6	Transponder Automatic Dump Enable OFF	Transponder Automatic Dump Enable ON
7	Transponder Automatic Dump OFF	Transponder Automatic Dump ON
8	Transponder Automatic Dump Enable OFF	Transponder Automatic Dump Enable ON

EXHIBIT 9 - THERMAL CONTROL SUBSYSTEM DIAGNOSTIC ROUTINE

	Check	Result	Instruction	Comments
1.	Check voltage calibration of channels 1, 2, and 3 of commutators 1 and 2.	True	Execute step 2.	Thermistor readings depend on calibration of voltage sources for accuracy.
		False	Print voltage deviation for each channel.	
2.	Check for reception of data on channels listed in Exhibit 7.	True	Execute step 3.	
		False	Print "No Data."	
3.	Store present values of channels listed in Exhibit 7.			
4.	Compare values stored in step 3 with values listed in Exhibit 7; i. e., subtract value from column 2 or 3 of Exhibit 7, as appropriate, and subtract column 4 or 5 of Exhibit 7 from value. Are differences negative?	True	Print "Value Exceeds Limits," and below print each channel number which exceeds limits, its value, the negative difference value, and the appropriate limit which is exceeded, i. e., upper or lower. First pass return to step 1. All subsequent passes execute step 5.	
		False	First pass return to step 1. For all subsequent passes execute step 5.	
5.	For each channel listed in Exhibit 7, subtract reading for previous time period, divide by 24 seconds, and store.			
6.	For each of the results of step 5, subtract the values of column 7 of Exhibit 7. Are differences negative?	True	Print "Rate Exceeds Limit," and below print each channel number which exceeds rate limit, its value, and the negative difference value.	
		False	Proceed to step 7.	
7.	Extrapolate temperature readings for each channel over n orbital periods. Calculate average temperature for each channel for each orbit. Calculate time rate of change of temperature per orbital period $(dT/dt)_n$. Then, $$T_n = T_i + n\left(\frac{dT}{dt}\right)_n$$ where T_i is the most recent temperature reading, T_n is the temperature after n orbital periods, and the weighted average orbital rate of change of temperature is: $$\left(\frac{dT}{dt}\right)_n = \frac{\left(\frac{dT}{dt}\right)_i + \frac{n}{n+1}\left(\frac{dT}{dt}\right)_{i-1} + \frac{n}{n+2}\left(\frac{dT}{dt}\right)_{i-2} + \cdots \frac{n}{2n-1}\left(\frac{dT}{dt}\right)_{i-n+1}}{1 + \frac{n}{n+1} + \frac{n}{n+2} + \cdots \frac{n}{2n-1}}$$ Subscript i refers to the most recent orbit average, subscript i-1 refers to the orbit average previous to i ; and so forth.		Print "Rate Exceeds Limit" for all values of $(dT/dt)_n$ which exceed values of column 7, Exhibit 7.	
8.	Same as step 4.	True	Same as step 4, except return to step 1.	
		False	Return to step 1.	

EXHIBIT 10 - THERMAL CONTROL SUBSYSTEM DECISION-ACTION CHART

Assumed Malfunction	Symptomatic Indications	Effects of Malfunction	Required Action
QI or QII or QIII Book temperature is excessive	Temperature reading of channel (CH) 32 or 33 or 34 of commutator (C) 1 is above the value in column 2 or 3, as appropriate, of Exhibit 7.	Overheating of other electronic components in Book	Determine what electronic components are "on" in the Book under consideration, and discontinue use of the one causing the excessive power demand.
QI or QII or QIII Book temperature is too low	Temperature reading of Ch32 or 33 or 34 of C1 is below value in column 4 or 5, as appropriate, of Exhibit 7.	Temperature too low for normal operation of electronics	Turn on electronic components in the Book under consideration that are not normally on to increase heat dissipation. (This action must be constrained so as not to exceed the battery capability.)
Oscillator Dewar Temperature is too low	Temperature reading of Ch35 of C1 is below value in column 4 or 5, as appropriate, of Exhibit 7.	Temperature too low for normal operation	Use command (Cmd) 2a or 2b to turn on redundant oven heater.
Optical Battery Temperature is too high	Temperature reading of Ch16 of C1 is above value in column 2 or 3, as appropriate, of Exhibit 7.	Excessive temperature will damage battery	Use Cmd $21b_1$ or $21b_2$ to manually turn on power dump. Check telltale register 3, bits 3 and 4, to confirm that above commands are carried out. If malfunction persists, call Power Supply Routine.
Transponder Battery Temperature is too high	Temperature reading of Ch8 of C2 is above value in column 2 of Exhibit 7.	Excessive temperature will damage battery	Use Cmd $22b_1$ or $22b_2$ to manually turn on power dump. Check telltale register 3, bits 7 and 8, to confirm that commands are carried out. If malfunction persists, call Power Diagnostic Routine.
Main Battery Temperature is too high	Temperature reading of Ch6 of C2 is above value in column 2 or 3, as appropriate, of Exhibit 7.	Excessive temperature will damage battery	Call Power Supply Diagnostic Routine
SECOR Transponder Temperature or SECOR transmitter temperature is too high	Temperature reading of Ch33 or 34 of C2 is above value in column 2 or 3, as appropriate, of Exhibit 7.	Overheating may cause malfunction of SECOR transponder	Use Cmd 23b to turn off power to the SECOR transponder.
R/RR Transponder Transponder temperature is too high	Temperature reading of Ch35 of C2 is above value in column 2 or 3, as appropriate, of Exhibit 7.	Overheating may cause malfunction of R/RR transponder	Use Cmd 25b to turn off power to the transponder.
"Rate Exceeds Limits" From Steps 6 and 7 of the diagnostic routine (Exhibit 9) for each channel listed under this heading, time rate of change of temperature is excessive	Rate exceeds limits of column 7 of Exhibit 7.	Excessive thermal stress	Adjust power dissipation in the spacecraft by turning electronic components on and off so as to reduce the time rate of change of temperature at the spacecraft locations which correspond to each of the telemetry channels listed under "Rate Exceeds Limits."

