

FINAL  
OAO-C COPERNICUS  
OPERATIONS REPORT

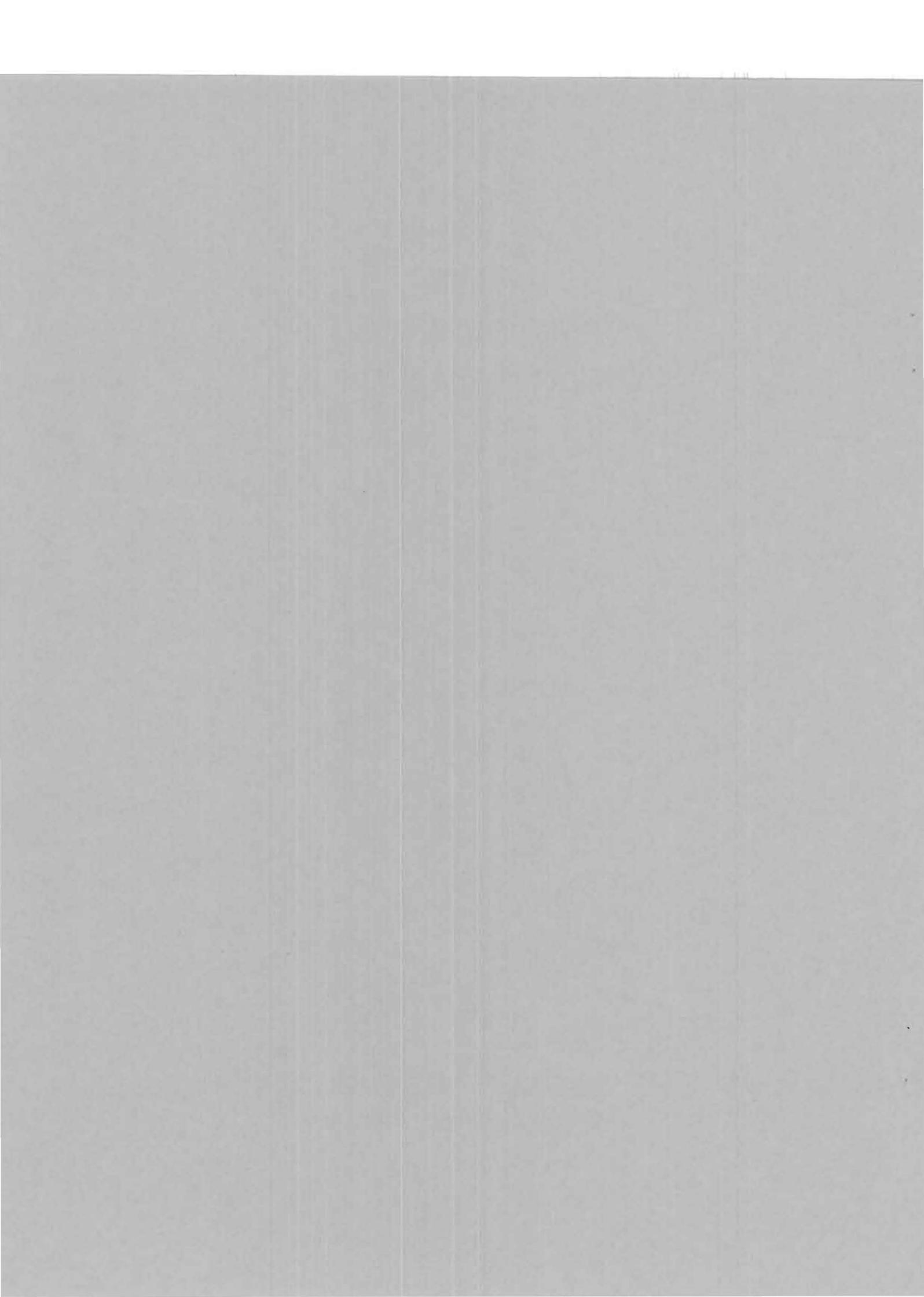
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**NASA**

National Aeronautics and  
Space Administration

\_\_\_\_\_ GODDARD SPACE FLIGHT CENTER \_\_\_\_\_

GREENBELT, MARYLAND



FINAL  
OAO-C COPERNICUS  
OPERATIONS REPORT

Prepared by Princeton University  
under  
NASA Contract NAS5-23576

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GODDARD SPACE FLIGHT CENTER  
Greenbelt, Maryland

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## SECTION 1

### SUMMARY OF INSTRUMENT PERFORMANCE

#### GUIDANCE

While the Princeton Experiment Package (PEP) was gathering stellar data, the pointing was maintained by centering the stellar image on the slit jaws of the experiment using the Fine Error Sensor (FES). To ensure that the guidance characteristics were similar over the range of stellar brightnesses observed, the high voltage of the FES was determined by an automatic gain control (AGC) that depended on stellar magnitude. During the mission, stars between -1.5 and 7.0 visual magnitude were regularly observed.

The experiment was designed with two different guidance tubes that could be operated separately or together. The channel A configuration (guidance tube A) was designed as the primary system and was used during the first 5 years of operation except when faint targets were observed. The channel C configuration (guidance tube B) was equipped with an operational amplifier to allow successful guidance on fainter stars and was used occasionally during this time. Because of suspected operational problems with channel A, beginning at orbit 27683, channel C was used exclusively until the final end of mission (EOM) tests that proved that there had been no malfunction in guidance tube A. Configuration B was a hybrid using both guidance tubes and was only used for brief tests.

Table 1-1 lists the orbits during which the different tubes were used. During the intervals listed in Table 1-1, experiment guidance data (guidance settle time, pitch and yaw error voltages, and AGC values) were collected. These data were tabulated along with the time of observation and target data to monitor the guidance performance. The stellar visual magnitude was plotted versus AGC for observations in intervals of about 1 year. AGC values can vary because of many factors such as stray light, location in orbit, pointing, etc., which result in considerable scatter in the plots.

Table 1-1  
List of Orbits and Guidance Channels

Orbit No.	AGC-Channel	Data Collected
0-12849	A	
12850-13506	C	Complete
13507-14943	A	
14944-15438	C	Complete
15439-16117	A	
16118-16165	C	Complete
16166-17254	A	
17255-17522	C	Complete
17523-27682	A	
27683-44861	C	(27683-34583)
44862-44890	A	Complete

These data were therefore fit by least squares straight lines for each year. Figure 1-1 shows these fitted lines for sets of channel C data acquired during the 3rd and 6th years of operation.

The plot shows the distribution of visual magnitudes up to about 7th magnitude. The lines plotted are only for those visual magnitudes between 1.5 and 5.5 since this is the region where most of the data were obtained. These two lines are the "best fit" for O and B stars only. The first line corresponds to orbits 12850 through 17473, and the second line corresponds to orbits 27683 through 33105. Channel C was used for both sets of data.

The upper limit or faintest visual magnitude that could be observed depended on the spectral type of the star. The hotter stars (e.g., O and B stars) had a fainter limiting magnitude. From the straight line fit to the data, a theoretical limiting magnitude corresponding to the maximum allowable AGC (8.6 volts) can be determined. Table 1-2 summarizes this limit as a function of spectral type for orbits 27683-33105 ("line 2").

An inspection of Figure 1-1 allows an estimate of the guidance system's degradation from the 3rd to 6th year of operation (lines 1 and 2, respectively). Comparing lines 1 and 2 shows that, for a given magnitude, a higher AGC was required to run the guidance system during the 6th year than during the 3rd year. Brighter than

