TECHNICAL MEMORANDUM 4007-6
MARCH 1966

GEOS A

POSTLAUNCH PERFORMANCE EVALUATION

Prepared by
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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EXPLORER XXIX (GEOS A)
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National Aeronautics and Space Administration
GEOS A Project

Approved by Jerome D. Rosenberg
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Prepared for

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by

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Under

Contract NASW 1238

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LIST OF ABBREVIATIONS AND ACRONYMS

APL	Applied Physics Laboratory
DAF	Data Acquisition Facility
DOC	Department of Commerce
DOD	Department of Defense
EST	Eastern Standard Time
GEOS	Geodetic Earth Orbiting Satellite
GOCC	Geodetic Operational Control Center
GSFC	Goddard Space Flight Center
Km	Kilometer
mc	Megacycles
mw	Milliwatts
NASA	National Aeronautics and Space Administration
n. mi.	Nautical Miles
OAO	Orbiting Astronomical Observatory
SAD	Solar Aspect Detectors
R&RR	Range and Range Rate
rpm	Revolution per Minute
SECOR	Sequential Correlation of Range
STADAN	Space Tracking and Data Acquisition Network
TRANET	Tracking Network
WWV	Time Standard Broadcasting Station

SECTION 1

INTRODUCTION

1.1 OBJECTIVE OF THIS REPORT

It is the objective of this report to present an evaluation of the performance of the Explorer XXIX (GEOS A) spacecraft during its first three months in orbit and to present the chronology of significant events during this period.

This report is directed to an evaluation of the initial performance of the spacecraft in orbit and the effect of its performance on the geodetic observations. It covers the injection into orbit after launch, gravity-gradient capture, tests with the injection of flashing light information into the memory in the spacecraft, operational readiness tests, and the operational performance of the spacecraft subsystems. No attempt is made to evaluate the scientific investigations themselves or the operations associated with the conduct of these investigations.

1.2 SUMMARY DESCRIPTION OF THE GEOS A SPACECRAFT

Explorer XXIX (GEOS A) was launched into orbit by an improved Delta launch vehicle (No. 34) on 6 November 1965 from Cape Kennedy, Florida. The spacecraft was designed and constructed by the Applied Physics Laboratory (APL) of the Johns Hopkins University, Howard County, Maryland. Its primary missions are to permit an intercomparison of satellite tracking systems accuracies, provide investigations of the earth's gravitational field, and provide data for improving worldwide geodetic datum accuracies and positional accuracies of satellite tracking sites.

The spacecraft is a gravity-gradient stabilized solar cell powered unit which carries electronic and optical geodetic instrumentation. The configuration of the spacecraft is shown in Figures 1-1 through 1-4. The spacecraft weight is approximately 385 pounds. The geodetic instrumentation includes four xenon optical beacons, which may be flashed at preselected times, four laser corner reflector panels, a range transponder (SECOR), a Doppler beacon, a range/range rate (R&RR) transponder, and a 136-mc telemetry and minitrack beacon.

The radio-Doppler beacon on the satellite transmits 250 mw at 162 mc, 450 mw at 324 mc, and 500 mw at 972 mc. These Doppler transmitters carry time markers that are to be maintained in synchronization with WWV to an accuracy of 0.4 milliseconds or better.