are far more reliable than the digital sections, attention was concentrated on the failure states that can occur in a logic unit or the matrix. Also, since in this case single failures appear more likely than multiple failures, the condition of both logic units being in failure states was not specifically considered. The possibility, however, of such an occurrence was pointed out where applicable and should be discussed at this point.

When a command is transmitted, one of the following four things will occur:

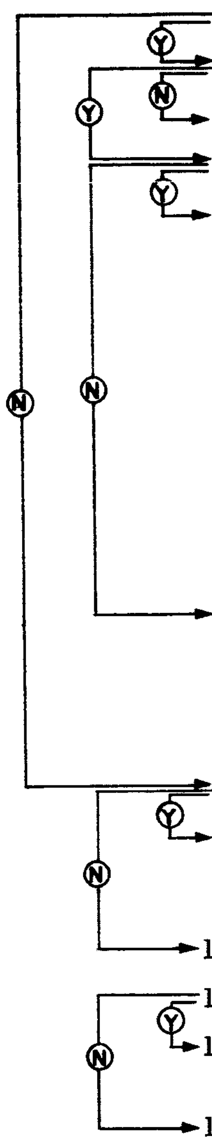
(1) The command is executed correctly.
(2) The command is not executed.
(3) One or more extra commands are executed along with the transmitted one.
(4) The wrong command is executed.

Occurrences (2) and (3) can be caused by failure(s) in either a logic unit or the matrix. Most of these possible failures are either row-, column-, or tone-oriented. Thus, multi-failure states can exist in which a given row, for example, cannot be selected from logic unit 1 and a given column cannot be selected from logic unit 2. In this example, only one command is actually lost, i. e., the one at the intersection of the specified row and column. If this happened to be the command one was attempting to execute, it might be concluded that the entire command subsystem was nonoperable.

In cases like this, two approaches are possible to determine the extent of the failure. "Trouble-shooting" can be done, i. e., commands can be transmitted solely for the purpose of determining which ones are available and from which logic unit. Another approach is to transmit only those commands called for by normal operation and to record whether they were executed and, if so, by which logic unit. Thus, after some period, the nature of the failure state could be deduced from the records. The decision as to which approach to use would have to be based on the importance of knowing the exact state of the subsystem and the risk of transmitting a command during trouble-shooting that the failure state would make impossible to retract.

Exhibit 11 presents a procedure for arriving at the corrective action for the various states that can occur. The failure state numbers

EXHIBIT 11 - COMMAND SUBSYSTEM PROCEDURE



1. Transmit command via logic unit 1.
2. Was command executed?
3. Was extra command executed?
4. Proper operation. Continue to use logic unit 1.
5. Was more than one extra command executed?
6. Failure in either logic unit 1 or, more likely, the matrix has caused failure state 12. Attempt to turn off the extra commands via logic unit 2. If failure is in the matrix, more extra commands may be executed in the attempt to turn off the previous extra commands. Unless failure is clearly in the matrix, continue operation with logic unit 2. Similar occurrences in the future would indicate that the failure is in the matrix. If this is the case, there is no remedy except to try to determine where the failure is, in order to inhibit transmittal of those commands which could cause undesirable extra command executions.
7. This could be a special case of failure state 12 due to a failure in the matrix, although more likely it is failure state 11 due to a failure in logic unit 1. Turn off the extra command with logic unit 2 and continue operation with logic unit 2.
8. Was wrong command executed?
9. Logic unit 1 is in failure state 10. Turn off wrong command, reissue first command via logic unit 2, and use logic unit 2 henceforth.
10. Reissue command via logic unit 2 and go to step 11.
11. Was command executed?
12. Logic unit 1 is in failure state 3, 4, 5, 6, 7, 8, or 13. Use logic unit 2 henceforth.
13. Go to power supply procedures and check command converters. If these routines indicate the converters and receivers are operable, then either the command subsystem is in failure state 1 or 9 or else both logic units are in some combination of states 3, 4, 5, 6, 7, 8, or 13.

shown in Exhibit 11 can be found in the failure mode and effect analysis, Appendix B, TAM 106-1.

