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EVALUATION OF SATELLITE MATERIALS BY USE OF GROUND-BASED PHOTOMETRIC OBSERVATIONS - PHASE II

BY

D. C. ROMICK, R. H. EMMONS, AND R. J. PRESKI
GOODYEAR AEROSPACE CORPORATION

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GER-14483
15 August 1969

Prepared under Contract No. NAS1-8276 by
Goodyear Aerospace Corporation
Akron, Ohio

For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
LANGLEY STATION
HAMPTON, VIRGINIA 23365

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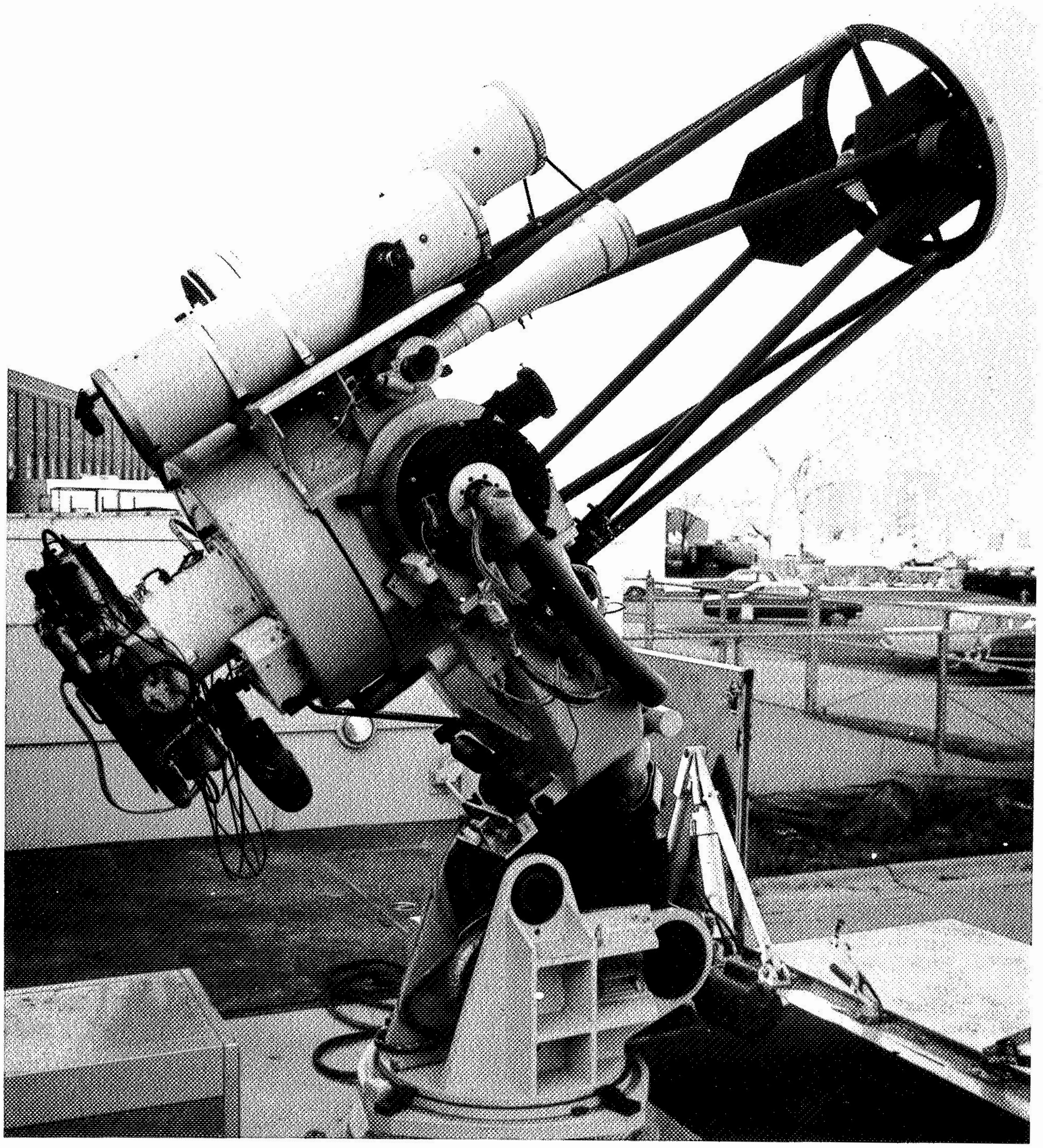


Mobile Observatory Telescope Complex

EVALUATION OF SATELLITE MATERIALS BY USE OF GROUND-BASED PHOTOMETRIC OBSERVATIONS - PHASE II

By
D. C. Romick, R. H. Emmons, and R. J. Preski
Goodyear Aerospace Corporation

SUMMARY

Goodyear Aerospace Corporation (GAC), under Contract NAS 1-8276 with the National Aeronautics and Space Administration's Langley Research Center, has performed five-color (UBVRI) photometric and polarimetric observations on the PAGEOS I, Echo II, Explorer 19 and Explorer 39 inflatable satellites. The observations were made from Palomar Mountain, California (1968) and Yuma, Arizona (1969), in a continuing program to evaluate satellite materials by ground-based photometry.