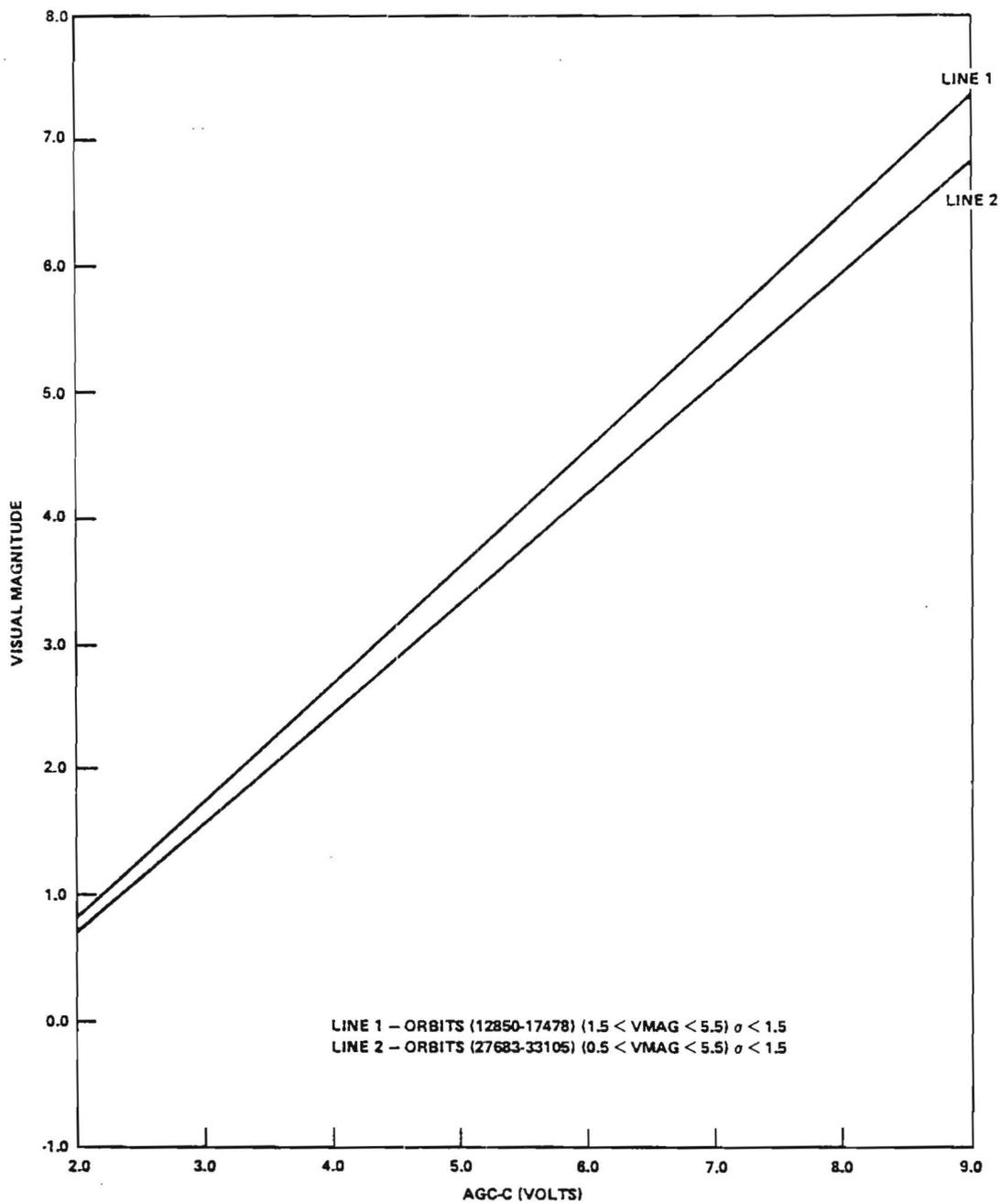


Figure 1-1. AGC-C versus Visual Magnitude

Table 1-2  
Limits for Predicted Visual Magnitude at Saturated  
AGC-C Voltage

Spectral Class	AGC-C Saturated	Y Intercept	Slope VMAG vs. AGC-C	Predicted Visual Magnitude
O	8.6 V	-1.36	0.97	7.0 ±0.4
B	8.6 V	-1.39	0.93	6.6 ±0.3
A	8.6 V	-2.41	0.99	6.0
F	8.6 V	-1.79	0.91	~5.7
G	8.6 V	-2.39	0.97	~5.5
K	8.6 V	-2.28	0.95	~4.8
M	8.6 V		Insufficient	Data

visual magnitude 4.5, the difference is not statistically significant. For the faintest stars, a loss in sensitivity of about 0.5 magnitudes had occurred. No appreciable degradation in the FES was observed in the last 2 years of the satellite's operation.

In normal operation, when the AGC exceeded 8.6 volts, the FES automatically returned control to the spacecraft's inertial reference unit (IRU). It was possible to override this limit using a mode of operation called the forced switch option (FSO), which used the onboard processor (OBP) to monitor the stability of the guidance. The FSO extended the ability of the FES by about 1.0 magnitude over the limits listed in Table 1-2. The FSO operational mode was discontinued August 31, 1978, when the OBP failed. Later, when some

OBP functions had been recovered, the FSO was useless because of the loss of spectrometer sensitivity (see Section 2).

Over a period of more than 8 years, the guidance system in the PEP performed beyond expectations. The overall guidance sensitivity degraded very little and equalled or surpassed all prelaunch predictions.

#### SPECTROMETER/TELESCOPE

Throughout the mission of the PEP, both spectrometer carriages performed at nominal design specification. No mechanical anomalies were ever noted. Before the OAO-C launch, carriage 2 was discovered to have a low-rate leak in its sealed lead-screw bellows assembly. This was considered, however, to have little consequence over the anticipated 1-year lifetime of the PEP, and a decision was made to continue with launch preparations.

The commanded carriage motion was extremely predictable, and all deviations from expected behavior were traced to electronic glitches, operational programming errors, or a lack of understanding of the nonstandard operation of the carriage motion control subsystem (special programs, configurations, etc.).

The static position indicators for both carriages possessed a known inherent ambiguity that occasionally resulted in a scientific data loss because of incorrect interpretation of the carriage position

status by operations personnel. On several occasions, the carriages were also inadvertently commanded to positions beyond their normal ranges of travel, but in each instance, the electrical limit switches were activated, and the motion of the carriages was halted before any physical stop was met.

The obscuration pattern of carriage 1 sensors by the carriage 2 collection mirror was determined early in the mission, and this effect was included, when necessary, in the observing programs. Stray light entering the vent ports of the far-UV sensors was also recognized as a problem. This effect was much reduced by judicious operations programs and data reduction correction procedures.

The carriages were always operated in the closed-loop mode. In an attempt to isolate the causes of unscheduled experiment high-voltage shutdowns and redundant unit switching, carriage motion controller C was placed on-line for a period of about 1 month in early 1978. Frequent adjustment of the carriage positions by real-time commanding was necessary during this interval. This was not due to any irregular behavior of the carriages, but was caused by the operations programs not having been designed to handle the more complex motion of controller C.

#### REDUNDANT UNITS

During the lifetime of the PEP, deliberate configuration changes were kept to a minimum. The most common configuration adjustment

was switching the on-line low-voltage power supply (LVPS-A to/from -B or -C). This switching was done to take advantage of the increased sensitivity provided by the FES QPMT-B electronics and was used for viewing faint objects. Such special viewing periods spanned several weeks before reverting to LVPS-A. This latter unit included an FES protection override feature and was used whenever possible.

During the first few mission years, the DHVPS's were normally not cycled, and a pair of the three available units were kept on continuously. An increase in unscheduled DHVPS shutdowns commencing in late 1977, however, required a revision of this basic operating philosophy. In early 1978, the DHVPS's were turned on only during actual data-taking intervals, and only those sensors required by the particular observing program were used.

In an attempt to isolate a possible cause for the frequent data high-voltage shutdowns and spurious unit switching experienced during the foregoing period, various units were tested on-line. This procedure yielded no suspect units.

During an LVPS-C to LVPS-A switching change in the winter of 1978, status displays and unexpected spacecraft motion indicated loss of the PEP guidance function in channel A. LVPS-C was quickly returned on-line and remained in that state until contact 44856 Santiago. An end-of-mission checkout of LVPS-A (FES channel A) indicated nominal guidance performance (no failure).

The only necessary switching because of failure involved the sequence controller (SC) function. SC-A analog data rate switching relay was stuck in the 16-second mode; SC-B failed during the occurrence of an extensive glitch and did not respond to subsequent "on" commands.

Thus, except for SC-C, the final on-line configuration of the PEP was the same as its immediate postlaunch configuration.

#### OPTICAL PERFORMANCE

The overall performance of the "optical" system (mirrors, phototubes, and associated electronics) was within expected limits for the first 5 years of the mission. Shortly after launch, telemetry indicated that the secondary mirror had not positioned itself properly. A check of the image size and shape in orbits 168-170 showed the image to be in focus. It was concluded that the secondary mirror was positioned correctly and that the telemetry was bad. A second check of the image size was performed in orbits 35250-35260 and showed no significant change in the image. A third set of image data obtained during the last month of the mission was lost. It is believed, however, that the image size and shape were maintained throughout the mission.

The only major change in performance occurred in the experiment far-UV sensitivity. During the first 5 years of the mission, the decline in instrument sensitivity was similar to that predicted

before launch: the largest decline occurred the first year with the shortest wavelengths being the most affected. Beginning near orbits 25000-30000, the decline in sensitivity accelerated, dropping by a factor of 5 in 1 year, with the largest decline occurring at the middle, rather than shortest, wavelengths. This decline continued throughout the remaining 3 years of the mission. Investigation of the cause for this decline is still under way. The best explanation at this time is that the decline is due to contamination of the optical surfaces in the spectrograph by an unknown material. The onset of the rapid sensitivity degradation in 1977 corresponds to the onset of solar maximum, suggesting that a process similar to that found in the Television Infrared Observation Satellite (Tiros) is working (Reference: Tiros Project Memo of October 12, 1979). Details of the decline in sensitivity can be found in Section 2.

No failure of any component in the optical system was recorded during the mission. All six phototubes and their associated electronics were functioning at termination.