Not shown in the exhibit but implicit in each action is an indication check. For most commands, there is a telltale indication available from telemetry. In some cases, there will be other telemetry indications and/or experiment response indications. The status of each command function (i.e., "off" or "on") should be known prior to command transmission and checked again after command transmission. This is necessary not only to learn whether the command was executed, but also discover whether an extra command or a wrong command was executed.

e. Telemetry Subsystem

No corrective action is possible in the event of telemetry failures other than turning off the telemetry subsystem if it is causing undue power drain. If possible, the power supply subsystem routines should be used to determine if this is the case.

That aspect of the telemetry subsystem given most consideration in this analysis was the nature of its failure states. The failure mode and effect analysis revealed 20 major failure states, as listed in Exhibit 12. In all states except state 1, some valid data will be transmitted. In order to make use of the transmitted data, one must be able to discern which of the data are valid and which are invalid. This should be fairly easily discernible for all but the following states:

State 3 (lose 60 channels)
State 4 (lose 56 channels)
State 12 (lose 1 commutated channel)
State 13 (lose 1 subcommutated channel)
State 14 (lose 5 telltale (TT) bits)
State 15 (lose 1 TT bit)

States 3 (lose 60 channels) and 4 (lose 56 channels) represent such major losses that, should one of them occur, it might be thought that both commutators were lost. In state 3, only five specific channels will be transmitted by each commutator, for a total of 10 channels. Seven channels will be transmitted by each commutator for a total of 14 channels in state 4.

EXHIBIT 12 - GEOS TELEMETRY SUBSYSTEM FAILURE STATES

Failure State	Loss
1	All telemetry
2	Both commutators
3	60 channels (30 from each commutator)
4	56 channels (28 from each commutator)
5	Commutator 2 and memory readout
6	Any commutator
6a	Commutator 1
6b	Commutator 2
7	Both subcommutators
8	Any subcommutator
8a	Subcommutator 1
8b	Subcommutator 2
9	All TT registers
10	Any TT register
10a	TT register 1
10b	TT register 2
10c	TT register 3
11	7 commutated channels
12	1 commutated channel
13	Any subcommutated channel
13a	1 subcommutated channel, subcommutator 1
13b	1 subcommutated channel, subcommutator 2
14	Any 5 TT bits, TT register
14a	5 TT bits, TT register 1
14b	5 TT bits, TT register 2
14c	5 TT bits, TT register 3
15	Any 1 TT bit, TT register
15a	1 TT bit, TT register 1
15b	1 TT bit, TT register 2
15c	1 TT bit, TT register 3

EXHIBIT 12 (Continued)

Failure State	Loss
16	Any flash intensity information
16a	Flash intensity information and flash count to memory
16b	Flash intensity information
16c	2, 3, or 4 flash intensity information
17	Memory readout
18	Time marker
19	Sync
20	All temperature indications

Analysis will be required to determine which channels are being transmitted.

States 12 and 13 are similar in many respects. They are both caused by similar failures, and, for both, only one channel (commutated for state 12, subcommutated for state 13) is lost. Also, for both states, the analog data in the channel will appear to take on some steady-state value. It will have to be determined whether the failure is in the telemetry equipment or in the equipment associated with the measurement. In some cases, this will create no problem. In cases where it is difficult to determine, the commutator could be commanded to stop on the channel in question, and the data could be examined as a function of time. Enough evidence may be gathered in this mode to make the determination.

State 14 (lose five TT bits) can cause difficulty in detection if the bits give apparently correct information (i.e., if they indicate that five command functions are "off" and they are in fact "off," or four of the five are in fact "off"). This could result in a command being given that might place the spacecraft in some undesired operational state. It can be reasonably assumed that, after enough commands have been given, the failure state will be known. In this case, it will be helpful if one of the lost bits is associated with an equipment which has an identifiable response (one of the transponders, for instance).

The high probability of not recognizing that state 15 has occurred can lead to the same type of result as for state 14. Again, if an equipment with a recognizable response is associated with the lost bit, the problem is simplified. This state differs from state 14 in that it is more difficult to identify.

APPENDIX A

APPLICATION OF DECISION THEORY TO THE OPERATIONAL ANALYSIS OF GEOS

The main body of this report has been concerned with possible malfunctions of the spacecraft, their discovery, and the appropriate corrective actions to be taken. In general, the assumption is made that the telemetry indications as received on the ground are correct. However, telemetry equipment can fail, and it may fail in such a way that false conclusions are drawn with respect to the spacecraft. Thus, some uncertainty about the in-orbit state of the spacecraft results, due to the questionable validity of the information sent back to earth. An unrecognized failure in telemetry could lead to a wrong corrective action decision and possibly to severe unwarranted satellite degradation.