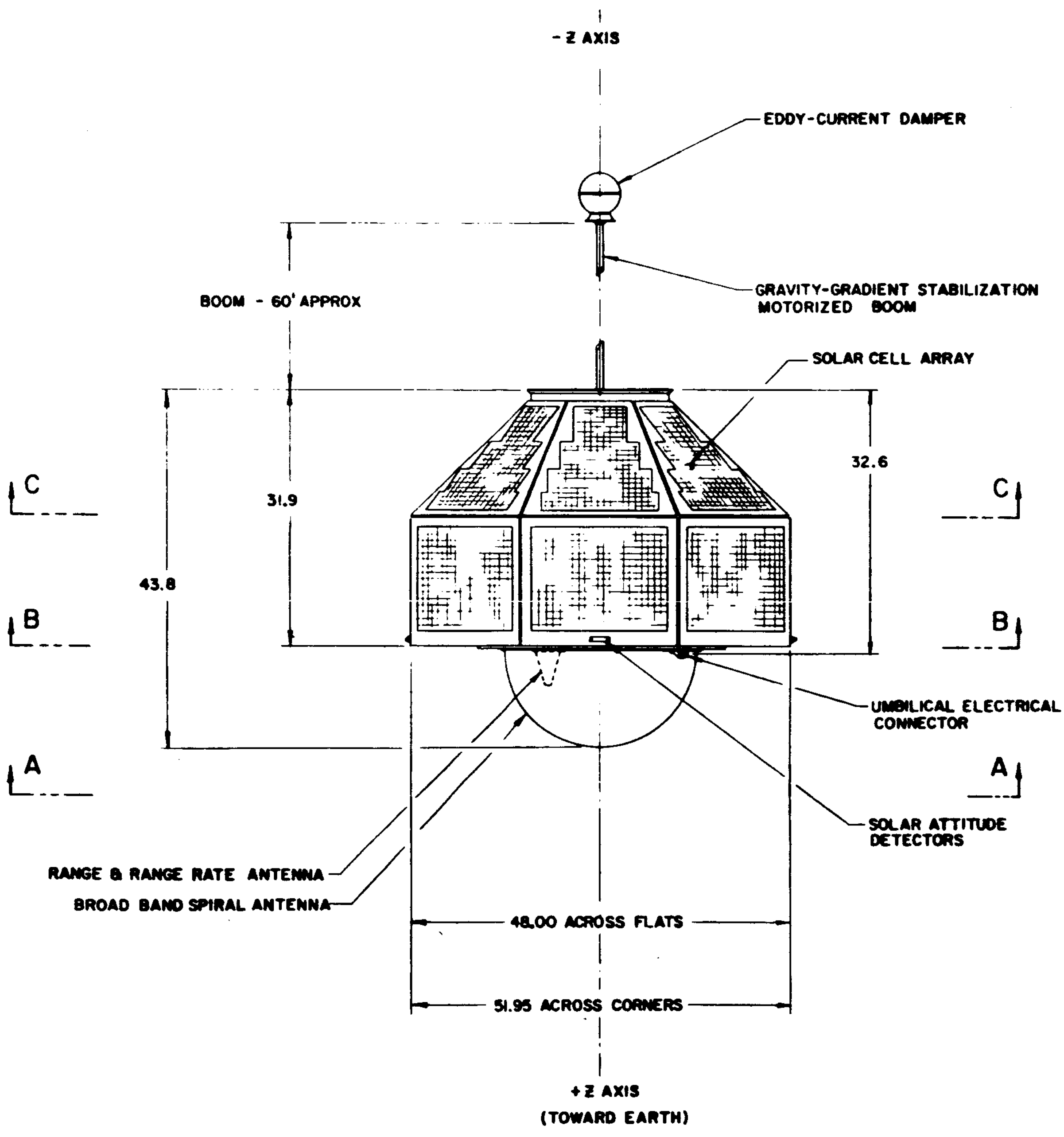


Figure 1-1. GEOS A Configuration

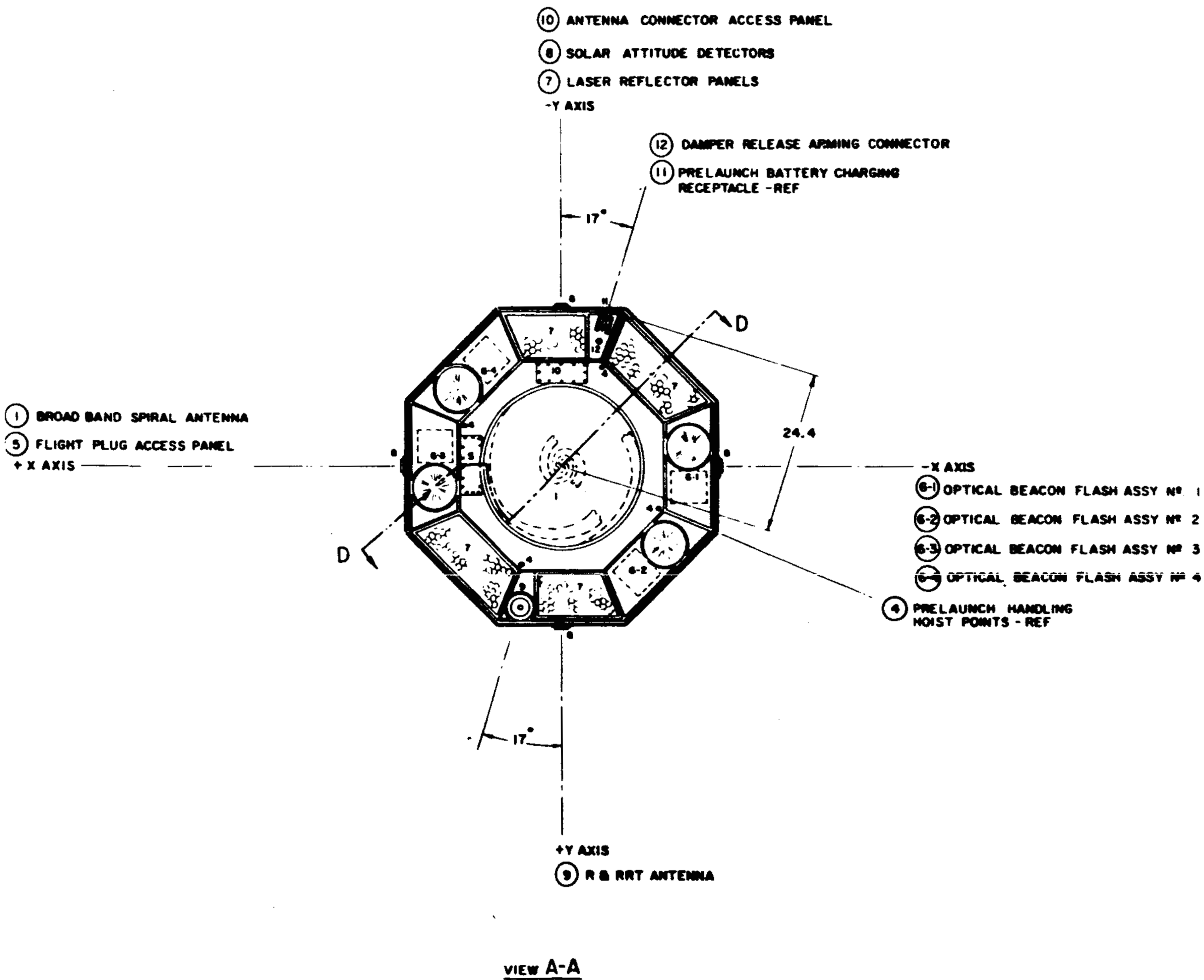


Figure 1-2. GEOS A Bottom View

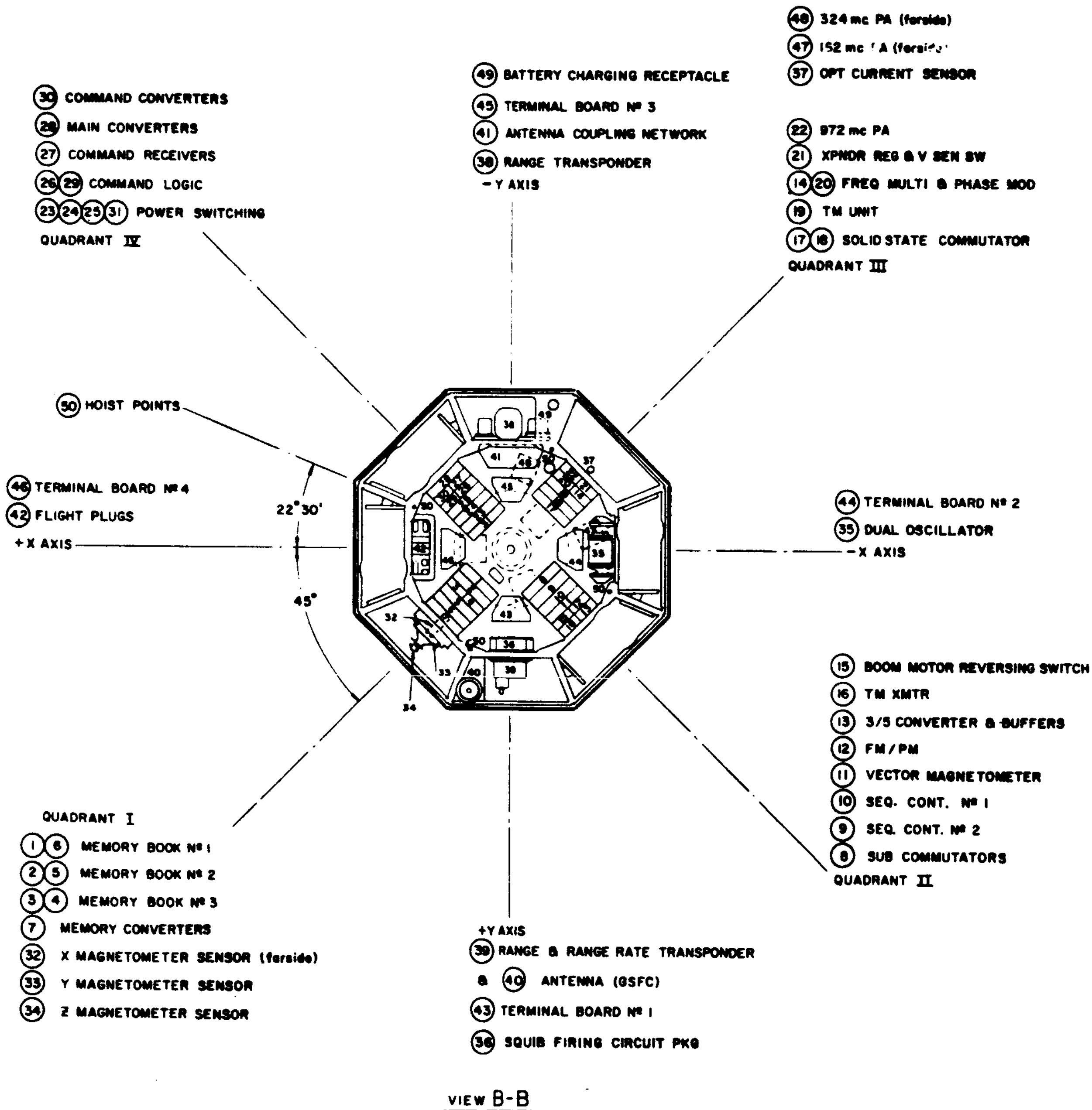
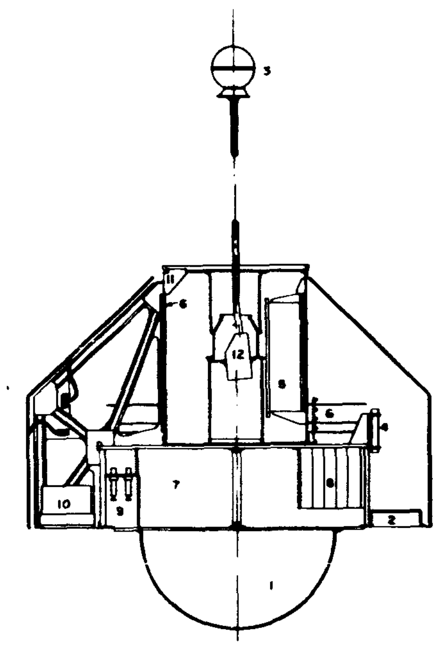


Figure 1-3. GEOS A View Through Body



1. BROAD BAND SPIRAL ANTENNA
2. LASER REFLECTOR PANELS
3. EDDY-CURRENT DAMPER
4. OPT CURRENT SENSOR
5. OPTICAL BATTERY UNIT
6. EDDY-CURRENT DAMPER RODS
7. BOOK COMPARTMENT
8. BOOK UNITS
9. FLIGHT PLUG COMPARTMENT
10. OPTICAL BEACON
11. SEPARATION SPRING PAD
12. BOOM UNIT

VIEW D-D

Figure 1-4. GEOS A Side View

SECTION 2

SUMMARY

2.1 OPERATIONS SUMMARY

Explorer XXIX (GEOS A) was successfully launched and injected into orbit on 6 November 1965, but with an apogee substantially higher than planned. Although this higher apogee has no significant effect on the performance of the spacecraft subsystems except to increase the satellite libration amplitude in pitch by 4.4°, it has a significant effect on the optical observational program. The increased range at apogee reduces the light intensity of the optical beacon available at the observing stations during apogee passes, resulting in a higher lamp output requirement which permits fewer flashes to be programmed. It also results in a reduction in the image size recorded on the photographic plates and, in some cases, a total loss of image for the less sensitive cameras. The significance of the increased libration amplitude on the observation program has not been sufficiently analyzed to date to ascertain its effect on the mutual visibility program for the observing optical stations. Further study of this is required.