To obtain high frequency response data recordings of these (and future) observations, a new 14-channel frequency modulated magnetic tape recorder was installed and used in NASA's mobile Satellite Photometric Observatory.

Data reduction and analysis of the PAGEOS I and Echo II observations were performed. The aluminized Mylar surface of the PAGEOS I satellite remains mirror-like (specular) with no measurable degradation. Although a comparison of these data with laboratory data indicates that the surface of PAGEOS I has not changed in reflectance in the blue, yellow, and red regions of the visible spectrum, there are differences in both the ultra-violet and infra-red bands. These U and I band differences either represent real changes due to the material's exposure to the space environment (degraded U-band reflectance, enhanced I-band reflectance), or, more likely, to errors in the adopted laboratory values. PAGEOS I's average radius of curvature remains 50 feet, as designed.

The Echo II data show a significant degradation in the specularity and reflectance properties of this satellite's surface since it was first photometrically observed in orbit (1967). The 1969 polarimetric data, however, indicate that a substantial amount of the satellite's amorphous phosphate thermal coating (Alodine) remained in its last months of orbital life.

Narrow-band eclipse entry observations of the Echo II and PAGEOS I satellites were performed during the two observing sessions. From these observations, it is possible to calculate ozone concentration at various locations over the earth.

INTRODUCTION

Using the NASA mobile Satellite Photometric Observatory (SPO) with 24-inch telescope, photometric and polarimetric measurements were obtained in 1968 and 1969 of the PAGEOS I, Echo II, Explorer 19, and Explorer 39 satellites from field sites in California and Arizona. These measurements, in five-color bands, were performed under NASA Contract No. NAS 1-8276, and were part of a second phase of an evaluation of satellite materials by ground-based photometry.

The approach employed in this work might be briefly stated as follows.

From observations of the intensity of sunlight passively reflected from a spherical artificial satellite, various inferences can be drawn concerning the present condition of its surface. In general, the following parameters may be obtained through the use of a ground-based photometric system:

(1) stellar magnitude (normalized)

(2) specularity and diffusivity of the surface of a satellite

(3) average and local radii of curvature (reflectance assumed)

(4) reflectance (radius of curvature assumed)

In this report the specular component of reflected light is called specularity. It is expressed as a percentage of the total reflected light.

The somewhat intricate procedures and theory by which these photometric data were calibrated, reduced, and analyzed are given in References 1, 2 and 3.

This report describes the observations and summarizes the data reduced for PAGEOS I and Echo II. Conclusions and recommendations from the analysis of these data are also presented. Other photometric data taken were not required to be reduced within the scope of this contract, including all data for the Explorer satellites, narrow-band observations of shadow entries of PAGEOS I and Echo II, and a special series of PAGEOS I passes.

INSTRUMENTATION

General

The five-color, four-channel cryogenically cooled instrumentation system developed and used on the NASA mobile Satellite Photometric Observatory on a previous contract (Reference 2) was employed for this program of observations except for the modifications described below. The U, B, V, R, I spectral regions utilized are similar to the system developed by H. L. Johnson, et al, (References 4 and 5). The response functions for this system are presented in Figure 1. As will be noted within the report, there are actually two V-bands; one obtained by the filter(s), plus S-20 photocathode response system (denoted in the report as V20 band), and the other by the filter(s) plus S-1 photocathode response system (V1 band). These two V-bands differ from each other by approximately 1 or 2 percent at most when simultaneously determined stellar and satellite values are compared. The actual response functions for all six bands (U, B, V20, V1, R, I) are presented in Reference 2.

The complete system performed well, and demonstrated its capability to obtain high-grade scientific measurement data -- even under the adverse high phase angle (bright, polarized sky) conditions specified under this contract for the polarization measurements.

Only three modifications (one substantial and two minor) to the instrumentation system were required under this contract. One was a contract task requirement to add an FM magnetic tape data recording capability. The others were (1) an operational requirement of minor nature involving a change of the Wollaston prism used for separating the polarization components, and (2) adding two narrow-band filters. In addition, two wide-field 5-inch refractor acquisition telescopes were fabricated, installed and utilized on the SPO during this contract period.

The required maintenance operations carried out during and between missions were approximately that which experience has shown to be typical for equipment of this type and complexity, and are also treated and discussed below.

Modifications

FM Magnetic Tape Recording Capability. - The main modification to the instrumentation system carried out under this contract was the addition of an FM analog magnetic tape data recording capability, and consisted of two steps carried out sequentially. The first step consisted of the temporary installation of the portable CEC Model VR-3300 recorder, and permanent installation of most of the other required elements of the recording system installation, and was performed prior to the first mission carried out under this contract. The second step, carried out prior to the second mission, was the removal of this recorder and the installation of the present full recording capability in the form of a CEC Model VR-3400 recording unit, and integrating it with the balance of the system (see Figures 2 and 3).