The problem considered in this appendix is to determine the best possible corrective action (in terms of least satellite degradation or loss) on the basis of possibly erroneous telemetry indications. The solution to this problem is naturally formulated in terms of decision theory.[1]

To illustrate the application of decision theory to this problem, a simplified example is presented below that attempts to come as close to the real-life problems as clarity of presentation will allow. It is not meant to be taken as a directly applicable statement about the GEOS spacecraft. In the power supply diagnostic routine, there are several items that deal with telemetry points associated with the command converter. Since the command system is a vital part of the spacecraft, this example will be concerned with the uncertainty in the state of the command converters, first when only a telemetry channel directly related to the converter is observed, and again when additional telemetry channels are observed for corroborating evidence.

[1] Chernoff, H., and L. E. Moss, Elementary Decision Theory (New York: John Wiley and Sons, Inc., 1959).

The true condition of an in-orbit spacecraft is called a state of nature. A state of nature could correspond to the unfailed, completely failed, or degraded states of part or all of the spacecraft. The symbology used for k states of nature is θ_1, θ_2, ..., θ_k. Possible actions, denoted by a_1, a_2, a_3, ..., a_j, are represented in the GEOS spacecraft by commands.

Using the above nomenclature, the problem is stated as follows:

θ_1 = Command converter in completely unfailed state.

θ_2 = Command converter is severely degraded state.

a_1 = Ignore telemetry data and proceed normally with operations.

a_2 = Issue no further command for any subsystem until status can be fully assessed; send terminal commands which leave on or turn on Doppler and SECOR and turn off all other active experiments.

For each action that is taken, there is an expected loss depending upon the true state of the spacecraft. This loss is measured according to the value of the spacecraft experiments. Each experiment has an expected value relative to the other experiments which could be lost if it is not functioning properly. The relative values, V, used for each of the experiments are as follows:

Optical beacon:	V_1	= 5/12
Doppler:	V_2	= 4/12
SECOR:	V_3	= 2/12
Range/range rate:	V_4	= 1/12

If the spacecraft is in a completely unfailed state, θ_1, and the operator takes the appropriate action, a_1, then the expected loss is zero. However, if the spacecraft is in state θ_1 and action a_2 is taken, then the optical beacon and range/range rate experiments are turned off and the loss is $V_1 + V_4 = 1/2$. When the command converter is severely degraded, state θ_2, the worst action which can be taken is to proceed as though nothing has happened, action a_1; thus the loss in this worst case is assumed to be 1. However, if action a_2, the correct action, is taken, the loss should be some intermediate value which reflects both the degraded state and the performance of the correct action. This loss is taken to be 1/2. $\ell(\theta, a)$, the expected loss due to the taking of action a when the spacecraft is in state θ , is summarized in the following table:

State of Nature θ \ Action a	a_1	a_2
θ_1	0	1/2
θ_2	1	1/2

Decision theory assumes that the state of nature is not known. If it were known, then the correct action would always be taken. Therefore, measuring device responses, in this case telemetry data and experiment data, are employed as indicators of the state of nature. Denote the response of the measuring device by x and the probability density function of x under a particular state of nature θ by $f(x/\theta)$.

For telemetry data which indicates whether certain equipment is in the "on" or "off" state, the probability distribution becomes a discrete one, with all the probability located at the two telemetry values corresponding to the "on" and "off" states. Such information is binary in character. In the case of analog telemetry data, the complete probability distribution is involved. These distributions may be predicted from reliability models of the telemetry subsystem and/or the experiments.

For a single telemetry channel, possible observations were assumed to be:

x_1 = Telemetry reading neither zero nor full scale.

x_2 = Telemetry reading zero.

x_3 = Telemetry reading full scale.

In the reliability analysis of the telemetry subsystem, the probability of losing one commutated channel in a 1-year period was found to be 0.0082. The following table contains the assumed probabilities of obtaining the telemetry reading x given state of nature θ .

State of Nature θ \ Possible Observations x	$f(x/\theta)$ x_1	x_2	x_3
θ_1	0.9918	0.0082	0
θ_2	0	1	0

Since $f(x_3/\theta) = 0$, x_3 can be disregarded for the remainder of this example.

The connection between the observation x and the action a is provided by a strategy. Strategies consist of specific actions to be taken in response to the measuring device. A tabular presentation of possible strategies when only one telemetry channel is observed is given below.