The initial gravity-gradient capture of the spacecraft on 8 November 1965, resulted in upside-down orientation of the spacecraft. An inversion maneuver was successfully performed one week after launch, on 13 November 1965, utilizing the NASA STADAN station ULASKA to initiate the maneuver and the Navy TRANET station at the Applied Physics Laboratory in Howard County, Maryland, to complete the maneuver. The NASA ROSMAN DAF station was backup to the APL station. Proper orientation of the spacecraft with its bottom surface facing the earth at all times was confirmed on the succeeding orbit.

After right side up gravity-gradient capture was achieved, it was ascertained from telemetry that the attitude measurement sensors onboard the spacecraft were not functioning properly. The automatic calibration sequence of the magnetometers used for attitude data was being randomly performed. In addition, it was determined that two of the solar aspect detectors were not functioning. Thus, accurate measurement of the spacecraft attitude has become difficult and the results of the attitude measurement program are considered to be questionable. As a result of these attitude measuring problems, reliable precise attitude information cannot be included in the mutual visibility program for the observing stations. This may mean that some of the optical observing stations will not observe light flashes when they are programmed for them.

During the week of 30 November through 6 December, prior to initiating worldwide geodetic and gravimetric investigations, Operational Readiness Tests were conducted to acquaint the geodetic participants with the GEOS operation. Formal tests were conducted with the optical participants by programming a number of spacecraft flashing-light operations, within spacecraft power constraints, to provide operating experience; to obtain spacecraft/observer data on the accuracy of predicted data; to evaluate spacecraft optical system operation; and to evaluate overall spacecraft/observer operations. Although not a scheduled part of this test, operations were scheduled concurrently with GSFC R&RR stations and Army SECOR stations (in CONUS) for R&RR and SECOR data, respectively.

Immediately following the Operational Readiness Tests the spacecraft was considered operational, and normal operations, in keeping with the geodetic objectives, commenced on 8 December 1965.

Backup memory injection tests were conducted during the period 1 December to 23 December. The object of this test series was to evaluate the GEOS/APL backup injection capability of the ROSMAN DAF station and to demonstrate the capability by performing a memory injection with the spacecraft. Initial tests were conducted at GSFC and ROSMAN with the GEOS prototype spacecraft, culminating in a series of simulated injections concurrent with the APL's injections and, finally, a successful spacecraft memory injection from ROSMAN on 23 December 1965.

Since the commencement of operations with GEOS A, all participating organizations and networks have been recording the outputs of the instrumentation onboard the spacecraft. This instrumentation is providing useful data, but some difficulties have been encountered with some of the instrumentation subsystems, hampering the progress of the investigations.

Of the four flashing lights on the spacecraft, telemetry data indicates a significant reduction in the light output of lamp #4, thus reducing the luminosity when four lamps are to be flashed simultaneously. Due to the higher-than-planned orbit, four lamp flashes are required during apogee passes for adequate illumination at some of the observing cameras. With only three lamps providing adequate intensity, some stations may not be able to obtain images on the plates until perigee occurs near the station.

The cause of the lamp failure is being analyzed by the Applied Physics Laboratory. Preliminary evidence suggests that damage to the lamp may have occurred prior to gravity-gradient capture of the spacecraft. During the period after injection into orbit and prior to capture, telemetry data indicated that for a long time the spacecraft solar cells were generating no power. From this it was deduced that the bottom surface of the spacecraft was oriented toward the sun. Thus, the lamp reflectors may have been acting as solar furnaces, focusing the sun's energy on the base of the lamp, damaging the lamp connection in some manner. An attempt is being made to simulate this condition in the APL thermal vacuum chamber.

APL has also observed that some of the flashes fail to occur after memory injection. Initially, this was ascribed to a memory injection problem, but subsequent observations indicated that most of the lost flashes were associated with the flashing of lamp #4.

Hence, it is considered that this lamp, rather than a memory failure, is the cause of the lost flashes. However, even with this problem, about 85 percent of the 13,000 programmed flashes, as observed by APL, occurred through 15 January 1966.

Missing flashes present an additional burden for both the investigators and operations personnel. For the investigators, plate data reduction becomes more difficult. For operations personnel, the dissemination of information concerning the missed flashes increases the coordination requirements.

The Army Map Service SECOR station at Herndon, Virginia, has reported interference between the SECOR transponder and the 324-mc Doppler. To date it has not been definitely established whether the problem exists in the spacecraft or at the ground station. An investigation of this problem is continuing.

Early in February 1966 the R&RR transponder temperature exceeded design limits and was turned off. At about the same time, the SECOR transponder temperature dropped below its design threshold. These events occurred when the spacecraft entered a full sunlight orbit, and it is suspected that the spacecraft is fixed in its yaw orientation with the R&RR transponder side of the satellite continuously facing the sun. The SECOR transponder is mounted on the opposite (dark) side. APL has undertaken an investigation of this situation.

The Doppler system is providing good signals, such that through 15 January 1966 85 percent of the 7500 data receptions were usable for computer runs.

The solar cell power generating subsystem is performing as planned.

2.2 CONCLUSIONS

Based on the material presented in this report, the following conclusions are drawn.

2.2.1 Orbit

GEOS A was successfully launched into the desired orbit, except that apogee was substantially higher than planned.

The higher-than-planned apogee has no deleterious effect on the spacecraft performance except that the theoretical libration amplitude in pitch is increased by 4.4° to a total of 9.4° due to the higher orbital eccentricity. Although the spacecraft is essentially unaffected by the higher apogee, the effect on the planned investigations is significant.

2.2.2 Stabilization and Attitude

The spacecraft gravity-gradient stabilization subsystem is working well and the inversion maneuver utilizing stations from two separate networks to command the spacecraft to achieve proper orientation was performed successfully.

The attitude determination sensors are not performing satisfactorily, causing the attitude determination analysis to be not entirely reliable.

The length of the gravity-gradient boom is not optimal for minimum libration angle. However, the risks involved in retracting the boom to its optimal length for a slight reduction in libration angle are not warranted at this time without further study and analysis.

2.2.3 Optical and Memory Subsystems

The degradation in performance of the optical and memory subsystems has caused difficulties with the investigations and has increased the workload in scheduling the observations. However, useful optical data are still being obtained from the optical system.

2.2.4 Electronic System Interference

Although interference has been reported between the SECOR and Doppler, the cause of this interference has not yet been isolated.

2.2.5 Thermal Problems

The R&RR and SECOR transponders are experiencing thermal excursions beyond design limits during full sunlight orbits. The cause of this remains to be established, although a fixed orientation of the spacecraft with the sun appears to be a possible explanation.

2.2.6 Telemetry and Command

The command and telemetry subsystems are functioning satisfactorily.

2.3 RECOMMENDATIONS

In view of the GEOS A operations and analyses performed to date, the following recommendations are made:

a. Increased effort should be made in future geodetic satellite launches to achieve the nominal orbit, since the geometric positioning of the observing stations prior to launch is predicated on the nominal orbit.

b. Detents should be properly located along the gravity gradient boom to automatically stop the boom movement at extended and retracted optimum positions for gravity-gradient capture, and for an inversion maneuver if required.

c. The reliability of the attitude determination sensors for GEOS B should be increased substantially to ensure measurement of the spacecraft libration amplitude in orbit.

d. A study should be conducted to ascertain the improvement in scheduling observations for the optical beacon that may be accomplished by including a libration amplitude prediction in the mutual visibility program for the observing stations. This study should be accomplished prior to a decision on the incorporation of an additional attitude sensor on GEOS B.

e. The problem associated with the degradation of the optical beacon lamps should be thoroughly investigated and steps taken to improve their operation and reliability in GEOS B. Digital circuits associated with the optical system should be desensitized so that fast noise spikes would not activate the 10-count circuit.

f. Reported interference between the SECOR and Doppler should be investigated to establish the cause of this interference, prior to initiating corrective action.

g. The R&RR and SECOR transponder thermal excursions should be investigated. If a fixed yaw orientation in space is found to be thermally detrimental to the spacecraft subsystems, consideration should be given to incorporating a means of yawing the GEOS B spacecraft, such as by magnetic torquing.