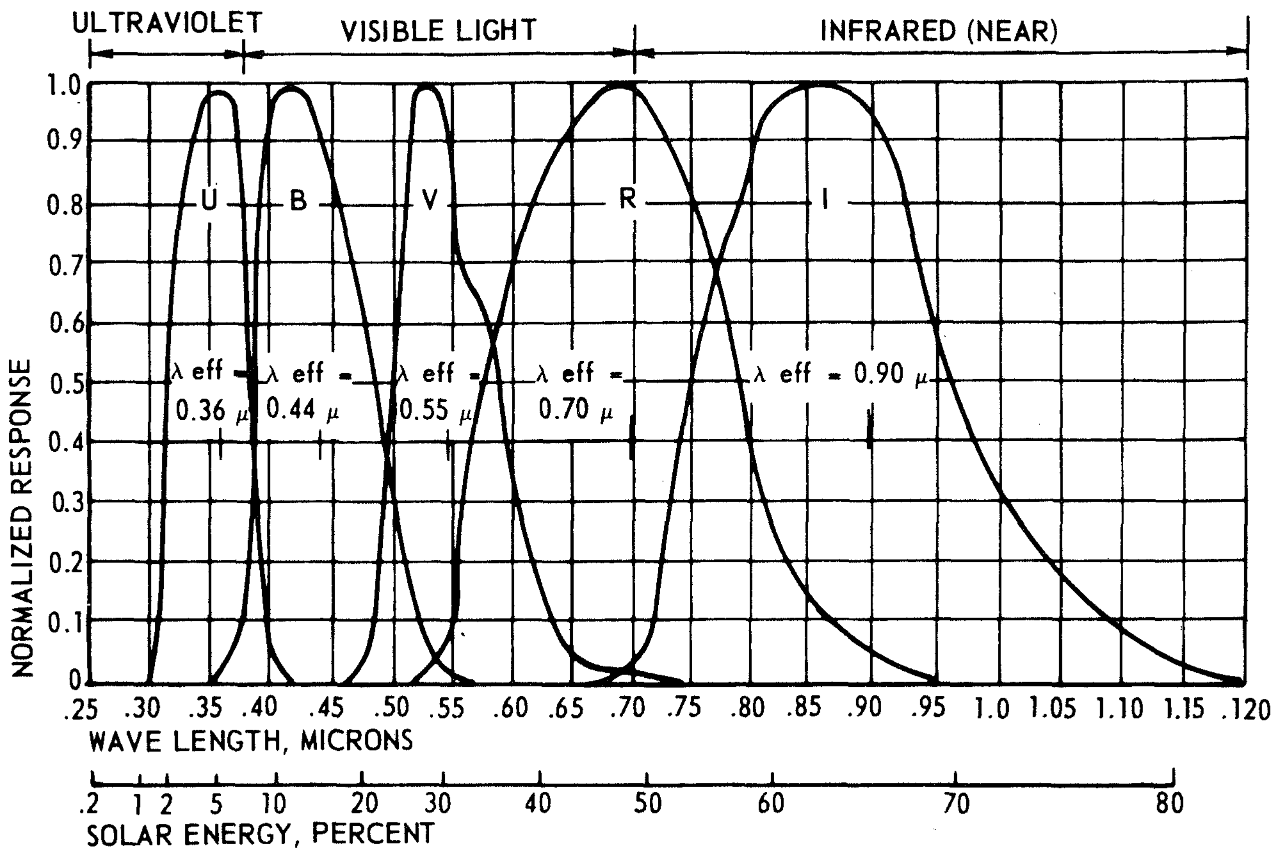


Figure 1. Normalized Response Functions for the UBVRI Spectral Regions