Possible Observations x \ Strategy s	s_1	s_2	s_3	s_4
x_1	a_1	a_1	a_2	a_2
x_2	a_1	a_2	a_1	a_2

Associated with each strategy and each state of nature is an expected loss $L(\theta, s)$. This loss is dependent upon the probability of observing x given θ in the following manner:

$$\text{i. e.,}\quad L(\theta_1, s_2) = f(x_1/\theta_1)\ell(\theta_1, a_1) + f(x_2/\theta_1)\ell(\theta_1, a_2)$$

$$= 0.9918(0) + (0.0082)(0.5) = 0.0041$$

The expected loss $L(\theta, s)$ for each strategy is presented below:

State of Nature θ \ Strategy s	s_1	s_2	s_3	s_4
θ_1	0	0.0041	0.50	0.5
θ_2	1	0.5	1	0.5

In order to select the appropriate strategy, one may choose that strategy which minimizes the weighted average of expected loss. This is the so-called Bayes strategy and is based on the a priori probabilities of the two states of nature $p(\theta_1)$ and $p(\theta_2)$. The appropriate strategy is thus the one which minimizes:

$$L(s) = p(\theta_1)L(\theta_1, s) + p(\theta_2)L(\theta_2, s)$$

The a priori state probabilities for the command converter are estimated to be:

$$p(\theta_1) = 0.999971$$

$$p(\theta_2) = 0.000029$$

based on a conventional failure mode and effects analysis and reliability model of the command converters.

Therefore:

$$L(s_1) = 0.000029$$

$$L(s_2) = 0.0041$$

$$L(s_3) = 0.50$$

$$L(s_4) = 0.5$$

and strategy s_1 is best (i. e., continue operating normally if only one telemetry commutator channel indicates a malfunction).

This result, which is somewhat contrary to intuition, is obtained because the probability of a single commutator channel failure is much greater than the probability of command converter failure.

This example, thus far being based on a single channel of telemetry information, is quite artificial in that additional evidence will in fact be available for determining the true state of nature and therefore arriving at the appropriate corrective action strategy. As an example of the effect of corroborating evidence, three telemetry channels which indicate command converter malfunction are assumed to be available. The states of nature, actions, and loss of expected value are unchanged.

The observation from the measuring device may now be described as a vector $\vec{x} = (x_{i1}, x_{i2}, x_{i3})$, where

$i = 1$, telemetry reading neither zero nor full scale,

$i = 2$, telemetry reading zero,

$i = 3$, telemetry reading full scale,

and the probabilities $f(x_{ij}/\theta)$, where $j = 1, 2, 3$ (designating telemetry channels) are the following:

State of Nature θ \ Possible Observations $\vec{x}$	x_{1j}	x_{2j}	x_{3j}
θ_1	0.9918	0.0082	0
θ_2	0	1	0

Again, x_{3j} will be disregarded for the remainder of this example.

There are four possible types of vectors which can occur. The vector probabilities are calculated from the following probability distribution, where it is assumed that the three telemetry channels fail independently:

$$f(\vec{x}/\theta) = \binom{3}{n_{x_{1j}}} \left[f(x_{1j}/\theta) \right]^{n_{x_{1j}}} \left[f(x_{2j}/\theta) \right]^{n_{x_{2j}}}$$

where

$n_{x_{ij}}$ = the number of channels with reading $i = 1, 2$.

The following table of probabilities, $f(\vec{x}_k/\theta)$, results:

k	$n_{x_{1j}}$	$n_{x_{2j}}$	$f(\vec{x}_k/\theta_1)$	$f(\vec{x}_k/\theta_2)$
1	3	0	0.976	0
2	2	1	0.024	0
3	1	2	0.00020	0
4	0	3	0.00000055	1

All possible strategies for the observations $\vec{x}_k$ are presented below:

Possible Observations $\vec{x}$ \ Strategy s	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8
$\vec{x}_1$	a_1	a_1	a_1	a_1	a_2	a_1	a_1	a_2
$\vec{x}_2$	a_1	a_1	a_1	a_2	a_1	a_1	a_2	a_1
$\vec{x}_3$	a_1	a_1	a_2	a_1	a_1	a_2	a_1	a_1
$\vec{x}_4$	a_1	a_2	a_1	a_1	a_1	a_2	a_2	a_2

	s_9	s_{10}	s_{11}	s_{12}	s_{13}	s_{14}	s_{15}	s_{16}
$\vec{x}_1$	a_1	a_2	a_2	a_1	a_2	a_2	a_2	a_2
$\vec{x}_2$	a_2	a_1	a_2	a_2	a_1	a_2	a_2	a_2
$\vec{x}_3$	a_2	a_2	a_1	a_2	a_2	a_1	a_2	a_2
$\vec{x}_4$	a_1	a_1	a_1	a_2	a_2	a_2	a_1	a_2

The expected loss $L(\theta, s)$ for each strategy is:

State of Nature θ \ Strategy s	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8
θ_1	0	0.00000028	0.00010	0.012	0.49	0.00010	0.012	0.49
θ_2	1	0.5	1	1	1	0.5	0.5	0.5
	s_9	s_{10}	s_{11}	s_{12}	s_{13}	s_{14}	s_{15}	s_{16}
θ_1	0.012	0.49	0.50	0.012	0.49	0.50	0.50	0.5
θ_2	1	1	1	0.5	0.5	0.5	1	0.5