SECTION 3

BACKGROUND

The overall objectives of the National Geodetic Satellite Program are to more accurately define the shape and size of the earth and the complete configuration of the earth's gravitational field, thus leading to more precise geodetic and space measurements in the future. Today, precise knowledge of the earth's size and shape affect such diverse matters as the accuracies of large-area maps, location of political boundaries, defining of limits to natural resources concessions, long-range navigation systems, certain types of communication methods, and satellite tracking and recovery. It is essential in defining the detailed structure of the earth's gravitational field, which aids scientists in better understanding the history, composition, and physics of the earth.

The earth-orbiting satellite has become a new measuring tool, and has contributed greatly to our knowledge of the earth's form, gravitational field, and mass distribution. These accomplishments have stimulated many discussions within the scientific community, recommendations by geodesists, and hearings before the U.S. Congress to determine means of taking full advantage of the potential of satellite geodetic techniques. As a result, the National Aeronautics and Space Administration, with the cooperation of DOD and DOC, has undertaken a National Geodetic Satellite Program to utilize satellites for geodetic purposes, make measurements, reduce and analyze data, and generally distribute results to the scientific communities throughout the world. The current program will require about five years to complete, and Explorer XXVII (BE-C), the first NASA satellite to have geodesy as its primary mission, was orbited successfully on 29 April 1965, from Wallops Island, Virginia. Table 3-1 lists the satellites currently in the National Geodetic Satellite Program.

TABLE 3-1. NATIONAL GEODETIC SATELLITE PROGRAM

Satellite	Description	Mission	Orbit	Launch Schedules
Beacon Explorer (BE-B)	120-pound magnetically oriented spacecraft equipped with Doppler and minitrack beacons, and laser reflectors.	Primary: Ionospheric data. Secondary: Gravimetric data, laser ranging exp.	1000-km orbit at 80° inclination (actual)	Launched 10 October 1964
Beacon Explorer (BE-C)	(Same as BE-B)	Primary: Geodesy data. Secondary: Ionospheric data.	1000-km orbit at 40° inclination (actual)	Launched 29 April 1965
Geodetic Satellite (GEOS A)	385-pound gravity-gradient stabilized carrying flashing light beacons, SECOR ranging transponder, Doppler beacons, laser reflectors, Goddard R&RR transponder, and Minitrack beacons.	Geodetic triangulation and trilateration, gravimetric data, laser geodesy, direct comparison of geodetic systems.	1000 to 2200-km orbit at 59° inclination (actual)	Launched 6 November 1965
Geodetic Satellite (GEOS B)	(Same as GEOS A)	(Same as GEOS A)	1100 to 1450-km orbit at 80° inclination (nominal)	First quarter 1967
Passive Geodetic Satellite (PAGEOS)	125-pound 30-meter, aluminized mylar sphere.	Geodetic triangulation	4200-km orbit at 87° inclination (nominal)	Second quarter 1966

The launch and injection into orbit of Explorer XXIX (GEOS A) involved a number of items that were launched for the first time by NASA, as follows:

- First launch of the improved Thrust Augmented Delta Vehicle.
- First gravity-gradient stabilized spacecraft launched by NASA
- First launch of the third stage to spacecraft adapter with the despin mechanism attached.
- First launch of the Nimbus fairing on the Delta vehicle.

SECTION 4

CHRONOLOGY OF EVENTS

The following is a chronology of the significant post launch events during the early orbiting phase of GEOS A.

Date	Event
11/6/65	Launch and successful injection of GEOS A into orbit took place. Gravity-gradient boom was extended three feet after orbit #3.
11/8/65	Gravity-gradient boom was extended to approximately 37 feet for gravity-gradient capture. Capture was confirmed but spacecraft was upside down.
11/12/65	Real-time telemetry links were checked out from NASA ROSMAN DAF Station and NASA ULASKA STADAN Station to Goddard Operations Control Center in preparation for spacecraft inversion maneuver.
11/13/65	Spacecraft inversion maneuver was performed successfully on orbit #83. GEOS A was properly oriented. The NASA ULASKA and ROSMAN Stations cooperated with APL in the maneuver.
11/18/65	Spacecraft memory was checked out and lamps were flashed for initial optical observations. The SECOR transponder was interrogated for the first time by the Army Map Service Station. The R&RR transponder was interrogated for the first time.
11/23/65	Camera calibration tests were initiated at Jupiter, (Florida) SAO, and special optical stations.
11/26/65	First indication was received of a problem in the flashing light circuitry.

Date	Event
11/30/65	Operation Readiness Test was initiated involving all program optical participants.
12/1/65	Memory injection tests with prototype spacecraft at GSFC were initiated.
12/4/65	Injection tests with prototype spacecraft at GSFC were completed.
12/6/65	Operational readiness test phase was completed.
12/7/65	Memory injection tests with prototype spacecraft was initiated at NASA ROSMAN DAF Station.
12/8/65	Scheduled operations for observational data from orbiting spacecraft were initiated.
12/10/65	Successful memory injection tests with prototype spacecraft at ROSMAN DAF Station were completed. AMS reported interference on SECOR data, thought to be caused by Doppler 324 mc.
12/23/65	ROSMAN DAF Station completed successful memory injection of orbiting spacecraft with two days of flash sequences.
2/5/66	R&RR transponder temperature exceeded design limits.
2/6/66	R&RR transponder was turned off pending thermal investigation.
2/6/66	SECOR transponder temperature dropped to lower-limit threshold.

SECTION 5

ORBITAL INJECTION OF EXPLORER XXIX (GEOS A)

The GEOS A spacecraft was to be placed into an elliptical orbit with an apogee of 800 n.mi., a perigee of 600 n.mi., an inclination of 59°, and an eccentricity of 0.0236. The vehicle and spacecraft functioned normally during countdown and launch, except for the failure to command second stage engine cutoff (SECO). This allowed the second stage to burn to fuel depletion, which resulted in an orbit apogee higher than nominal.

The following table compares the planned and actual orbital elements:

Parameters	Planned	Actual
Apogee (n.mi.)	800	1227.31
Perigee (n.mi.)	600	600.25
Inclination (deg.)	59	59.38
Period (min.)	111.5	120.31
Eccentricity	0.0236	0.0715

5.1 INJECTION PERFORMANCE

Although the spacecraft is gravity-gradient stabilized in orbit, during the injection phase (third-stage burning) it was spin stabilized, despun after burnout of the third stage, and then separated from this stage prior to gravity-gradient capture.

Spinup of the third stage, third stage burning, despin, and spacecraft separation occurred satisfactorily. The actual time of occurrence, compared to the planned nominal time, is given in Table 5-1. Spinup rate was to be approximately 144 rpm and residual spin after despin was to be 0 ± 3 rpm. The actual measured residual spin rate during the first orbit of the spacecraft over Alaska was ascertained from telemetry to be 1-1/4 rpm, well within

TABLE 5-1. SIGNIFICANT FLIGHT EVENTS

EVENT	EXPECTED TIME (T+ seconds)	ACTUAL TIME (T+ seconds)
Lift-off	T+0 (1300:00.0 EST)	T+0 (1338:43.25 EST)
TAD Motor Separation	T+70	T+71
MECO	T+149.2	T+149.1
Stage II Ignition	T+156.2	T+155.7
Jettison Fairing	T+541.7	T+537.9
SECO	T+541.7	T+537.9
Spin-up	T+1106.2	T+1106.2
Stage II/III Separation	T+1108.2	T+1108.2
Stage III Ignition	T+1121.2	T+1118.1
Stage III Burnout	T+1143.7	T+1141.5
Despin	T+1201.2	T+1190.8
Spacecraft/Stage III Separation	T+1226.2	T+1209.8

tolerance. The ±3 rpm spin tolerance was predicated on the structural strength of the gravity-gradient boom, which can not safely be extended until the residual spin rate is within this tolerance.

The nominal trace of the first six orbits of GEOS A after injection into orbit is shown in Figure 5-1.