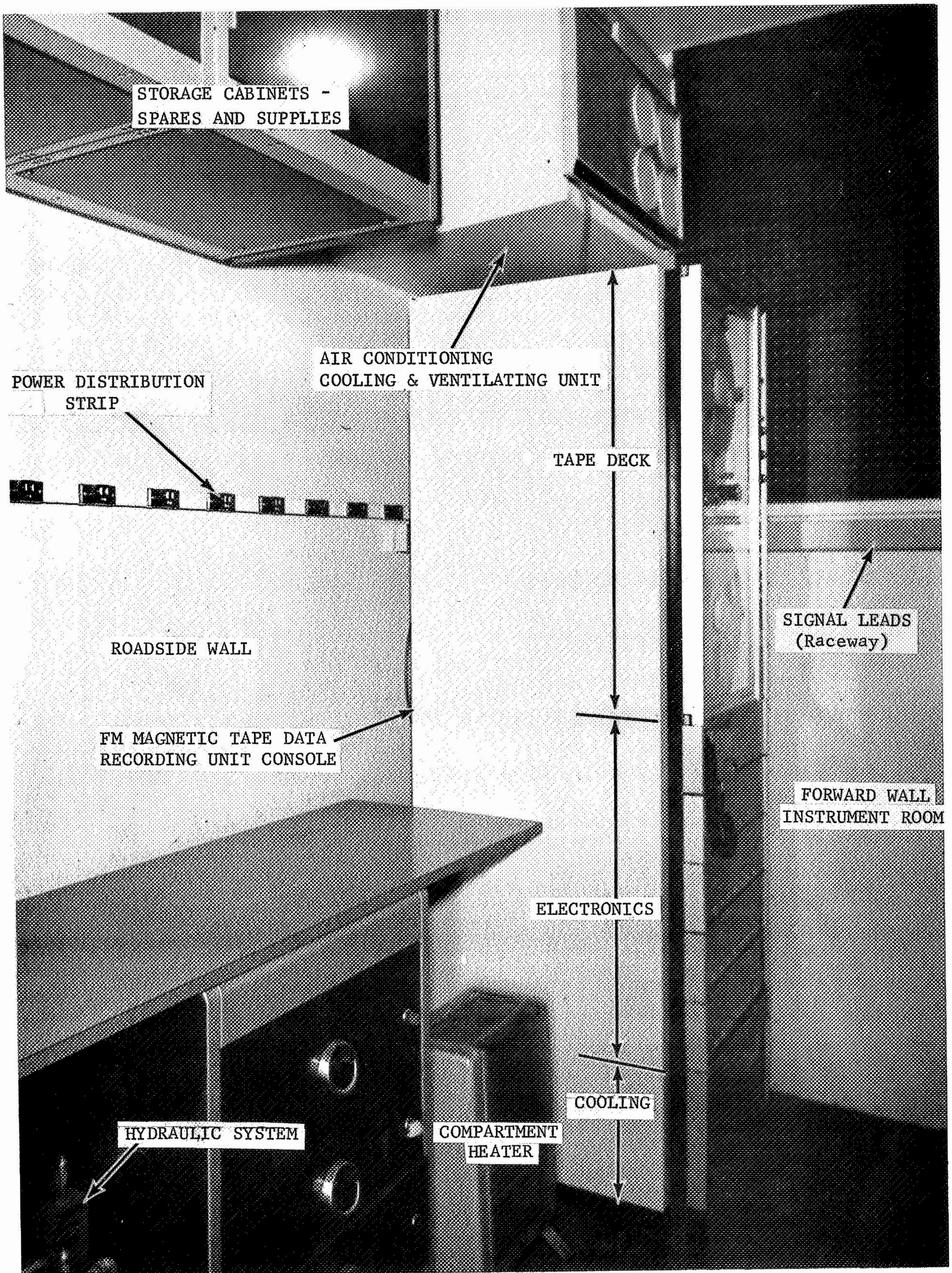


Figure 2. Roadside Wall of Instrument Room, with FM Magnetic Tape Data Recorder Installed.