The weighted average of expected losses obtained under the a priori probabilities given in the previous example, are:

	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8
L(s)	0.000029	0.000015	0.00013	0.012	0.49	0.00012	0.012	0.49
	s_9	s_{10}	s_{11}	s_{12}	s_{13}	s_{14}	s_{15}	s_{16}
L(s)	0.012	0.49	0.50	0.012	0.49	0.50	0.50	0.5

If these losses are ordered and the strategies studied, it can be seen that in general the strategies which require the least corroborating evidence before action a_2 is taken (i. e., send terminal commands) have the greatest loss. Thus, as would be expected, the more corroborating evidence available, the less value of the spacecraft is lost. Strategy s_2, which takes action a_1 unless all three channels give a zero reading, is the best strategy in this case.

This, of course, is precisely the strategy that would be taken on an intuitive basis. Thus, when telemetry failure is assumed to occur on a channel-by-channel basis, the application of decision theory does not result in conclusions beyond what would be obtained by intuitive considerations. By using the previously given diagnostic routines and decision-action charts, a failure can be isolated and the appropriate action taken. The problem of obtaining incorrect telemetry data on a single channel and therefore taking a wrong action is inconsequential if corroborating evidence is sought before taking action on the basis of a single telemetry channel reading. The telemetry assignments for GEOS A make corroborating evidence quite readily available. The diagnostic routines and decision-action charts presented in this report reflect the philosophy of seeking corroborative evidence. The application of decision theory to GEOS operational reliability analysis in the grosser situation where there is substantial loss of telemetry and a concomitant increase in uncertainty is expected to yield results which are nonintuitive. This application is presently under consideration.

APPENDIX B

COMMAND LIST

GEOS A Command System Functions and Command Tone Assignments

Command	Command Function	Command Tones	Telltale Indication Number(1)	Telltale Indication State
1a	Oscillator 1 Select	DDD	B-1	High
1b	Oscillator 2 Select	DDB	B-1	Low
2a	Oscillator Oven 1 ON	DDE	A-1	High
2b	Oscillator Oven 2 ON	DDC	A-1	Low
3a	Main Converter 1 ON	EED	A-2	High
3b	Main Converter 2 ON	EEB	A-2	Low
4a	162 MC Transmitter ON	EEE	See channel 30, commutator 2	
4b	162 MC Transmitter OFF	EEC		
5a	324 MC Transmitter ON	CCD	See channel 31, commutator 2	
5b	324 MC Transmitter OFF	CCB		
6a	972 MC Transmitter ON	CCE	See channel 32, commutator 2	
6b	972 MC Transmitter OFF	CCC		
7a	Telemeter System ON	BBD		
7b	Telemeter System OFF	BBB		
8a	TM Function FM/PM ON	BBE		
8b	TM Function FM/PM OFF	BBC		
9a	Vector Magnetometer ON	DED	A-3	High
9b	Vector Magnetometer OFF	DEB	A-3	Low
10a	Solar Only ON	DEE	A-4	High
10b	Solar Only OFF	DEC	A-4	Low
11a	Commutator 1 Hold ON	DCD	B-2	High
11b	Commutator 1 Hold OFF	DCB	B-2	Low
12a	Commutator 2 Hold ON	DCE	A-5	High
12b	Commutator 2 Hold OFF	DCC	A-5	Low

Note: (1) A corresponds to telltale register 1; B corresponds to telltale register 2; C corresponds to telltale register 3.

Command	Command Function	Command Tones	Telltale Indication Number	Telltale Indication State
13a	Memory Select: 1 ON, 2 OFF	DBD	A-6	High
13b	Memory Select: 1 OFF, 2 ON	DBB	A-6	Low
14a	Boom Squib Enable OFF	EDD	B-3	High
14b	Boom Squib Enable ON	EDB	B-3	Low
15a	Boom Squib Fire and 3.9v Zener IN	BDE	B-4	Low
15b	Boom Safe and 4.7v Zener IN	BDC	B-4	High(1)
16a	Boom Bypass ON	DBE	A-7	High
16b	Boom Bypass OFF	DBC	A-7	Low
17a	Boom Out	ECD	A-8	Low
17b	Boom In	ECB	A-8	High
18a	Boom Motor ON	ECE	A-9	Low
18b	Boom Motor OFF	ECC	A-9	High
19a	162 Phase Modulator ON	EBD	B-5	High
19b	162 Phase Modulator OFF	EBB	B-5	Low
20a	324 Phase Modulator ON	CDD	B-6	High
20b	324 Phase Modulator OFF	CDB	B-6	Low
$21a_1$ (2)	Optical Power Dump OFF	CDE	C-1:C-2,3	High:High
$21b_1$	Optical Manual ON: Automatic OFF	CDC	C-1:C-2,3	Low:High
$21a_2$	Optical Manual OFF: Automatic ON	CDE	C-1:C-2,3	High:Low
$21b_2$	Optical Manual ON: Automatic ON	CDC	C-1:C-2,3	Low:Low
$22a_1$ (2)	Transponder Power Dump OFF	CED	C-5:C-6,8	High:High
$22b_1$	Transponder Manual ON: Automatic OFF	CEB	C-5:C-6,8	Low:High
$22a_2$	Transponder Manual OFF: Automatic ON	CED	C-5:C-6,8	High:Low
$22b_2$	Transponder Manual ON: Automatic ON	CEB	C-5:C-6,8	Low:Low
23a	Range Transponder ON and Voltage Sensing Switch Reset	CBE	B-7	High
23b	Range Transponder OFF	CBC	B-7	Low
24a	Range Transponder Manual	CEE	B-10	High