5.2 HIGH ORBIT EFFECTS

As previously stated, the apogee of GEOS A is higher than planned, resulting in an orbit eccentricity larger than nominal. The effects of this higher orbit and eccentricity are of no significance as far as the performance of the spacecraft and its subsystems in orbit are concerned. Although the greater eccentricity does increase the satellite gravity-gradient libration amplitude, the increase is not sufficient to adversely affect the gravity-gradient stabilization of the spacecraft. However, the effects of the higher orbit on the utility of the spacecraft are significant.

A detailed analysis of the high orbit effects on the geodetic investigations is contained in Reference 2. The effects pertain only to the optical investigations and may be summarized as follows:

a. The higher altitude increases the range of the spacecraft from the optical observing stations, which results in a lower light intensity, at the camera, from the optical beacon lamp flashes. This causes a smaller image size to be recorded on the photographic plates, or results in a total loss of image for the less sensitive cameras.

b. A number of observing stations were specifically positioned to provide optimal geometric configurations based on the nominal orbit. The strength of this geometry has been weakened by the higher orbit.

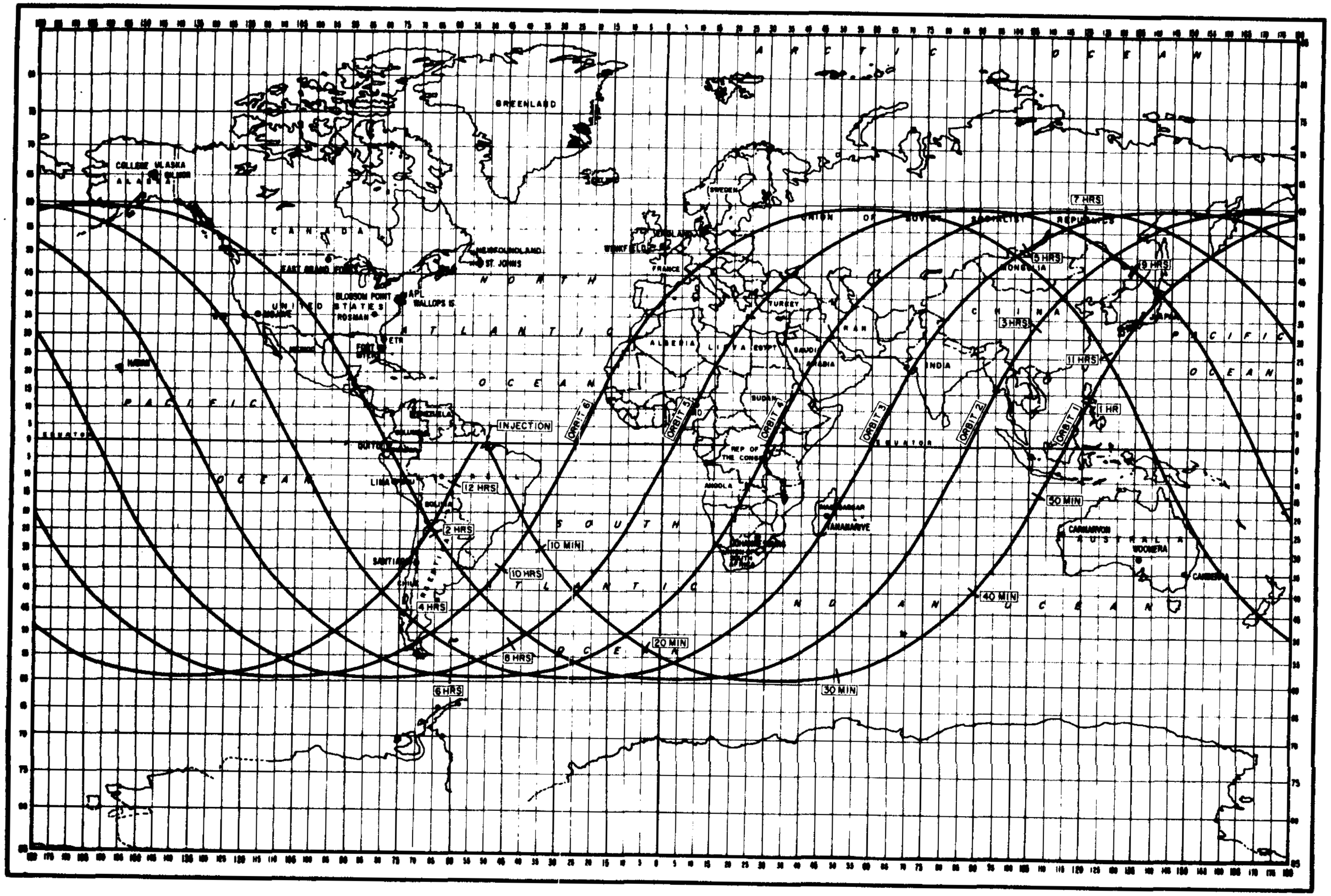


Figure 5-1. GEOS A Nominal Subsatellite Plot

c. The higher orbit requires more lamps to be flashed simultaneously in flashing sequences to provide adequate luminosity for recording at the observing stations. Due to spacecraft power limitations, this reduces the number of flash sequences that may be programmed per orbit, reducing the number of observations that may be made.

d. The increased satellite libration amplitude due to the greater eccentricity will affect the mutual visibility program accuracy. However, the extent of this effect on the observation program requires further study and analysis before its magnitude can be ascertained.

e. The higher apogee increases the mutual visibility for any lamp flash, which may permit more stations to observe each flash. This tends to offset the disadvantages previously mentioned.

SECTION 6

GRAVITY-GRADIENT CAPTURE

The GEOS A spacecraft is gravity-gradient stabilized in orbit to keep the bottom surface of the satellite facing toward the earth at all times. During the launch phase and initial orbits the gravity-gradient boom was retracted within the spacecraft. Gravity-gradient capture occurs only after the boom is extended the proper length. This can only be accomplished when the residual spin rate of the spacecraft has been reduced below a predetermined threshold.

6.1 INITIAL GRAVITY-GRADIENT CAPTURE

Prior to initiating gravity-gradient capture of the spacecraft, the Applied Physics Laboratory moditored the residual spin rate during the first three orbits to ascertain whether the on-board eddy current rods would damp the 1-1/4 rpm residual spin rate to less than 0.3° per second, below which the boom could safely be extended to the desired length of 40 feet for capture. This monitoring revealed that the spin rate was not damping down.

For gravity-gradient stabilization, the GEOS A spacecraft incorporates a single extendible boom, mounted within the spacecraft structure, with an eddy current damper attached on the end. This damper consists of a hollow sphere of aluminum, rigidly attached to the extendible rod. A bar magnet is located inside the sphere, such that it is free to rotate within the sphere. The magnet will then orient itself parallel to the geomagnetic field vector and hence will be magnetically anchored to the field. The location of this damper within the spacecraft during the launch phase places it between the Ni-Cd batteries; hence, in its retracted position it would be locked to the battery cases. It is probable that this occurred, and it became necessary to extend the boom several feet so that the damper could assist in damping the residual spin of the spacecraft. The extension to three feet was commanded on the fourth orbit.

After extension of the boom to three feet, the spacecraft was observed to despin to essentially zero. However, it was observed from telemetry that the bottom surface was apparently oriented toward the sun, since no current was being generated by the solar cells. Since prolonged exposure to sunlight could possibly damage the instrumentation on the bottom surface, APL decided to extend the boom early to 40 feet for capture, rather than wait for a favorable opportunity to ensure right side up capture.

The boom extension was initiated on 8 November 1965. The detents on the boom for automatic stopping were located, prior to launch, at three feet, 15 feet and 50 feet. Hence, to stop the boom at 40 feet it was necessary to command the stop. The timing of the stop command could be based either on the required elapsed time determined from the ground calibration of the boom extension rate or by observing by telemetry the number of turns of the boom drum while the boom is extended. APL elected the latter method, with the former method as a backup. The extension command was initiated but, prior to full extension, the telemetry signal was lost and the stop command was given, based on elapsed time.

Since the extension rate in the space environment could differ somewhat from the ground calibration, the exact extension length of the boom could only be estimated. From the time difference between the start and stop commands it was estimated that the boom extended approximately 37 feet instead of the optimum 40 feet.

The probability of right side up capture was only 50 percent since the spacecraft had a random orientation prior to capture. After capture occurred and the librations damped down, it was determined that the spacecraft was actually captured upside down and an inversion maneuver was required.