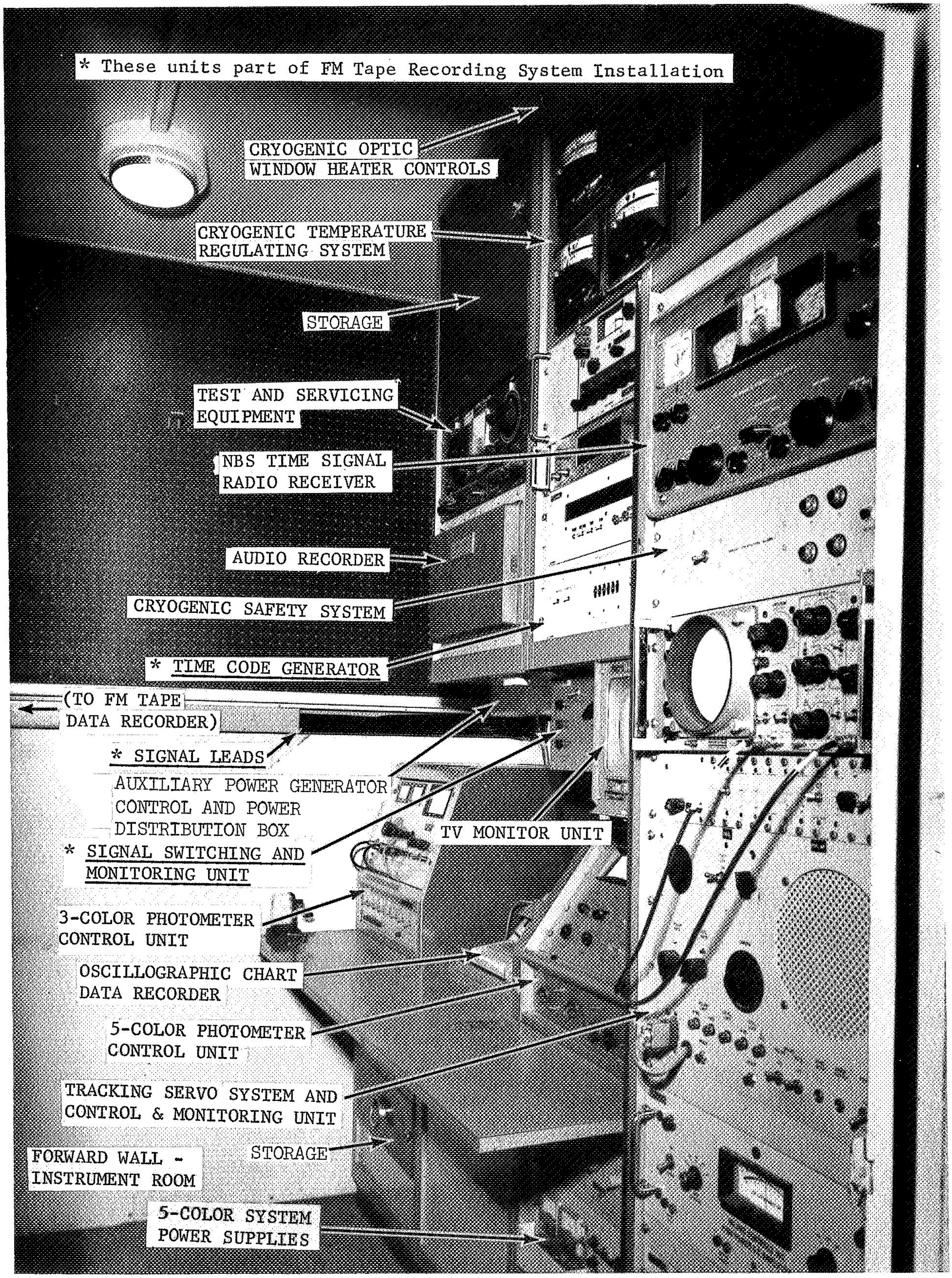


Figure 3. Curbside Wall Showing Instrumentation, Operating and Storage Racks.

The initial installation, which was utilized during the 1968 Palomar mission, included the following installed equipment:

(1) the interim VR-3300 recorder unit

(2) the time code generator

(3) the data monitoring unit junction box

(4) interconnecting signal cabling, raceway, and associated wiring and connections

The final installation, which was used during the 1969 Yuma mission, consisted of the same elements except for the replacement of the interim VR-3300 recorder with the full VR-3400 unit recorder, and a modification of the time code generator and monitor unit. The work carried out, and the resulting installation is described below.

System and Installation Design and Engineering: Two alternate installation arrangements were designed and submitted for selection. One provided for installation of recording units, split into two side by side sections, in the cabinet racks above the right hand (curbside) table, with the displaced electronic equipment, time code generator, etc. mostly going to the lower forward cabinet racks under left-hand (roadside) work table. The other design placed the entire recorder unit intact on the floor in the forward left-hand (roadside) corner of the instrument room. To do this, the left work table (which had stopped forward of the hydraulic system) was moved aft one whole section over the hydraulic unit, and the other electronics was mounted at the operator station in the racks above the right-hand (curbside) table. Extra cabinets to compensate for the displaced storage space were installed on the upper left wall matching those on the right.

After studying the illustrations of both proposed installations, considering operating facility, cooling effectiveness, installation servicing access, etc., the second design (involving the floor mounting of the recorder rack in the forward left corner of the compartment) was selected; refer to Figures 2 and 3.

The criteria for the recording system was specified in the contract work statement. Using these guidelines, the specific record and reproduce electronics was specified for setting up the recorders. The recorders were then set up and checked out by LRC and furnished as GFE along with the time code generator and monitor switching unit. Mounting brackets and interconnecting cabling installation was also designed.

Installation: Following the design and specification of all equipment, cabling, connectors, etc. expedited procurement of all purchased parts (coax connectors, setting dials, raceway channels, etc.) proceeded on the basis of advanced material releases made shortly after starting of design work. The

GFE items were received and checked, and brackets and monitor control box were fabricated. The interim VR-3300 recording unit was mounted on top of the table in the left-forward corner, thus providing compatibility of the signal input cabling installation with that to be later used for the VR-3400 installation. The remaining electronic equipment was installed, the displaced equipment re-installed, and the interconnecting cabling raceways and cables were installed and connected. Signal connections to the instrumentation output and oscillograph recorder input, power connections, etc. were completed and checkout performed of the entire installation. The new cabinets were also installed, and the observatory immediately dispatched to Palomar Mountain, for start of the first mission.