#### V TUBES (FLUORESCENCE AND SF)

The near-UV photomultiplier tubes (V1, V2, and V3) are covered by windows made of  $MgF_2$ . The passage of cosmic rays and other high-energy particles through these windows causes the tubes to record very high background count rates. The background is composed of a primary "short-term" component and a secondary "long-term"

phosphorescence component. The primary component is a photoelectron burst of duration  $\leq 0.125$  second caused by the passage of a cosmic ray through the window material. The secondary component or phosphorescence is due to the accumulated damage to the windows by repeated passage of energetic particles.

Since the primary component of the background is a short ( $\leq 0.125$  second) burst and these bursts are separated in time by approximately 0.5 second, they can be eliminated by sampling the photomultiplier counting register at a rate high enough to discriminate against the cosmic ray bursts. The maximum rate at which the OBP can be commanded is 0.125 second, which is sufficient for distinguishing the time of bursts. Counting registers 1 and 3 can be sampled at the 0.125-second rate, but only tubes V1 and V3 can be assigned to these registers. Consequently, V2 cannot be sampled at the 0.125-second rate.

An observing program, called the "short frame" program (taken from the fact that only a partial data frame is stored every 0.125 second), was initiated in 1975 using the V1 photomultiplier tube and the 0.125-second sampling rate. Because the sampling rate is 112 times more rapid than the normal 14-second rate, the available 8K of data storage becomes full after only approximately 4 minutes of data taking. Since there are normally only two or three contacts per orbit in which the data can be transmitted to the ground, short frame data taking is fairly inefficient. However, in many cases, it

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allowed observations to be made that otherwise could not be obtained in the ordinary data-taking mode. Generally, the ordinary mode was useful only when observing stars that were bright enough so that the stellar signal was much larger than the background.

#### POWER SUPPLY

Copernicus was launched with three DHVPS's and three LVPS's. At the end of the mission, all six power supplies were functioning. The only anomaly to occur involved the DHVPS and glitches (unscheduled reconfigurations). Beginning in the first year after launch, configuration changes of the redundant units, data registers, entrance slit, guidance package, and the power supplies would spontaneously occur. From the very first glitch (orbit 131), the DHVPS was suspected as a cause. The glitches were rare (a few per year), and attempts to explain them met with unsatisfactory results. They were considered essentially random events that could not be avoided.

Late in 1977, the glitch problem became severe. The DHVPS would shut down many times per month (sometimes many times per day), stopping data gathering and, at times, putting the spacecraft into an unsafe mode. The glitches seemed associated with the DHVPS and gross solar activity, but until 1979, no way was found to avoid them. At that time, a Glitch Avoidance Scheduling Procedure (GASP) was instituted, virtually halting the glitches. Analysis of the glitch data appears to absolve the DHVPS as the direct cause of the glitches. They are, however, a significant part of the glitch. A

glitch is thought to occur as follows: a power surge occurs somewhere in the spacecraft and is detected by the DHVPS. Protection circuitry shuts down the DHVPS, propagating the surge through the system, thereby altering the status of support electronics. One DHVPS, unit B, experienced a change in protection circuitry in 1973. After shutting down, it would turn itself partially on. DHVPS B was noted to be less sensitive to the power surges than either DHVPS A or C.

Details of the glitches and their effects on the mission can be found in Section 2.



## SECTION 2

### MALFUNCTIONS AND RESULTANT IMPACT

#### MECHANICAL FAILURES

The few failures that occurred within the PEP did not compromise or severely limit its basic scientific mission. These failures are itemized as follows:

a. Secondary Mirror/Focus Mechanism

During the immediate postlaunch checkout of the PEP, status data indicated incomplete uncaging of the telescope's secondary mirror/focus mechanism assembly. Subsequent data analyses suggested failure of the telemetry monitor circuits and not of the uncaging operation.

An attempt to change the telescope focus in orbit was also unsuccessful. Position status data of the secondary mirror implied that no motion was produced by commanding. Because the final focus adjustment prior to launch was calculated to include the effects of the launch environment, the telescope was believed to be near best focus. Image shape tests confirmed this status. End-of-mission attempts were made to move the secondary mirror, but again, no motion was observed.

b. Calibration Lamps

Postlaunch checkout of the calibration lamps confirmed launch survival and no significant changes in the spectrometer

wavelength calibration. The lamps were infrequently used thereafter. During a special series of observations about one third into mission lifetime, however, both lamps failed to operate. End-of-mission attempts to ignite calibration lamp A were unsuccessful.

c. Sequence Controllers A and B

Sequence controllers A and B were the only failed PEP electronic units at end-of-mission. SC-A AD transfer rate relay failed in the 16-second mode. This occurred within the first half year of the mission. Tests made with the unit indicated that the 16-second analog data store rate was effectively suppressed with the electronic data-handling equipment (EDHE) in its store cyclic mode. At the same time, PEP digital data continued to be stored at its asynchronous rate (i.e., one digital block every 1/4 spacecraft-minute). Thus, this unit could have been placed on-line in the event of failure of both SC-B and SC-C. SC-B went off during a severe glitch in early 1978 and failed to respond to subsequent turnon commands.

SENSITIVITY DEGRADATION AND EFFECTS

The principal malfunction in the PEP was the rapid decline in the far-UV sensitivity. The decision to terminate the spacecraft was based partly on the loss of far-UV sensitivity. Figure 2-1 shows the relative sensitivity of the high-resolution far-UV phototube U1

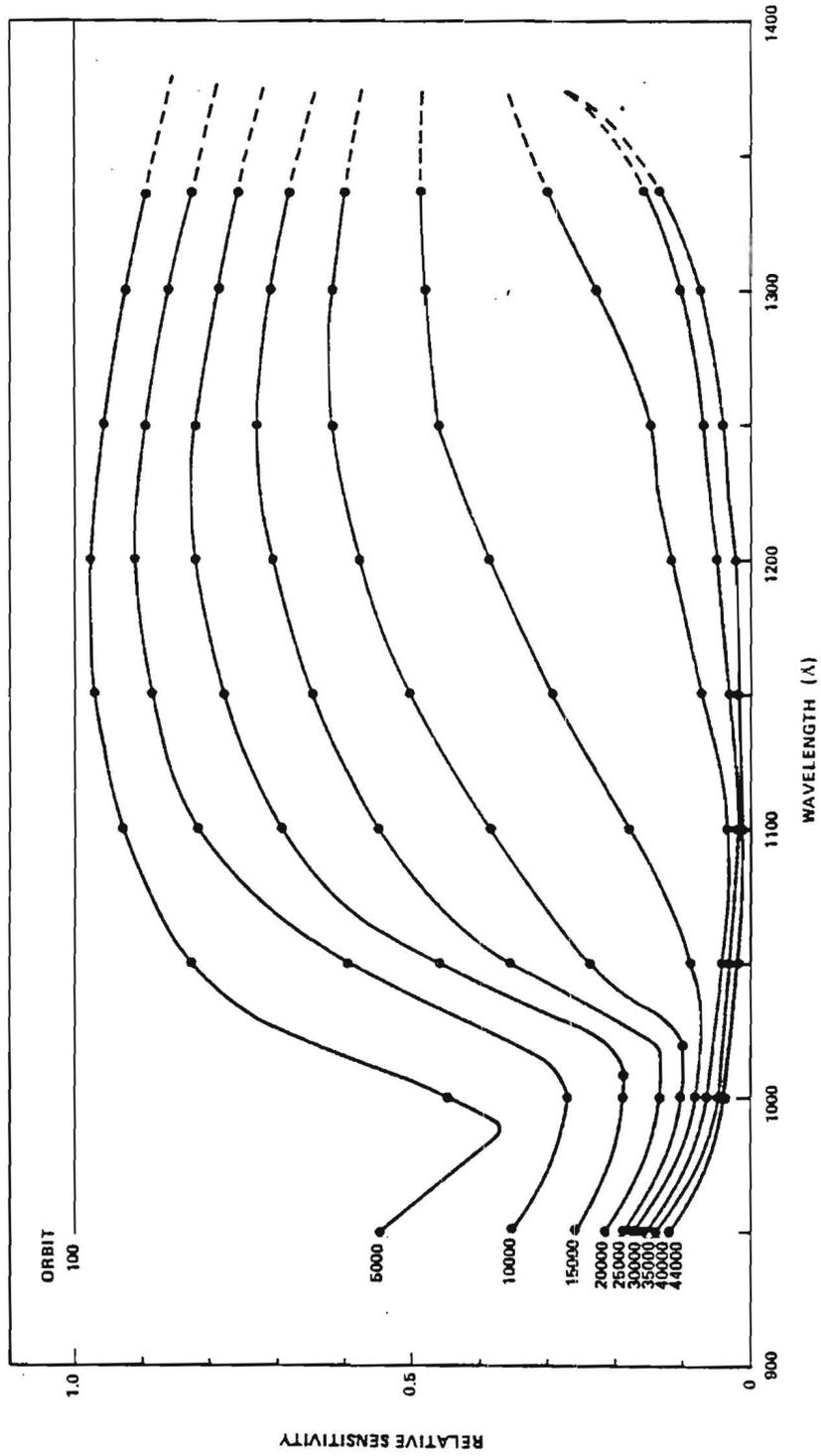


Figure 2-1. U1 Relative Sensitivity

from orbits 100 to 44000. In the first 25000 orbits (5 years), the decline was close to that predicted before launch. A rapid (approximately 50 percent) decline at shorter wavelengths was experienced during the first year followed by smaller declines in subsequent years. At longer wavelengths, the decline was more gradual and reasonably constant (approximately 10 to 15 percent per year) through the first 25000 orbits.