6.2 INVERSION MANEUVER

An inversion maneuver is accomplished by retracting the boom a predetermined amount to increase the spacecraft rotational rate above orbital rate, thus causing the spacecraft to tend to turn over. After a short coast period, the boom is then re-extended for capture with the spacecraft reoriented 180° from its initial orientation.

The inversion maneuver can be accomplished from a single ground station, but for the GEOS A orbit the timing is critical due to the short continuous visibility of the spacecraft from a single station. By selecting two stations along the orbit with some overlapping visibility, the time for the maneuver can be extended by having one station retract the boom and the next station commanding the re-extension. Hence, a two-station maneuver was performed.

For the GEOS A inversion maneuver the NASA STADAN station ULASKA was selected to initiate boom retraction and the APL TRANET Station at Howard County, Maryland, to re-extend the boom, with the NASA ROSMAN DAF station backing up APL. The maneuver was successfully performed on 13 November 1965, on orbit #83 and the inversion was confirmed by telemetry from the ULASKA Station on orbit #84.

The boom was initially retracted to the 15-foot detent, which automatically stopped the retraction. Since there was no detent at 40 feet, but one at 50 feet, it was decided to extend the boom to 50 feet to ensure accurate knowledge of the boom length. Although calculations indicate optimum boom length at 40 feet to minimize the thermal bending effects on libration amplitude, it was considered that the effect of the additional length could be ascertained from the attitude measurement sensors and, if desirable, the boom could be retracted at a later date to 40 feet without affecting right side up capture.

During the inversion maneuver, telemetry of the retraction and extension was recorded, from which retraction and extension rates could be determined for comparison with the ground calibration (see Figure 6-1). From Figure 6-1 it may be noted that the measured rates differ from the ground calibration, indicating the desirability of using detents to stop boom extension for retraction at any desired point.

6.3 SPACECRAFT LIBRATION MEASUREMENTS

The GEOS A attitude measurement sensors consist of three magnetometers mounted along three orthogonal axes (see Figure 1-3) and a set of solar aspect detectors (SAD) also mounted on three orthogonal axes (X, Y, Z of Figures 1-1 and 1-2). The location of the X axis and Y axis SAD's is shown in Figure 1-2. The SAD on the third axis (Z axis of Figure 1-2) is mounted on top of the spacecraft (-Z axis).

Each solar aspect detector consists of two calibration cells, a linear detector and a cosine detector. The two calibration cells are configured so that one cell has a maximum acceptance angle of 8° and the other 30°. The output of both cells is summed and telemetered to a ground receiving station. The transition from a high output level (two-cell output) to a single cell output provides a reference voltage level at the known 8° angle.

6.3.1 Attitude Sensor Performance

The history of the SAD's on GEOS A is as follows:

a. The +X calibration sensor failed during launch.

b. One linear sensor failed during launch.

c. The -X calibration sensor failed shortly after launch.

d. All five cosine detectors have degraded in orbit.

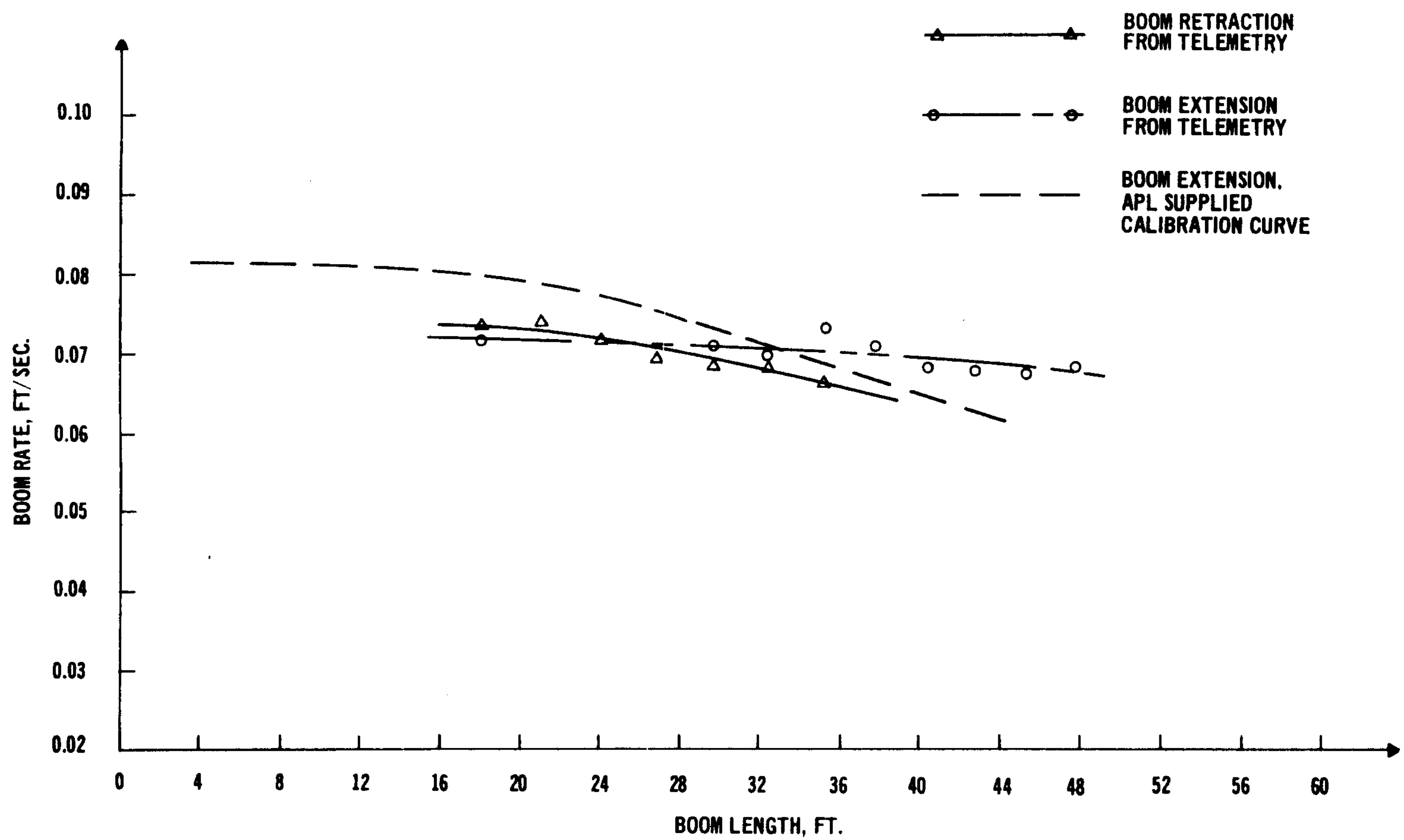


Figure 6-1. Calibration Curves, Boom Rate vs. Boom Length

The magnetometer sensors produce an analog voltage proportional to the magnetic field intensity along their axis. Calibration is accomplished by energizing a calibration coil in each magnetometer. The normal calibration sequence is the application of the high calibration voltage followed by a telemetry readout, twice, the application of the low calibration voltage followed by a readout, twice. It has been observed that this sequence is not being maintained in orbit, as the sequence appears to be random. In addition, the calibration may also be affected by the flux linkage of the magnetometers, due to the presence of the despin rods.

As a result, it has been difficult to assess the spacecraft libration amplitude from the attitude sensor telemetry data. APL is conducting an extensive study to evaluate the data returned from the spacecraft. Rough preliminary results of the study indicate that the spacecraft is performing as expected.

6.3.2 Theoretical Attitude Prediction

The four primary sources of attitude perturbations are gravitational, magnetic, solar and orbit eccentricity factors. The gravitational perturbation is due to the oblate shape of the earth. The magnetic disturbance torques arise from the magnetic damper on the end of the boom and the residual dipole of the spacecraft. Solar disturbances are due to center of solar radiation pressure and center of mass offsets, and to thermal distortions of the gravity-gradient boom. The orbit eccentricity introduces a forcing function, due to the geometry of the orbit, to increase libration amplitude. For the GEOS A orbit, the steady-state peak libration angle from this effect has been computed to be 4.4° in pitch (Reference 2).

In summary of all the computed perturbation effects for GEOS A, the following are best-case and worst-case conditions given:

Best Case: 25 November 1965
Roll = 0.5°
Pitch = 5.5°
Total angle = 5.5°
(Due to orbit precession, this occurs every 56 days.)