Notes:

(1) B-4 is high only when B-3 is low and the spacecraft and booster are separated.

(2) Both commands 21 and 22 are 4-state sequential commands.

Command	Command Function	Command Tones	Telltale Indication Number	State
24b	Range Transponder Normal	CEC	B-10	Low
25a	R/RR Transponder ON and Voltage Sensing Switch Reset	EDE	B-8:B-9	High:Low
25b	R/RR Transponder OFF	EDC	B-8:B-9	Low:High
26a	R/RR Transponder Manual	CBD	B-11	High
26b	R/RR Transponder Normal	CBB	B-11	Low
27a	AOL 1 Start Flash	BEE	B-12	High
27b	AOL 1 Flash OFF	BEC	B-12	Low
28a	AOL 2 Start Flash	BCE	B-13	High
28b	AOL 2 Flash OFF	BCC	B-13	Low
29a	Memory Load Start	EBE	A-12	High
29b	Memory Load Telltale Reset	EBC	A-12	Low
30a	Memory Converter 2 ON	BDD	A-13	Low
30b	Memory Converter 1 ON	BDB	A-13	High
31a	Voltage Sensing Cutoff Override ON	BED	B-14	Low
31b	Voltage Sensing Cutoff Override OFF	BEB	B-14	High
32a	TM Time Marker ON	BCD	B-15	High
32b	TM Time Marker OFF	BCB	B-15	Low

APPENDIX C

TELEMETRY LIST

Commutator 1

Channel	Telemetry Assignment	Channel	Telemetry Assignment
1	+0.25v Calibrate	20	Memory Converter Input Current
2	0v Calibrate	21	Memory Converter +10.7 Voltage
3	-0.25v Calibrate	22	Memory Converter +4.0 Voltage
4	Main Solar Current	23	Memory Converter -10.7 Voltage
5	Main Battery Current	24	Main Converter +21v Current
6	Main Converter Input Current	25	Main Converter -32v Current
7	Command Converter Input Current	26	Command Converter +21v Current
8	Transponder Solar Current	27	Command Receiver 1 AGC
9	Transponder Battery Current	28	Command Receiver 2 AGC
10	6 Mil Glass N on P	29	Telltale Register 3
11	6 Mil Glass P on N	30	Flash Assembly 1 Temperature
12	X Magnetometer Voltage	31	Flash Assembly 4 Temperature
13	Y Magnetometer Voltage	32	Quadrant 1 Book Temperature
14	Z Magnetometer Voltage	33	Quadrant 2 Book Temperature
15	Range Transponder Transmitter Temperature	34	Quadrant 3 Book Temperature
16	Optical Battery Temperature	35	Oscillator Dewar Temperature
17	Telltale Register 1	36	+0.25v Calibrate
18	Subcommutator 1/Optical System Current	37	+0.25v Calibrate
19	Optical Battery Current	38	+0.25v Calibrate

Commutator 2

Channel	Telemetry Assignment	Channel	Telemetry Assignment
1	+0.25v Calibrate	20	SECOR Plate Current
2	0v Calibrate	21	SECOR 250 Voltage
3	-0.25v Calibrate	22	Range and Range Rate Receiver Output
4	Main Bus Voltage	23	Range and Range Rate RF Power Detector
5	Main Battery Voltage	24	Oscillator Regulator Voltage
6	Main Battery Temperature	25	Main Converter -32 Voltage
7	Command Converter Input Voltage	26	Command Converter +21 Voltage
8	Transponder Battery Temperature	27	Command Converter +4.0 Voltage
9	Transponder Bus Voltage	28	Command Converter -10.7 Voltage
10	Solar Calibrate	29	+Z SAD Temperature and Solar Science Temperature
11	Linear Solar Attitude Detector (SAD)	30	162 MC RF Power Detector
12	+Z SAD	31	324 MC RF Power Detector
13	+X SAD	32	972 MC RF Power Detector
14	+Y SAD	33	SECOR Receiver Temperature
15	-X SAD	34	Boom and Main Converter +21v
16	-Y SAD	35	Range and Range Rate Transponder Temperature
17	Telltale Register 2	36	+0.25v Calibrate
18	Subcommutator 2/Optical Battery Voltage	37	+0.25v Calibrate
19	SECOR Regulator Output Voltage	38	+0.25v Calibrate

Subcommutator 1

Subchannel	Telemetry Assignment
1	Optical System Current
2	Flash Intensity 1
3	Flash Intensity 2
4	Optical System Current
5	Flash Intensity 3
6	Flash Intensity 4
7	Flash Intensity 1
8	Optical System Current(1)

Note: (1) Subcommutator reads subchannel 8 until switched by memory signals during an optical flash sequence.