After orbit 25000, the character of the decline was significantly different. At the shortest wavelengths ( $<1000 \text{ \AA}$ ), a slow decline continued until termination. At the middle wavelengths (1000 to  $1300 \text{ \AA}$ ), a dramatic decline occurred. Between orbits 30000 and 35000, the sensitivity of the U1 tube decreased by a factor of 2.25 at  $1100 \text{ \AA}$ . By orbit 40000, another factor of 5 was lost. Thus, in 10000 orbits, more than a factor of 10 was lost. At longer wavelengths ( $>1300 \text{ \AA}$ ), the decline was not as rapid (a factor of 4 in 10000 orbits), but it was larger than that observed before orbit 25000.

The low-resolution far-UV phototube U2 exhibited a behavior similar to that of U1. The only significant difference was that during the period of rapid decline (orbits 25000-44000), it showed a greater decline than U1. The U2 wavelength dependence was similar to that of U1.

The near-UV phototubes, V1 and V2, did not exhibit the rapid decline seen in the far-UV phototube. They displayed an initial rapid decline followed by a much slower decline until the end of the mission. At orbit 25000, both V1 and V2 were at approximately 70 percent of their launch sensitivity. By orbit 44000, they still retained 60 percent of their sensitivity at launch.

Clearly, something occurred between orbits 25000 and 30000 that greatly affected the sensitivity of the far-UV phototubes. This is also the period in which glitches began to occur in abundance (Section 2). This suggests that the two malfunctions may have the same cause or that the sensitivity decline was somehow caused by the effects of the glitches.

W. L. Upson II has been conducting an analysis of the sensitivity loss, which is nearing completion. His preliminary results will be presented, and a full report will follow at a later date.

The initial decline in sensitivity, orbits 0-25000, is similar to that seen in other devices. The cause is thought to be primarily due to the decay of the photocathodes. The rapid decline occurring after orbit 25000 is, however, quite anomalous. Investigations conducted shortly after the onset of the rapid decline absolved the power supplies and other control units as the cause of the sensitivity loss. This left only contamination of the optical surfaces

and/or photocathodes as the cause of the decline. This suspicion is further supported by the fact that U2 showed a greater decline than U1 (U2 undergoes one more reflection than U1).

At the same time that Copernicus was experiencing this rapid decline in sensitivity, Earth sensors on Tiros-N, NOAA-A, and 5D/1 were also noted to display significant sensitivity losses. Analysis revealed that their sensitivity loss was due to contaminants on the optical surfaces. The contaminants came from outgassed material reacting with atmospheric oxygen to produce polymers. The increased solar activity in 1977 raised the mean density of oxygen in the upper atmosphere and caused the polymer production to increase dramatically (see report from Tiros Project for details).

Analysis of the data suggests that a similar reaction may have occurred in the PEP. The most likely location for the contaminant is in the spectrograph. Ample materials exist for outgassing, and the spectrograph is open to space so that atmospheric oxygen can enter (direct observation of oxygen atoms confirms their increased abundance at the altitude of the spacecraft in 1978 through 1981). U1 and U2 show greater declines because of the peculiar absorbing properties of the contaminant. The peak absorption appears to occur between 1050 Å and 1150 Å. U2 shows more loss because the incoming light undergoes an extra reflection to enter the phototube. Further analysis is continuing. A final report on the decline and possible causes will be issued when the analysis is complete.

The impact on Copernicus operations caused by the loss of sensitivity was to lengthen all observations. Programs were run several times to get the data quality obtained with a single run before 1977.

#### IMPACT OF V TUBE FLUORESCENCE AND SHORT FRAME

As explained in Section 1, the background levels in the near-ultraviolet tubes (V1, V2, V3) were much larger than expected. It has been determined that passage of energetic particles (cosmic rays, particles, etc.) through the windows covering the tubes causes a short-term fluorescence and a long-term phosphorescence. The sum of these two components results in a background count rate of approximately 7000 counts/14 seconds in V2 and approximately 10,000 counts/14 seconds in V1. Therefore, V1 and V2 were useful only for fairly bright stars, where the stellar signal was much larger than the background. With the advent of the short frame program in 1975, the V1 tube began returning higher quality data. However, short frame observations required the use of the OBP (except for the technique implemented in 1980, whereby the spacecraft was commanded from the ground). From 1975 to 1980, the OBP had numerous minor failures and three major failures. The major failures resulted in the OBP being inoperable from April 8 to August 7, 1977; August 30, 1978 to June 26, 1979; and June 28 to October 3, 1980, a total of 17 months.

#### GLITCHES AND GASP

Unscheduled reconfigurations (glitches) of the Princeton Package have occurred since orbit 131. These glitches have ranged from very

minor events (register reassignment and commutator steps) to events major enough to greatly endanger the spacecraft. Approximately 260 glitches were recorded in the 45000 orbits of the mission. The incidence of glitches in the first 5 years (25000 orbits) was very low, a few per year. The impact on operations was very small, data loss being the only lasting effect.

Beginning near orbit 27000, glitches became much more common: 80 percent of all glitches have occurred since orbit 27000. The impact of this high rate of glitches was twofold: first, a substantial amount of data was lost. This required rescheduling observations, but in some cases resulted in permanent scientific data loss. Second, the danger to the spacecraft was greatly increased. The only hard failure of a major PEP unit occurred during one such glitch (Section 1). Given these factors, every effort was made to identify the cause of the glitches and to establish a method by which they could be avoided.

The onset of glitches in late 1977 suggested a connection with solar activity. An initial check of the data seemed to support this, but as more glitches occurred, it was determined that solar activity was not the trigger. Various other glitch avoidance techniques were tried, but none seemed to work. In early 1978, an analysis conducted by E.L. Wilson showed that most of the glitches were occurring when the telescope was pointed in the plane of the orbit near the point where the spacecraft is approaching the target at maximum

velocity. Figure 2-2 presents the orbital latitude distribution of the glitch targets; Figure 2-3 shows the distribution of glitches with position in the orbit.

Using these two correlations, the Glitch Avoidance Scheduling Procedure (GASP) was developed. The GASP involved scheduling observations, as much as possible, to occur when targets were greater than 40 degrees from the orbital plane. When this was not possible, the high voltages were turned off during the period of high glitch probability (+30 to +120 degrees as shown in Figure 2-2). The GASP was made operational on April 1, 1979. Immediately, almost all glitches stopped. The only glitches that occurred after that time were due to either relaxing the GASP requirements (to obtain more observing time) or human error in implementing the GASP. The only impact that the implementation of the GASP had on operations was to reduce the observing efficiency, since part of the orbit could not be used for data taking.

Analysis of the glitch data has failed to identify a specific cause for their occurrence; however, many things have been learned. No connection was found between glitches and the Earth's latitude or longitude, spacecraft day or night, or short-term solar activity (flares, storms, etc.). No single electronic unit was identified as the source of the problem. The similar behavior of all the glitches implies that the cause may be in the spacecraft or a global event