Worst Case: 7 October 1966
Total Angle = 9.5°
(Libration angle is expected to be under 5° 60 percent of the time.)

6.4 STABILIZATION EVALUATION

The spacecraft appears to be well stabilized in orbit by the gravity-gradient stabilization subsystem, indicating that the eddy current damper on the end of the boom is performing satisfactorily. The spacecraft has had proper orientation with respect to the earth after inversion maneuver, with the bottom surface facing toward the earth at all times. The inversion maneuver was performed without incident, utilizing a combination of STADAN and TRANET Stations to command the maneuver.

Though the spacecraft attitude measurement sensors are not operating satisfactorily and cannot be used for reliable and precise measurement of spacecraft libration amplitude, the effect of the total libration amplitude on the geodetic investigations has not been thoroughly studied, as indicated in Paragraph 5.2. Thus, the need for accurate amplitude measurements has not been proven as yet.

For future geodetic satellite developments with particular reference to GEOS B, it appears desirable to increase the reliability of the attitude detection sensors to ensure the accurate determination of the libration amplitude.

SECTION 7

INITIAL OPERATIONAL PROGRAM

After gravity-gradient capture of the spacecraft and damping of the librations, a series of readiness tests was conducted with all opitical observers utilizing the spacecraft optical beacon. Subsequently a memory injection test was conducted at the NASA ROSMAN DAF Station. Upon completion of the readiness tests the spacecraft was declared operational and programmed operations utilizing the spacecraft commenced on 8 December 1965.

7.1 READINESS TESTS

During the period from November 30 through December 6, Optical Operational Readiness Tests were conducted with all optical observers to provide operational experience in the spacecraft/observer flashing light operations. Full details of these tests are given in Reference 3.

7.1.1 Test Operations

These tests provided the maximum number of optical events that could be programmed within the spacecraft power constraints at the time. Each optical observer was provided with a number of programmed events to gain operational experience with the spacecraft and to permit NASA to obtain preliminary indications of the accuracy of observations, accuracy of prediction data, etc. Observations from a number of the observers indicated that prediction data and spacecraft/observer timing accuracies were adequate for successful optical observations. The observers completed the required operational optical reports for the GSFC Geodetic Operations Control Center (GOCC) and, for the most part, reports were received in the alloted time period. The test also permitted evaluation of the following:

a. Spacecraft/observer/control center operations

b. APL Light Flash Request and memory injection tape program operations

c. APL Injection Station Operations

d. GEOS spacecraft memory and flashing light system operation

e. GOCC operational performance

Although not a scheduled part of these tests, electronic operations were scheduled concurrently for R&RR and SECOR, and data obtained to demonstrate their successful operation.

All flash schedules, with the exception of the December 2 schedule, were successfully loaded into the spacecraft memory from the APL Howard Coundty Injection Station. The spacecraft successfully executed the programmed flash sequences, although several flash sequence malfunctions were detected on APL telemetry data whereby only part of the flashes in a programmed sequence occurred. These were attributed to noise spikes generated by lamp assembly #4 triggering the 10-count circuit with spurious "noise spikes," causing the 10-count circuit to activate (count) and preempt the remaining flashes of that programmed sequence. This problem has continued to affect the operation of the GEOS spacecraft (see Paragraphs 8.1 and 8.2).

7.1.2 Improvements

During the course of these tests the GOCC modified and firmed operations and operational procedures. The need for improved delivery of observational predictions to international participants was demonstrated, resulting in changes in their delivery from the GOCC. Procedures for developing 038-01 photographic plates were modified, giving better definition to the flashing light images on exposed plates.

7.1.3 Optical Results

Table 7-1 tabulates the results of the optical observations made during this period. In this table it can be seen that a large number of flashes were not observed, due to weather, station equipment problems, et cetera. It is important to note, however, that for photographs taken and plates examined, an average of 55 percent of the expected images were found.

7.2 NASA ROSMAN DAF MEMORY INJECTION TESTS

Memory injection tests were conducted to demonstrate the capability of providing backup injection capability for the GEOS spacecraft. The ROSMAN station was selected because of its mutual visibility with the APL Howard County Station, the availability of most of the equipment required to effect a GEOS injection and the availability of trained station personnel. Full details of these tests are given in Reference 3.

7.2.1 GSFC Tests With Prototype Spacecraft

Preliminary injection tests were first conducted on a closed-loop basis from the GSFC Orbiting Astronomical Observatory (OAO) Control Center to the prototype GEOS spacecraft setup at the GSFC test station during December 1, 2, and 4. This center was used because of its General Mills AD/ECS computer similar to the one at ROSMAN.

These tests verified the performance of the injection program developed for the AD/ECS computer and verified ground station/spacecraft equipment compatibility. Both synchronous and resynchronizing injections were successfully conducted with the prototype spacecraft.

7.2.2 ROSMAN Tests with Prototype Spacecraft

Injection tests with the GEOS prototype spacecraft were conducted at the ROSMAN station from December 7-10. Essentially

TABLE 7-1. OPTICAL SUMMARY

DATE	TOTAL MVE'S	(1) TOTAL POSSIBLE FLASH PARTICIPANTS	(2) TOTAL POSSIBLE FLASHES FOR OBSERVER	(3) PHOTO TAKEN; NO IMAGES FOUND			(4) PHOTO TAKEN; IMAGES FOUND	(5) NO PHOTO TAKEN				REMARKS
				PLATE NOT EXAMINED	OTHER	TOTAL		WEATHER	EQUIP	OTHER	TOTAL	
NOV 30	13	77	539	91	35	126	81	196	28	98	322	
DEC 1	8	70	490	91	56	147	106	154	21	62	237	
DEC 2												EVENTS CANCELLED BECAUSE OF LATE INJECTION
DEC 3	16	75	525	63	90	153	82	259	7	28	294	
DEC 4	16	77	539	56	35	91	81	308	0	42	350	
DEC 5	13	80	560	77	42	119	50	252	21	56	329	
DEC 6	22	106	742	84	175	259	51	280	7	98	385	

Note: All Data Taken from Station Optical Reports

(1) Total number of flash events visible to all scheduled participants.

(2) Total possible lamp flashes; i.e., total number visible events X 7 lamps per flash event. (all events had 7 flashes)

(3) Numbers given are the possible flashes for mutual observation; i.e., one event missed by one station gives a 7; one event missed by two stations 14, etc.

(4) Number of images reported.

(5) Number of total possible flashes missed; same as (3)

the same tests were conducted at ROSMAN as at the GSFC, the primary purpose of these tests being to assure injection program and actual ground station/spacecraft compatibility and to provide training for station personnel.

Several local equipment problems arose that had not been encountered at the GSFC. These were overcome by minor program changes. Both synchronous and resynchronizing injections were successfully performed. In performing synchronous injections a Δt time correction was put into the computer program to compensate for delays in the ground station equipment, atmospheric propagation delay, and spacecraft equipment delays. This provided the necessary correction to provide ground station synchronization within one 22.750 cps (43 ms) clock pulse interval of the spacecraft clock.

Both synchronous and resynchronizing injections were successfully performed with the spacecraft. In addition, the backup synchronous injections were performed to check-out the program.

7.2.3 ROSMAN Injection Test With Orbiting Spacecraft

7.2.3.1 Injection Monitor/Simulation

Prior to performing a memory injection with the orbiting GEOS A spacecraft, the ROSMAN station monitored and simulated a memory injection along with an APL injection on the night preceding the ROSMAN injection attempt (December 22). Bit and frame sync were readily obtained, all indications being that a ROSMAN injection would have been successful.

7.2.3.2 Spacecraft Injection

On December 23, the ROSMAN station successfully completed a synchronous memory injection on the GEOS A orbiting spacecraft, with all 65 command words readily confirmed. APL monitored the injection and confirmed its success. Although not a scheduled part of the test, this injection was the first time the spacecraft had been loaded for two-day flash times. As in the preceding monitor/simulation, bit and frame sync were readily obtained. The programmed backup synchronous injection was not attempted since the initial injection was successful.

The resynchronizing injection was not attempted since there was no spacecraft clock error.