The conversion to the final installation, incorporating the VR-3400 recorder unit, was carried out at the GAC Phoenix (Arizona) plant where the observatory was taken at the completion of the Palomar observing mission. This consisted mainly of removing the VR-3300 unit, moving and re-installing the left work table and cabinets one section rearward, fabricating the new brackets, and installing the new recorder. When associated modifications (time code generator, digital code insertion dials, monitor unit) were completed and the system reconnected with the new recorder, the final complete installation was checked out. After some minor debugging, the observatory was then dispatched to Yuma for the start of the second (winter) observing mission on 17 January 1969.

The complete installed recording system was demonstrated during checkout and subsequent field operations to be capable of the specified wide band (high response frequency) data recording, along with required switchable monitoring and playback modes, utilizing the specified signal information on the fourteen available recording channels as shown in Table I.

This equipment, after some initial shielding and grounding connections to eliminate all signal lead noise pickups, performed satisfactorily throughout the mission in all functional modes.

Wollaston Prism Replacement. - During the period since the NASA Satellite Photometric Observatory was developed (1966-1969), it has been operated at various sites (Akron, Ohio, Yuma, Arizona, Palomar Mountain, California) during all seasons and under all types of temperature conditions. While these widely varying temperatures have not affected the operation of the observatory as a whole, some of the optical components of the system have been affected; specifically, the Wollaston prism and the depolarizers (both of which employ calcite). As a result of the ranges encountered during these time (from below 0° to around 100° F) periods, defects developed in the Wollaston prism which is used for determining percent linear polarization. In fact, two successive Wollaston prisms, made of calcite crystals cemented with butyl methacrylate have cracked, probably due to this kind of thermal effect.

The coefficients of thermal expansion of the calcite and the adhesive are incompatible for temperature excursions ranging below 32° F. At these temperatures,

TABLE I.--FM MAGNETIC TAPE RECORDER CHANNEL ASSIGNMENTS

FM Magnetic Tape Recorder Channel	Assignment
1	WWV Time
2	VRI Pre-Amplifier Gain
3	VRI Differential Amplifier Gain
4	UBV Pre-Amplifier Gain
5	UBV Differential Amplifier Gain
6	VRI Filter
7	UBV Filter
8	Head or Half-Wave Plate Angle
9	Signal B
10	Signal A
11	Integrator B Gain
12	Integrator A Gain
13	NASA 36 Bit Code (Modified)
14	Spare

stresses are likely to be generated which exceed the cleavage plane strength of the calcite crystal. It is rather interesting to note that Yerkes Observatory in Wisconsin has had similar problems with this type of Wollaston prism.

Mr. S. F. Pellicori of the University of Arizona suggested using Dow Corning 200-Fluid* (dimethylpolysiloxane compound), which is a contacting agent used in the high-viscosity form to reduce flow rate (Reference 6). It is moisture repellant, chemically inert, fairly stable under ultra-violet radiation, and has excellent optical properties.

Also suggested for this use (by the manufacturer of the Wollaston prism) was Dow Corning Sylgard Compound 51* which is known to be unaffected over a temperature range of -65 to +100° C. This coupling agent has low chemical reactivity and is stable to ultra-violet radiation. It does not set to a hard bond, but retains the resilience of a thick gel. (Reference 6) It also has good optical properties.

* Trademark

Since the manufacturer was uncertain which he would be able to fabricate successfully, two Wollaston prisms were ordered; one with each type of adhesive. Both prisms were apparently manufactured satisfactorily; the prism with the Dow Corning Sylgard #51 adhesive was installed on the photometer and used during the Yuma 1969 mission. The other prism has been retained as a spare.

Narrow-Band Filters. - Simultaneous photometric observations (in two or more spectral regions) of artificial satellites entering or leaving the earth's shadow can be used to determine the vertical distribution of various atmospheric constituents. By choosing one of the wavelengths at the peak of the Chappius absorption band (∼6020 Å) and the other in a region of low absorption (∼7030 Å), one may determine the amount of ozone at certain heights and the total amount of ozone for a given position on the earth (Reference 7). Since the NASA mobile Satellite Photometric Observatory has a four-channel photometric system, it is possible to obtain simultaneous signals from two spectral regions.

Narrow-band filters with peak wavelengths centered at 6022 and 7029 Angstroms were purchased and installed in unused positions on the filter holders preceding the EMI-9558QA (S-20) and EMI-9684A (S-1) photomultipliers, respectively, and observations performed on the Echo II and PAGEOS I satellites as they entered eclipse during the Palomar 1968 and Yuma 1969 missions. The dates of these observations are presented in Section "Field Missions". The characteristics of the filters are presented in Table II.

TABLE II. - CHARACTERISTICS OF FILTERS USED IN ECLIPSE PHOTOMETRY OBSERVATIONS

Peak Wavelength	6022Å (S-20)	7029.5Å (S-1)
Percent Transmittance at Peak Wavelength	43.5%	50.5%
Bandwidth at Half Intensity Points	14Å	18Å
Zero Transmittance Wavelengths	5919Å and 6119Å	6927.5Å and 7127.5 Å

Maintenance. - In addition to the above modifications, a number of maintenance items required attention during operations under this contract, although these were not in excess of that normally encountered for equipment of this type and complexity level. Most of this maintenance was carried out during the field observation missions and integrated with those operations. There was no serious maintenance operations interference with mission measurements (the actual amount encountered can be inferred from the observation record as presented in Section "Field Missions").