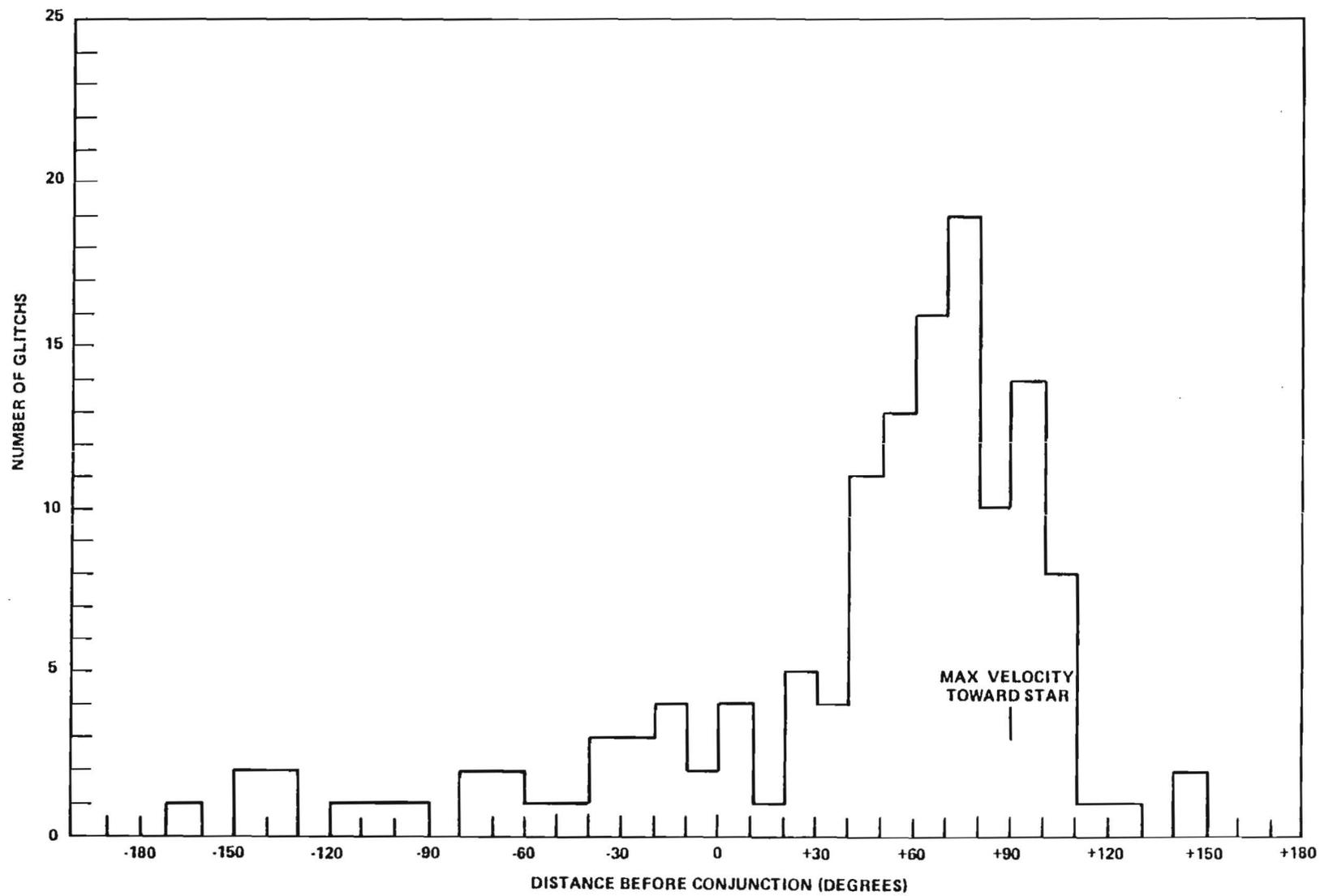


Figure 2-2. Distribution of Glitches with Position in Orbit

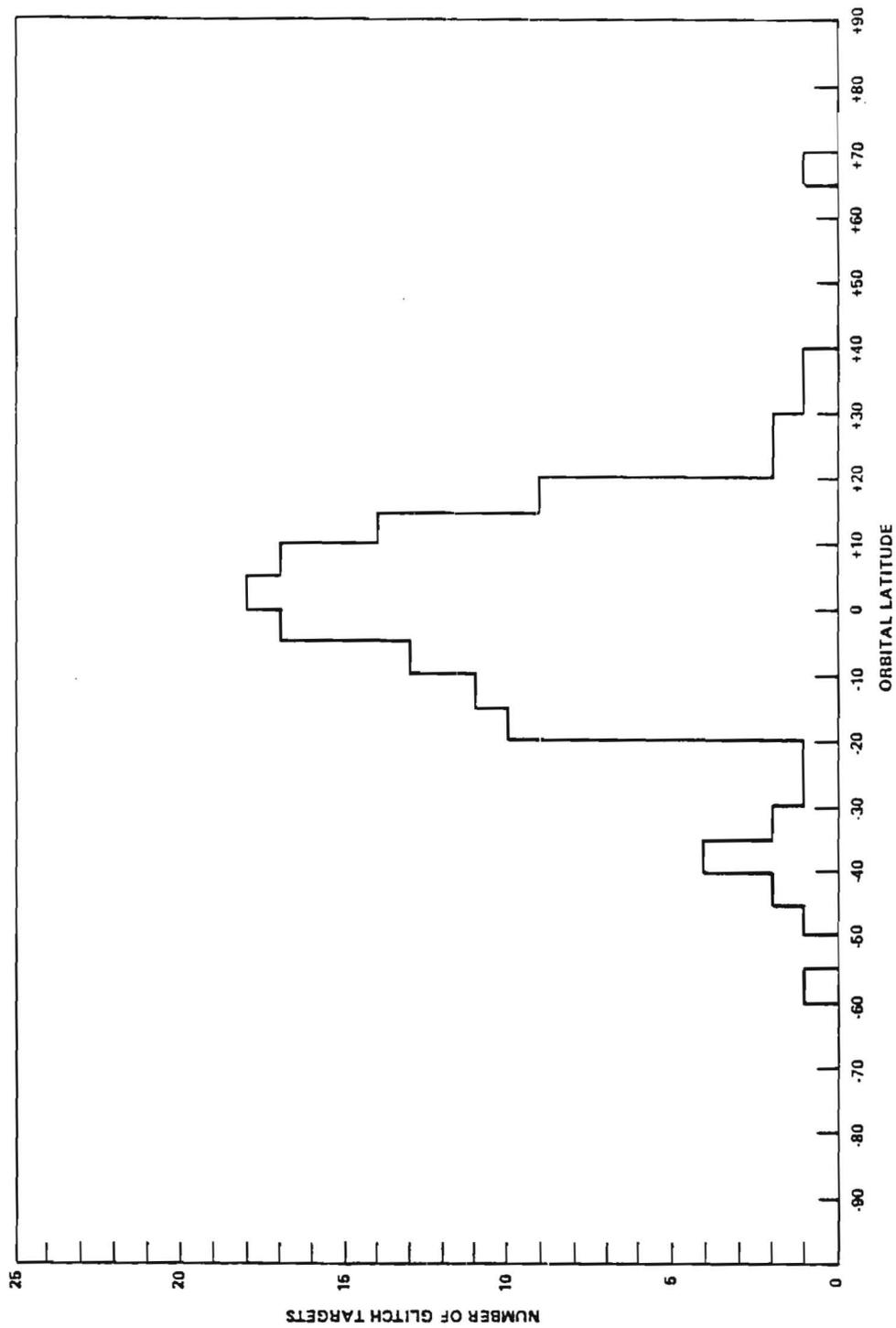


Figure 2-3. Orbital Latitude Distribution of Glitch Targets

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(i.e., affecting all Princeton units). The trigger for a glitch must be associated with the density of the Earth's atmosphere. The increase in glitches in late 1977 correlates well with the onset of significant solar activity. Solar activity will cause the Earth's atmosphere to expand, thus increasing the mean density at the altitude of Copernicus. The occurrence of glitches at the point of maximum velocity toward the target supports the idea that the Earth's atmosphere is the ultimate cause of the glitches. The point of maximum velocity toward the target is also the point at which the maximum RAM pressure is exerted on the spacecraft. The strong orbital latitude dependence supports this concept: glitches occur only when the open end of the telescope is pointed in the direction of the spacecraft motion.

A glitch is thought to occur as follows: as the spacecraft approaches the glitch point, the power levels in the Princeton Package become unstable. Shortly after this, the high-voltage protection circuitry senses a power change and shuts down the high voltage. This in turn produces a transient in the system, and other units may be affected. A glitch has occurred.

## SECTION 3

### ORBITAL OBSERVATIONS AND OPERATIONS

#### OBSERVATIONS

##### MILESTONES

The milestone tables contain a chronological listing of all spacecraft slews and observational targets with their respective execution times. Other information is also included such as the orbit number of data storage dumps, the astronomical sequence list (ASL) name of the observation, and the beta and theta angle of the spacecraft during the observation. The milestone tables appear in Appendix A (which is available upon request).

##### TESTS

Throughout the operational lifetime of the spacecraft, many tests were performed, as can be seen in the milestone tables. A detailed discussion of all tests would not be appropriate to give here. However, the tests generally were two types: signal tests and configuration tests. Signal tests were performed on relatively faint targets to determine the counting rates in the photomultiplier tubes or the guidance tubes (i.e., the AGC value). Configuration tests were performed to determine which units, channels, etc., to use while observing.

SPECIAL OBSERVATIONS (SHORT FRAME)

Short frame observations were conducted in three different ways:

- a. Commands were stored in the OBP and were executed at the appropriate time. The resulting data were stored in data storage and were relayed to the ground by the wideband or narrowband transmitter.
- b. Commands were stored in the OBP and were executed so that data were being obtained during contact with ground stations. The data were not stored, but were sent in real time to the ground station by the narrowband transmitter. This method of operation was called the "real-time" short frame method.
- c. Commands were sent to the spacecraft from the ground at the same rate as the OBP commanding rate. This technique was initiated in August 1980 and was used when the OBP was nonoperational. This method was called the "real-time ground command" short frame method.

The preceding paragraphs point out that, during short frame observations, full use of the NASA ground station network was needed. However, lack of network support at these stations resulted in the loss of approximately 25 percent of the requested observing time. Before 1979, most of lost support was due to conflicts with the International Sun-Earth Explorer (ISEE) series of satellites.