7.3 SPACECRAFT OPERATIONS FOR INVESTIGATIONS

During the first two months of operation considerable data have been accumulated, by the participating networks, from the outputs of GEOS A. The outputs include the optical beacon flashes, laser returns and the outputs from the three transponders onboard the spacecraft, namely, the range, Doppler and R&RR transponders. The SECOR range data is in doubt because of the suspected Doppler interference. Due to the large worldwide geographical distribution of the participating stations, the data flow to GSFC is slow. Hence, no data analysis results are available to date to indicate the utility of the spacecraft in the performance of its geodetic mission.

SECTION 8

SPACECRAFT PERFORMANCE

The spacecraft is performing reasonably well in orbit and is providing outputs for the planned investigations. However, some difficulties have been encountered in the operation of the spacecraft which have hampered the conduct of the investigations.

8.1 MEMORY SUBSYSTEM

A memory subsystem is incorporated in GEOS A to provide programmed flash sequences of the optical beacon. The memory is loaded by commands from the ground and can provide up to 68 hours of programmed beacon flashes, although it is normally loaded daily. During the early operational use of the spacecraft through 15 January 1966, approximately 13,000 flashes were programmed, of which about 1,400 were lost, as observed and estimated by APL. Table 8-1 presents a breakdown of the causes of the lost flashes and the associated failures.

TABLE 8-1. LOST FLASHES AND ASSOCIATED FAILURES

FUNCTION	TOTAL PROGRAMMED	LOST	% SUCCESS
1. Memory injection	62	12	81
memory failure		7	89
ground problems		5	92
2. Sequences	1,876	159	91.5
memory failure		87	95
ground problems		72	96
3. Short sequences	1,717	96	94
(due to 10 count)	(not lost)		
4. Individual flashes	13,013	1,395	89
memory failure		613	95
ground problems		453	97
short due to 10 count		329	97

Through 15 January 1966, 62 memory injections had been performed (this number does not include injections for the sole purpose of correcting the spacecraft clock). Seven of the 62 memory injections were dumped because of memory failures, and five more were incorrect because of ground problems such as operator errors or ground support equipment failures. The term "memory failures" is not used in its literal sense because the actual cause of failure is not known at this time. One hypothesis is that the problem stems from noise generated by optical beacon lamp #2, because each unscheduled memory dump has occurred at the instant of flash, each time lamp #2 has been programmed. The number of lost flash sequences also are listed as caused by memory failures or ground problems.

Another problem, short sequences, has occurred 96 times out of approximately 1,700 programmed sequences that were not lost. A short sequence is one in which all of the programmed flashes (either five or seven) do not occur. Flash lamp #4 has been programmed each time that a short sequence has occurred, and one hypothesis is that noise impulses from this lamp are triggering the 10-count circuit, causing it to register 10 counts before a sequence is completed. The 10-count circuit is a safety device to disable the flash circuits if 10 flashes occur before being reset by the start of the sequence pulse. Its purpose is to prevent the optical battery from being discharged by a malfunction that causes continuous flashing. It should be noted that the 10-count circuit is in the optical beacon subsystem, not in the memory subsystem.

The lost flashes are listed in three subcategories: ground problems, short sequences, and memory failures. Those lost due to ground problems and short sequences relate to problems previously discussed. Most of those lost due to memory failures were the result of unscheduled memory dumps; however, at infrequent intervals, several flashes have been lost due to other memory failures.

8.2 OPTICAL BEACON

The optical beacon subsystem is made up of a sequence controller, four xenon flash lamps, and a power supply for each lamp. The sequence controller regulates lamp flashes in response to signals from the memory subsystem. Sequences of five or seven flashes, at four-second intervals, can be provided using any chosen combination of flash assemblies. Problems concerning this subsystem are:

a. Noise generated during lamp flashes (referred to in the previous section on the memory subsystem)

b. Imprecise knowledge of lamp flash intensity

c. Nonoptimization of output of voltage regulators that charge the energy storage capacitors.

After GEOS A was orbited and before gravity-gradient capture (Paragraph 6.1) the beacon lamps may have been exposed to direct sunlight for a period up to 10 hours. During this period, the rays from the sun were focused on the base that supports the xenon tube rather than on the tube itself because the specified beam shape approximates a hollow cone. It is theorized that the apoxy coating on the base was vaporized and formed a carbon path from the trigger electrode (which is on the outside of the xenon tube) to the grounded reflector. Then, when the lamp is triggered, the trigger pulse is conducted to ground over a noise-producing path. A possible solution to this problem is to use beryllium oxide, a ceramic, for the bases.

A second result of the solar furnace effect referred to in the previous paragraph has apparently caused a problem in determining the light intensity of the flash lamps. The output of the flash detector cells has steadily decreased since GEOS A was orbited and it is hypothesized that the coating vaporized by the solar furnace effect has coated the cells and at least partially cut down the amount of light reaching them. In addition, the capacitance of the energy storage capacitors installed in GEOS A shortly before launch was not properly measured, and subsequent calibration of the light output was performed under extremely poor conditions. This problem will be solved for GEOS B by properly specifying the method of measuring the critical parameters of the capacitors.

Energy storage capacitors are charged by a separate regulated power supply for each lamp. The output voltage of each power supply is a function of certain sensing resistors, which should be selected so that the capacitors will be charged to 880 volts. Available resistors could not be combined for exactly 880 volts, so the combination that resulted in the next lower voltage was used.

APL has reported the following status of the operation of each lamp as of mid-January 1966:

Lamp #1 This is operating nominally

Lamp #2 The malfunction presently associated with the operation of this lamp unit is a total zeroing of the memory (memory dump) and a loss of timing. Nine malfunctions of this type have occurred.

Lamp #3 In single lamp flashing of this lamp, eight flashes in four sequences were lost out of 559 programmed flashes. The lost flashes in each sequence were always the first and the second.

Lamp #4 This unit has caused malfunctions more often than any other. The effect has been to truncate the flash sequence. The 10-count circuit is thought to come into play during the malfunction.

8.3 DOPPLER, R&RR AND SECOR TRANSPONDERS

The Doppler, R&RR and the Army range (SECOR) transponders have functioned satisfactorily through the end of January 1966.

Some interference between the SECOR transponder and the Doppler has been reported by the Army Map Service SECOR station at Herndon, Virginia. However, to date it has not been definitely established as to whether the problem exists in the spacecraft or at the ground station. A further investigation of this problem is currently underway.

8.3.1 Doppler Transponder

The Doppler system is providing good signals, such that through January 1966 85 percent of the 7,500 data receptions have been used for computer runs.

8.3.2 R&RR Transponder

The R&RR transponder functioned normally until 4 February 1966. At that time the spacecraft entered a period of full sunlight in orbit and the transponder temperature began to rise until it exceeded the upper temperature design limit. On 6 February 1966, the transponder was turned off and the temperature dropped to a level within design limits. The cause of this temperature increase is suspected to be the continuous exposure to the sun of the transponder side of the spacecraft (see Figure 1-3). The spacecraft has been observed to have no rotation about the yaw axis, so this side remains oriented toward the sun. An investigation of this problem has been initiated by APL.

8.3.3 SECOR Transponder

Shortly after the R&RR transponder temperature was observed to be increasing, the temperature of the SECOR range transponder, mounted on the opposite side of the spacecraft (Figure 1-3) was observed to be decreasing. The temperature dropped to the lower operational limit in early February and is stabilizing at that level. SECOR has had difficulty in maintaining operation at this temperature.

8.4 COMMAND SUBSYSTEM

The command subsystem is functioning normally and the spacecraft subsystems have responded to all ground commands. Although APL has prime responsibility for commanding the spacecraft, the NASA STADAN Stations have also demonstrated satisfactory command capability.

8.5 TELEMETRY SUBSYSTEM

The telemetry subsystem has functioned normally since launch and is continuing to supply data on the performance of the spacecraft. No difficulties have been encountered with this subsystem.

SECTION 9

REFERENCES

1. Technical Memorandum No. 4007-2, "GEOS A Launch Evaluation Report," prepared for NASA by System Sciences Corporation, Falls Church, Va., January 1966.

2. Technical Memorandum No. 4007-5, "GEOS A High Orbit Effects," prepared for NASA by System Sciences Corporation, Falls Church, Va., February 1966.

3. Technical Memorandum No. 4007-4, "GEOS A Readiness Test Evaluation Report," prepared for NASA by System Sciences Corporation, Falls Church, Va., February 1966.