The two most significant maintenance problems encountered were in (1) the recording oscillograph (during the first mission at Palomar), and (2) the polarization optics (during the second mission at Yuma).

The significant problem with the oscillograph recorder during the first mission involved the paper drive transmission and train. Because of the extent of the difficulties encountered, the recorder manufacturer was called upon to correct the problem.

The polarization optics problem on the second mission occurred as a sequence of several difficulties at nearly the same time. These however were handled by the field crew, and without serious operational delay, although correction twice required removal and partial disassembly of the instrumentation head. The first problem in these series, encountered shortly after installation of the new Wollaston prism, involved the rotating half-wave plate. It was found that the plate was not rotating properly, due to slippage of the half-wave plate element in its housing. After this was corrected, improper rotation soon reoccurred, caused by a shear pin failure (requiring replacement).

The most significant other operation, performed prior to the start of the first mission, was replacement of the C quality photomultipliers with the A quality tubes. These changes in the electro-optical system in turn were sufficient to require replacement of resistors in the high voltage balance circuits to compensate for the new characteristics, which is a significant operation (see Reference 8, paragraph 6.6.5.5.2, p. 6-29).

Instrumentation Summary. - The modifications made and their use on the missions carried out under this contract have added to the capability of the observatory system to give it great flexibility and fast data gathering capability. The new narrow-band filters, and their use for satellite eclipse photometry is a part of this extended flexibility and operational capability. This, maintained as described above, represented a performance capability perhaps best demonstrated by the quality of results obtained and reported herein. This was done with a pair of relatively short missions, a relatively small (3-man) field crew, and with less than ideal weather (particularly on the second mission), which amply demonstrates the effectiveness of the present instrumentation system as well as that of the overall observatory system and the operating techniques employed. The 5-inch acquisition telescopes proved to be quite convenient in the tracking of satellites.

FIELD MISSIONS

Field Preparation

The contract statement of work specified that the first observation site (summer of 1968) would be in the area of Palomar Mountain, California, and that the second site (winter of 1969) would be in the vicinity of Yuma, Arizona. For the first mission it was found both possible and desirable to arrange for reuse of the same Palomar Mountain site used for the initial PAGEOS I photometric surveillance in 1966, under Contract No. NAS 1-6189 (Reference 1).* This site, at Skyline Lodge, was registered with the Smithsonian Astrophysical Observatory (SAO) at Cambridge, Massachusetts, as station number 8683 in their global satellite tracking network (thus facilitating tracking information flow). The specific site for the winter mission at Yuma, Arizona was selected and arranged for by NASA's Project Monitor, Mr. M. L. Brumfield, who traveled to Yuma in December 1968 for this purpose. The site chosen was one offered by the Yuma Marine Corps Air Station (MCAS), and was located at the extreme southeast corner of their base. Subsequently, GAC arranged for its SAO registry as satellite tracking station number 0159. The coordinates of the two above sites are as follows:

Site	SAO No.	W. Longitude	N. Latitude	Altitude Meters, MSL
Palomar Mountain California	8683	116° 50' 55"	33° 18' 37"	1720
Yuma, Arizona	0159	114° 34' 49"	32° 38' 28"	60

Before field observations could be performed, all field site arrangements were finalized, the mobile observatory was packed and made road-ready, and travel arrangements for both the observatory and crew were completed.

At the Palomar Mountain site preparations included spreading a dust inhibitor, providing for electrical "shore" power, and installing an office telephone. At the Yuma site preparations included borrowing the use of one of the MCAS' 20 KW transportable diesel motor generators, and the rental of an office trailer and chemical toilet. Common to both sites was the problem of providing a certain and continuous supply of liquid nitrogen. Through the rental of two 150-gallon insulated tanks at each site, required deliveries were thereby kept to approximately one week intervals. At Palomar Mountain deliveries were made from a supplier in San Diego. At Yuma, deliveries were made from Phoenix. It is noteworthy that no observation on either mission had to be aborted due to a lack of liquid nitrogen.

*Several other sites were surveyed and evaluated (Table Mt. and Laguna Mt. in California and Mt. Hopkins in Arizona)

Satellite Predictions and Orbital Geometry

The observing missions were scheduled in advance in accordance with satellite "visibility windows" forecast from a projection of the local orbit sweep times. It was these window determinations which permitted selection of suitable mission periods. They also established the required mission start-up times of 9 September 1968 and 15 January 1969 for the summer and winter missions, respectively. Just prior to, and during the mission, discrete local pass predictions were generated by GAC's E1215 computer program (Reference 3) in terms of culmination times, conventional altitude - azimuth and right-ascension-declination coordinates, and also four-axis coordinates, from the latest orbital elements received from the Smithsonian Astrophysical Observatory. Visual positional fixes on the satellites were used to correct the ephemeris until new orbital elements were received.