Starting in June 1979, the priority for short frame observations was raised substantially, and these problems subsided somewhat. During this time, approximately 15 to 20 percent of the requested contact support was denied, mostly because of conflicts with the the High-Energy Astronomy Observatory (HEAO) and the Solar Maximum Mission (SMM).

## OPERATIONS

### DATA LOSS

OAO-3 Copernicus operated at an efficiency of 97.8 percent through its 44890 orbits of life. A total of 1001 orbits of scientific data were lost. The largest single source of data loss was problems with the experiment (17 percent, 166 orbits). This was followed by Network-induced losses (15 percent, 146 orbits), human error (13 percent, 132 orbits), and spacecraft problems (13 percent, 127 orbits). The remaining data loss was due to many small problems (solar eclipse, low-lead time, failure to acquire target, etc.).

### CONSOLE ACTIVITY

During the operational lifetime of the Copernicus satellite, the performance of the PEP was monitored continuously (during spacecraft contacts) at the PEP console. Commands were sent to the spacecraft from the console to correct carriage positions, turn on and off data high-voltage power supplies, use different redundant units, change operational configurations, and protect the package after glitches.

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Commanding activity at the PDP console is recorded in the Grumman Aerospace Corporation (GAC) console logbook and the PEP console logbook. Both of these logbooks were studied, and a chronological list of all commands sent from the PEP console was tabulated. A study of the sequence of activities at the console reveals five fairly distinct operational phases that the spacecraft encountered:

- Orbits 1-2000--This was the first year of operation and was an operational development phase.
- Orbits 2000-12000--This was a fairly active period of commanding, mostly to correct scheduling errors.
- Orbits 12000-27000--A very calm period for problems. Most of the commanding was the result of planned tests.
- Orbits 27000-35000--This was a very active period for commanding because of the high frequency of glitches.
- Orbits 35000-44890--A fairly calm period for commanding. The occurrence of glitches was virtually stopped by implementing a new observing procedure.

Following is a more detailed discussion of each of these phases. Figure 3-1 graphically displays the console activity throughout the mission.

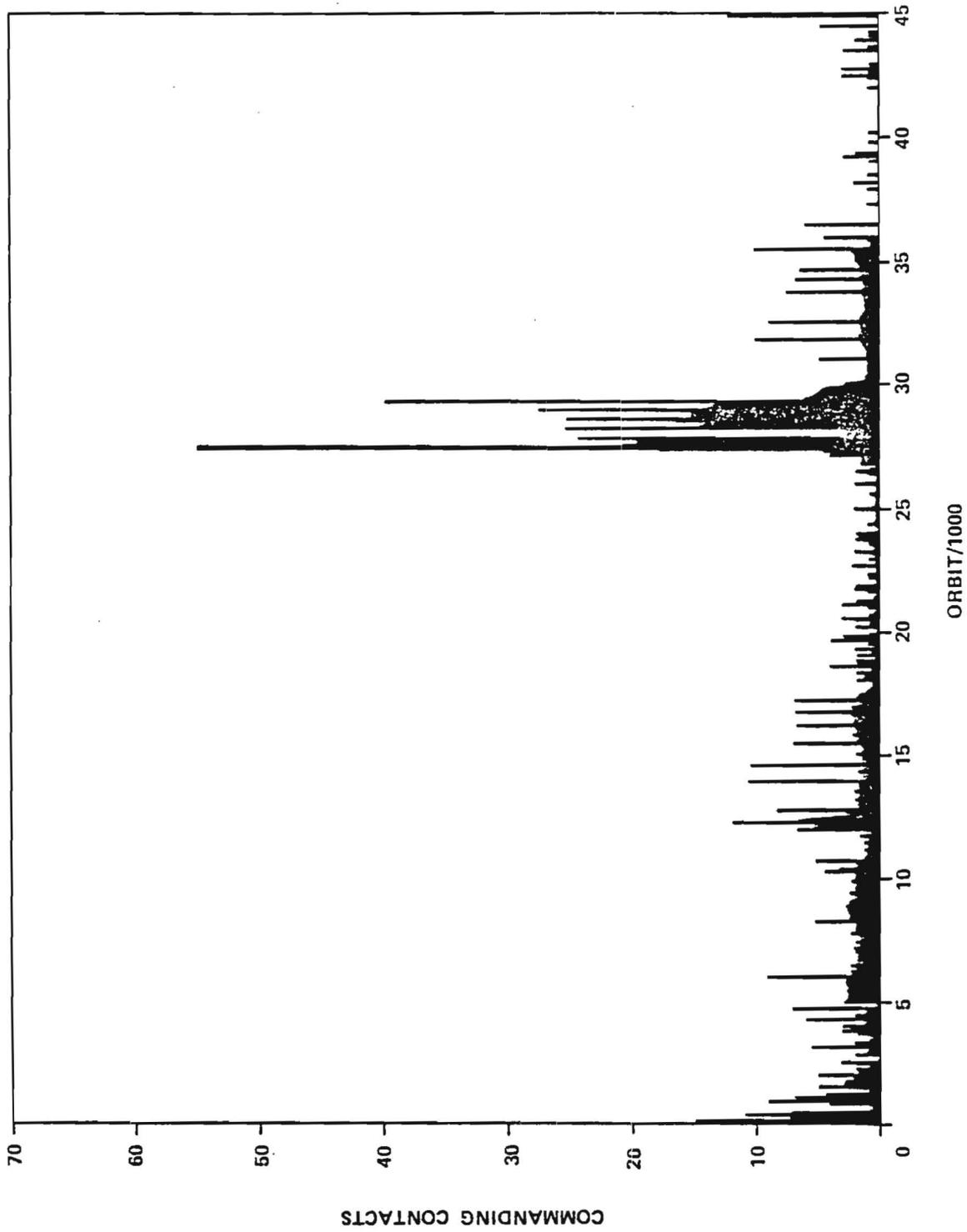


Figure 3-1. Mission Console Activity

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### Orbits 1-2000

The orbital range is the period in which the PEP was turned on, tested, and put into operation. The first PEP command was sent in orbit 56. Commanding continued at a high rate through orbit 256. After that point, commands were sent primarily to correct carriage positions and to remove the effects of minor glitches. By orbit 2000, the commanding rate was reduced to the rate that would be held for the next 10000 orbits.

### Orbits 2000-12000

During this period, the rate of real-time commands from the console was fairly high--the average being about 3 commanding contacts (contacts at which commands were issued) per 100 orbits. Techniques for generating schedules had not been developed to the point of being error free. Consequently, 70 percent of the commands sent from the PEP console were to correct scheduling errors. At this time, most console operators did not have much experience in real-time commanding from the console. Therefore, relatively many mistakes were made, which had to be corrected with further commands. These console operator errors were the cause of about 30 percent of the commanding during this period.

### Orbits 12000-27000

This was a period of very little console activity other than during planned testing. Beginning around orbit 14000, the short frame mode

of data acquisition was tested, which required some real-time commanding. Guidance offset and gain tests were also run from the console to study the possibility of viewing faint objects. In addition, some unplanned real-time commanding was necessary as a result of planetary and other special observations. Toward the end of this period (orbits 20000-27000), console activity fell to a very low level of less than one command per 100 orbits.

#### Orbits 27000-35000

A dramatic increase in the frequency of glitches caused a corresponding increase in console activity during this period. Real-time commanding initially reached an all-time high of 55 commands per 100 orbits, as high-voltage supplies and redundant units were simply commanded back to the original configuration after a glitch. Later, in an attempt to prevent the glitches, various changes in operating procedure were tried, most requiring some console activity. One such switch in the use of a redundant unit caused frequent carriage problems, which then required additional real-time commanding. Eventually, the data high-voltage power supplies were cycled on and off each orbit coinciding with observation periods. At first this was done in real time from the console, but then later it was incorporated into the scheduling procedure. This greatly reduced the frequency of glitches, but it was not until the institution of the GASP, beginning around orbit 35000, that they were virtually eliminated.

Orbits 35000-44890

This was a fairly quiet period for console activity as a result of instituting the GASP technique. By taking into account the specific orientation of the spacecraft during an observation, an appropriate high-voltage turnon time could be found so as to avoid a glitch. (A more detailed description of this procedure can be found in Section 2 of this report.) However, there continued to be a small number of scheduling errors and glitches, which were responsible for most of commands sent in real time from the console.

Also during this period, more observations were conducted in the short frame mode because of the declining sensitivity of the instrument. The partial failure of the OBP, however, led to a real-time short frame worker that required command support from the GAC console.

Additional real-time commanding was indirectly a result of the declining priority of OAO. Many contacts were lost to higher priority satellites during this time, and occasionally this resulted in the loss of all memory load points. This caused the execution of the coast hold sequence, which then necessitated some real-time commanding before being able to return to normal operations.

Late in the life of OAO, there was much console activity because of end-of-mission testing. This is discussed in detail elsewhere.