Subcommutator 2

Subchannel	Telemetry Assignment
1	Flash Assembly 1 and Flash Assembly 2 Positive Ramps
2	Flash Assembly 1 and Flash Assembly 2 Negative Ramps
3	Optical Battery Voltage
4	Flash Assembly 3 and Flash Assembly 4 Positive Ramps
5	Flash Assembly 3 and Flash Assembly 4 Negative Ramps
6	Flash Assembly 1 and Flash Assembly 2 Negative Ramps
7	Flash Assembly 1 and Flash Assembly 2 Positive Ramps
8	Optical Battery Voltage (1)

Note: (1) Subcommutator reads subchannel 8 until switched by memory signals during an optical flash sequence.

Telltale Register 1
Commutator 1, Channel 17

Telltale Number	Telltale Indication: High	Telltale Indication: Low
1	Oscillator Oven 1 ON	Oscillator Oven 2 ON
2	Main Converter 1 ON	Main Converter 2 ON
3	Vector Magnetometer ON	Vector Magnetometer OFF
4	Solar Power Only ON	Main Battery ON
5	Commutator 2 Holding	Commutator 2 Running
6	Memory 1 ON	Memory 2 ON
7	Boom Midway Bypass ON	Boom Midway Bypass OFF
8	Boom Motor DRIVE IN Ready	Boom Motor DRIVE OUT Ready
9	Boom Motor OFF	Boom Motor ON
10	Booster Unseparated	Booster Separated
11	Squib Safe and 4.7v Command Zener IN	Squib Fire and 3.9v Command Zener IN
12	Memory Load Start	Memory Load Telltale Reset
13	Memory Converter 1 ON	Memory Converter 2 ON
14	Vector Magnetometer Calibrate	Vector Magnetometer Normal
15	162-324 Phase Modulator Power ON	162-324 Phase Modulator Power OFF

Telltale Register 2
Commutator 2, Channel 17

Telltale Number	Telltale Indication High	Telltale Indication Low
1	Oscillator 1 ON	Oscillator 2 ON
2	Commutator 1 Holding	Commutator 1 Running
3	Boom Enable OFF	Boom Enable ON
4[(1)]	Boom Squib Enabled and Not Fired	Boom Squib Enabled and Fired
5	162 MC Phase Modulator ON	162 MC Phase Modulator OFF
6	324 MC Phase Modulator ON	324 MC Phase Modulator OFF
7	Range Transponder ON	Range Transponder OFF
8	R/RR ON	R/RR OFF
9	R/RR Oscillator ON	R/RR Oscillator OFF
10	Range Select ON	Range Select OFF
11	R/RR Select ON	R/RR Select OFF
12	Alternate Optical Logic 1 ON	Alternate Optical Logic 1 OFF
13	Alternate Optical Logic 2 ON	Alternate Optical Logic 2 OFF
14	Voltage Sensing Cutoff Switch IN	Voltage Sensing Cutoff Switch Bypassed
15	TM Time Marker ON	TM Time Marker OFF

Note: (1) Telltale 4 is meaningful only if booster is separated from the spacecraft and BOOM Enable is ON.

Telltale Register 3
Commutator 1, Channel 29

Telltale Number	Telltale Indication: High	Low
1	Optical Manual Dump OFF	Optical Manual Dump ON
2	Optical Automatic Dump Enable OFF	Optical Automatic Dump Enable ON
3	Optical Automatic Dump Enable OFF	Optical Automatic Dump Enable ON
4	Optical Automatic Dump OFF	Optical Automatic Dump ON
5	Transponder Manual Dump OFF	Transponder Manual Dump ON
6	Transponder Automatic Dump Enable OFF	Transponder Automatic Dump Enable ON
7	Transponder Automatic Dump OFF	Transponder Automatic Dump ON
8	Transponder Automatic Dump Enable OFF	Transponder Automatic Dump Enable ON
9	Flash Clock Start Confirm	Flash Clock Standby
10	Optical Flash Count = 10	Optical Flash Count = 10
11	Optical Relay 1 ON	Optical Relay 1 OFF
12	Optical Relay 2 ON	Optical Relay 2 OFF
13	Optical Relay 3 ON	Optical Relay 3 OFF
14	Optical Relay 4 ON	Optical Relay 4 OFF
15	Boom Clamp Released	Boom Clamp Not Released