## SCHEDULING PROCEDURES

The Princeton Experiment Package scheduling procedure (Figure 3-2) involved the use of the following four programs:

SLEWER ④--The SLEWER program performed the calculations for a change in spacecraft attitude.

ASL ③--The purpose of the ASL program was to convert the wavelengths requested by the astronomer into the appropriate carriage motion commands. These carriage motion commands were then used as input to the AVATAR program.

AVATAR ①②⑤--AVATAR was the basic scheduling program. It was used to update the Network Computing Support Section (NETCONS) and orbital elements and to generate timelines and schedules.

TGIF ⑦--The TGIF program was used to check the accuracy of the schedules before they were released to GAC for further processing. In addition, the program produced a clear, readable command list, which was later used in monitoring the status of the experiment package.

The first step in scheduling an observation was to update the NETCONS and orbital elements. ① This was performed once every 1 to 2 weeks. The time and duration of forthcoming contacts and the most recent values of orbital parameters, as determined by NASA, were input to AVATAR for later use in generating schedules.

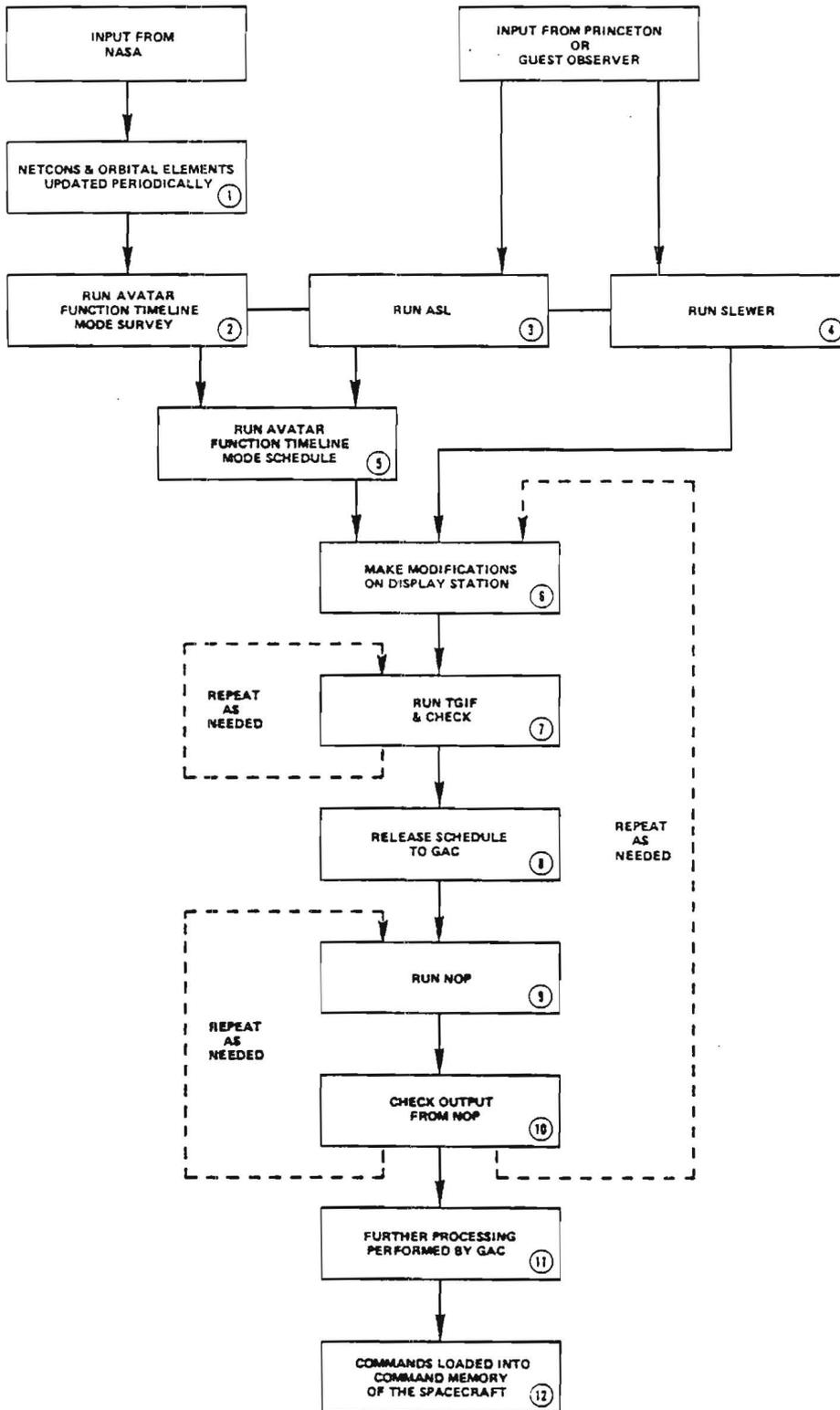


Figure 3-2. Flow Chart of the PEP Scheduling Procedure

When the NETCONS and orbital elements were updated, a survey was run to display orbital and target occultation information.<sup>②</sup> This was used in determining input to the scheduling program such as when to begin scheduling observations and where to specify an "open" contact (i.e., no observation during the contact so that data storage can be dumped and the status of the experiment package checked). Additional input to the scheduling program was generated by ASL.<sup>③</sup> Given the coordinates of the target, the day of observation, and the velocity of the target as specified by the astronomer, ASL produced a deck of cards containing all required carriage motion commands.

The final step before running schedules was to determine the spacecraft slew to the new attitude and the time required to complete the slew. By inputting the coordinates of the old and new attitude and the time that the slew was to begin, the SLEWER program produced the needed information.<sup>④</sup>

At this point, a schedule was run, fitting all required carriage motion commands into the observation time available.<sup>⑤</sup> Additional necessary commands, such as data storage on and off commands, were generated by the program as well, and a listing of the commanding sequences was printed. This output was then manually modified using a display station.<sup>⑥</sup> Changes were made to make commanding more efficient, to correct errors in the schedule resulting from constraints of the scheduling program, or to insert any other commands needed, such as a spacecraft slew. Once these changes were made, a TGIF was run.<sup>⑦</sup>

The TGIF program performed checks on the modified schedule to find errors either previously overlooked or generated while making modifications. It then listed all errors found and printed out the schedule in its current form. The schedule was modified again to correct errors; the process repeated as necessary.

Once the errors had been removed, the schedule was released to GAC<sup>⑧</sup> to be merged with spacecraft commands and University College of London (UCL) experiment commands, and later it was used as input to the Normal Operations Program (NOP).<sup>⑨</sup> The NOP performed additional checks to ensure proper commanding, and, if no errors were found, printed a listing of all commands and their times of execution. This listing (the "contact message") was given to the PEP office to be checked for accuracy,<sup>⑩</sup> and, if there were no problems, it was approved for further processing by GAC<sup>⑪</sup> and eventual transmission to the spacecraft.<sup>⑫</sup>

SECTION 4  
SOFTWARE DESCRIPTION

GENERAL DESCRIPTION

The primary hardware configuration used by the PEP Operations Group at the Goddard Space Flight Center (GSFC) was the M&DO-G2, an IBM System 360 Model 65. The operating system at project termination was 360/65 OS/MVT Release 21.8 in conjunction with HASP II, Version 4.0. This final configuration had 512 kilobytes of primary storage, 1024 kilobytes of main storage, and 4096 kilobytes of large capacity storage. Secondary storage facilities included two IBM 2314 DASD units and a complement of IBM 2401-series tape units. An IBM 2260 Display Station and an IBM 029 card punch were located in the PEP Operations Group Office.

All special and production programs were executed in the batch mode. Use of the 2260 Display Station was limited primarily to the modification of PEP observing schedules.

A complete description of the computing environment is provided in "Mission and Data Operations, IBM 360 User's Guide," Volume I, J. Balakirsky, Code 531, December 1978.

The operations programs used by the PEP Operations Group consisted of several frequently used major programs and a complement of minor ones. The latter were developed to handle special situations and to

extend the capabilities of the major production programs. Although some scientific data reduction routines were used, the principal purpose of the software system was to create PEP observing programs and to expedite this creation process.

The major components of the PEP software package were:

- AVATAR
- SFW (aliases: ATROCITY and OBAFGKM)
- SLEWER
- AUGURY (alias: FUTURE.TIMELINE)
- ASL (alias: CGP)
- TGIF (alias: XPEP)
- PREDICTOR

Functional descriptions of these programs are as follows:

#### AVATAR

AVATAR was the prime schedule-generating program of the PEP operations activity. Its main functions were (1) to create PEP observing schedules given a specified target and a set of PEP commands and (2) to update a collection of data sets used in this creation process. A third, infrequently used, function of this program was to provide listings of some of these schedule-related data sets. To accomplish these tasks, three AVATAR functions were available: TIMELINE, UPDATE, and OUTPUT. Each of these functions had several modes that

performed a particular task within its parent function. The valid functional modes for each of the three main functions are listed in Table 4-1.

Table 4-1  
Valid Functional Modes

TIMELINE	UPDATE	OUTPUT
SURVEY	SUN	SUN
SCHEDULES	MOON	MOON
SUMMARY	NETCON	NETCON
BETAROLL	ORBITAL ELEMENTS	ORBITAL ELEMENTS
	DID	
	GMTZ	
	COMMANDS	

The names of the functional modes listed above for function UPDATE indicate the kinds of data contained in the data sets used for schedule creation in the TIMELINE function. NETCON, for example, maintained data pertaining to the NASA ground stations, which were available to the OAO-C spacecraft.

The chief purpose of the TIMELINE function was to provide spacecraft environment information and PEP target occultation information over a specified period of time (mode SURVEY) and, if directed, to generate a PEP schedule based on this information and on a list of PEP commands required to accomplish a particular scientific objective (mode SCHEDULE).

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The spacecraft/target data previously mentioned were generally calculated at intervals of 1 spacecraft-minute and included the following items:

- Whether or not the spacecraft was in contact range of a ground station, and, if so, the ground station identity
- Whether the spacecraft was in orbital day or in the Earth's shadow
- Whether the spacecraft was in a region of the South Atlantic Anomaly (SAA)
- Whether the specified target was unocculted or occulted by the Earth, and, if occulted, what was the type of occultation.

Much of this information could be made available in tabular form. Each of the foregoing conditions and subconditions, however, was given a special identifying computer-printable character. By concentrating the symbols for each condition into a single line and by including a line representing time, a very useful graphic display was obtained. This display was called a "timeline." It was produced by all functional modes of the TIMELINE function except BETAROLL. That mode produced a table containing spacecraft beta angles and optimum roll angles for multiple targets over a period of 1 year. Mode SUMMARY produced a timeline that included no target

occultation data. Mode SURVEY produced a complete timeline including multiple target occultation lines on multiple target input. Mode SCHEDULE, the workhorse, produced a complete timeline for a single target and extra lines indicating the type of motion being executed by the PEP carriages.

The SCHEDULE mode had many options to control the method by which it operated on the PEP command list, to produce an observing program. It also automatically inserted PEP FES request and settle time commands at the beginning of each (unocculted) PEP observing interval. Termination commands were similarly inserted.

The many options of AVATAR available to the operations group made this program a potent operations tool.

#### SFW

The Short Frame Worker (SFW) program was derived from AVATAR and was used to schedule short EDHE frame observations. Because of the rapid rate at which the spacecraft data storage was filled during the execution of such a worker, special techniques, not provided by AVATAR, were needed to efficiently create SFW observing schedules.

Input to the SFW program consisted of specially encoded commands describing the type of worker (scan data or background), the starting time of the worker, and at which time the stored data were to be transmitted to a ground station.

Output included a timeline (as described for AVATAR) and the SFW observing schedule. Many spacecraft group commands were included in this output. Insertion of these commands was done automatically by the SFW program.

Even with this output, extensive manual modification of the initial observing program was required. This was frequently due to loss of ground station support, and modifications were necessary to maintain the scientific objectives of the observations.

#### SLEWER

The purpose of this program was to generate efficient spacecraft target-to-target slewing sequences for input into the PEP operational schedules.

Basic input to this program included the initial and final spacecraft pointings and the time of initiation of the slew. Initial and final spacecraft roll angles could be optionally specified. Pointing data were assumed to be at Epoch 1950, and these data were transformed by the program to pointings at epoch of date. Optionally, these pointing transformation operations could be suppressed. Specific slew legs from a given pointing could also be inputted.

For each target-to-target input request, the program generated a set of 24 possible 3-leg slewing sequences. This procedure and other OAO slewing-related items are described in "Mathematical Analysis

for the Orientation and Control of the Orbiting Astronomical Observatory Satellite," P.B. Davenport, NASA/Langley, 1963 G-299.

The program then determined the 3-leg slewing sequence that would be selected by the OAO-NOP. The selecting rule was to use that triad whose largest slew leg was smaller than the largest slew leg of any other triad. This special slewing sequence was then checked to ensure that no spacecraft slewing restrictions would be violated. Most important among these restrictions were limits on the maximum length slew leg (40 degrees for P and Y; 20 degrees for R) and the maximum allowable deviation of the spacecraft from optimum roll at a particular beta angle.

If any restriction was violated, the program would attempt to find an acceptable slew among the remaining triads, suggest an initial specific slew that would create an acceptable triad, or, at worst, calculate a midpoint between the specified targets and compute two sets of slews.

Slew timing data for acceptable slews were also provided by this program.

#### AUGURY

This program was used to obtain target timelines for observations that might occur beyond the current range of network contact data provided by the Mission and Data Operations (M&DO).

Input to the program generally consisted of the current set of OAO orbital elements, target positions, ground station longitudes and latitudes, SAA size, Sun and Moon positions over the range of applicability, start of timeline data, and duration of timeline.

The output consisted of a modified timeline display with the timeline(s) presented on an orbit-by-orbit basis for the input target(s) specified. Information related to each orbit was also displayed, including Greenwich mean time (GMT) of ascending node, OAO mission orbit number, ground station contacts, and Princeton University orbit class. A spacecraft elapsed time (SET)/GMT table was also included for each orbit.

This output enabled operations personnel to determine the observing efficiencies of future proposed observations or other useful information.

#### ASL

The purpose of this program was to generate a set of high-level symbolic language-type PEP carriage motion commands from basic wavelength-based data. These latter data, ASL, were generally written by a scientific investigator for a specific target or set of targets. It specified the various combinations of carriage motion (scan routines) desired at designated wavelengths. This information was then translated by the ASL program into the higher level command language required by the OAO-NOP.

Along with the ASL data, input to this program included target position, approximate day of observation, and a target velocity. The output included a listing of the generated high-level commands and a corresponding card deck that could be directly inputted into AVATAR, the main scheduling program.

Embedded in the output listing were the carriage positions and wavelengths at insertion of each command and at regular intervals during their execution periods. It also indicated the occultation status of the carriage 1 sensors because of the carriage 2 collection mirror. This program acted, in effect, as a carriage motion simulator.

The basic output of this program (symbolic commands and their execution times) was processed by another independent program (TESTOR). This program calculated carriage positions on a command basis and compared its results with those obtained by the ASL program. Any differences found were flagged, and the discrepancy investigated. This check was considered necessary since the carriage motion and requisite timing was complex and the basic ASL's were often written by astronomical researchers who were less familiar with these problems.

#### TGIF

This program was used to verify the accuracy of the PEP schedules after their creation (most often by AVATAR) and after their

subsequent manual modification using the IBM 2260 Display Station Functions.

Input to this program consisted of:

- The name of the schedule to be processed
  
- The PEP carriage positions and ON/OFF status of the PEP DHVPS's at execution of the first PEP command within the schedule
  
- A title generally indicating the schedule's name, the target(s), and program(s) that the schedule included

The output of this program included diagnostic messages indicating record format errors, out of sequence records, errors in PEP command timing, and attention flags for various events. The output format was easily readable, and it enabled operations personnel to determine at a glance when special events were to occur, when the PEP/FES was enabled, when the dual-halt condition was present in the PEP electronics, the positions of the PEP carriages at insertion of each PEP command, and the ON/OFF status of the DHVPS's.

Release of a PEP schedule to GAC for further processing did not occur until the output of this program was found to be acceptable. In addition, it was used to check spacecraft command memory and was

used by PEP console operators in the OAO-OCC for real-time status reference.

#### PREDICTOR

The purpose of this program was to provide information relating to various target pointing parameters that were needed in preplanning observations.

The program produced a tabular history of these parameters for various standard pointings, usually on a daily basis over a specified period of time. These parameters included target orbital longitude and latitude, beta angle and spacecraft optimum roll angle, and Moon target angular separation. Information on an actual target was obtained by interpolation of these tabulated data.

Actual targets whose position indicated an orbital latitude between +40 and -40 degrees, for example, were considered for data high-voltage shutdown, and their scheduling was postponed or special techniques (e.g., GASP) were used when generating their observing schedules. Other parameters indicated when high spacecraft pitch/yaw wheel speeds might be expected, when the Moon was too close to a potential target, and when the beta angle exceeded 90 degrees.

This program was a valuable aid in planning the PEP target observing sequence.

## OTHER PROGRAMS

While the bulk of the scheduling function was performed by AVATAR and the other programs previously described, special observing problems and normal evolution of operations required the development of additional software.

During the final operations era, for example, the beginning of a PEP observing interval was often delayed beyond the point at which the target became unocculted, the normal AVATAR start time of observation. Instead of modifying AVATAR, the program was instructed to introduce a large, precalculated, FES settling time, an available AVATAR option. This delayed actual scientific observing until the desired start time. Another program, operating on the AVATAR output, modified the FES settling periods to their normal 2 spacecraft-minutes and inserted data high voltage on and off commands.

Manipulations as described were not uncommon, and much of this additional software was directed to reducing the manual effort required to shape an AVATAR-generated schedule into final form. Given all the vagaries of the scheduling process, a single program to handle all observing requirements would be exceedingly complex.