To establish the time-correlated altitude, slant range, and phase angle geometric circumstances of the satellite for the purposes of photometric data reduction and analysis, the observed time correction was used to compute the satellite's effective mean anomaly at the epoch of the orbital elements.

Field Operations

Field site operational status for the first (Palomar) mission site was reached on 11 September 1968; and for the second (Yuma - winter) mission on 18 January 1969. Operations were complete for these missions on 28 October 1968 and 13 March 1969, respectively (see Section "Observations" for schedules).

The tasks routinely performed during operations by GAC's three-member field crew were:

(1) Detailed daily observation planning, including plotting and selecting calibration stars, from satellite 4-axis and conventional pass predictions, in accordance with home-office schedules and priorities.

(2) Instrumentation maintenance (between observations), cryogenic cool-down, general readiness and 4-axis telescope settings (prior to observations), and secure (following observations).

(3) Observations of satellite and associated pre- and post-pass star calibrations.

(4) Visual time-position observation during each satellite pass for determination of the time residual and corresponding correction of the ephemeris.

(5) Arrangements for deliveries of liquid nitrogen, motor generator fuel, and the purchase of other operating supplies as required.

(6) Daily packaging, labeling and airmailing of data.

(7) Maintaining operations and instrumentation logs; administration and coordination (home office, field personnel, weather bureau, etc.)

On the Palomar mission much special effort was required in connection with the oscillograph recorder's paper transport mechanism. An even greater crew effort was required during the Yuma mission in replacing the Wollaston prism and otherwise servicing the polarimetric instrumentation (see section "Maintenance" above).

Each mission, of course, also involved commercial driver coordination, initial deployment and final packing and breaking camp including dispatch of the Observatory back to GAC (to GAC Phoenix after the first mission, and to GAC Akron after the second).

Crew director and astronomer for the 1968 Palomar and 1969 Yuma missions was R. H. Emmons. C. L. Rogers was responsible for instrumentation at Palomar. E. Kalasky, who assisted Mr. Rogers at Palomar assumed full instrumentation responsibility at Yuma. F. Doll served as Mr. Kalasky's assistant at Yuma.

The nominal three-men field crew was augmented for one week during each mission: L. Sannes provided general assistance early in the Palomar mission. C. L. Rogers provided engineering back-up and assistance during the first week of the Yuma mission.

Satellites Observed

During the late summer/early fall, 1968, and winter, 1969, observation periods, photometric and polarimetric observations were performed on the following artificial satellites.

(1) Echo II

(2) PAGEOS I

(3) Explorer 19 (photometric only)

(4) Explorer 39 (photometric only)

These observations were of various types including multicolor measurements, continuous color type measurements, polarimetric measurements, and narrow-band eclipse (shadow entry) measurements.

The formal definition of multicolor and continuous type photometric measurement passes are as follows: multicolor passes are those in which the UBV and VRI filter wheels are continuously sequenced with an integration time of 2 to 3 seconds in each color before switching to the next color. Continuous type passes are those which are taken in one each of the spectral bands for the UBV and VRI regions for the entire pass, or the various colors are sequenced with an integration time of 30 seconds to 4 minutes (depending on the duration of the satellite's visibility). Explorer satellites are examples of the shorter integration period (30 seconds or 1 minute), while PAGEOS I continuous passes are taken for a period of 4 minutes before switching to a new pair of colors.

Polarization passes are taken in two modes: (1) by rotating a half-wave plate through 10 - 36° steps for U, B, V observations, and (2) by removing the half-wave plate and rotating the Wollaston prism through 7 - 36° steps, it is possible to obtain data in the U, B, V, R, I spectral regions. The former method utilizes a 2-second integration time per half-wave plate position, while the latter also utilizes a 2-second integration period. (These methods are dictated by the spectral bandwidth characteristics of the achromatic half-wave plate installed.)

Eclipse type passes (shadow entry) are taken on satellites for a period of several minutes before the predicted eclipse entry, and subsequently through the period when the signal disappears in the sky background. The amount of time between eclipse entry and disappearance is approximately 20 seconds, typically.

Photometric observations of PAGEOS I passes were obtained as follows:

Palomar Mountain, California   Summer/Fall 1968

14 Multicolor observations
September 12, 13, 14, 15, 16, 17, 18, 19, 21 (2), 22 (2), 23 (2)

5 Continuous color observations
September 12, 19, 23, 24 (2)

3 Narrow-band observations (shadow entry)
October 23, 24, 25

Yuma, Arizona Winter 1969

14 Multicolor observations
January 22, 27, 28, 29 (2), 30, 31, February 2, 5 (2), 6, 7 (2), 8

4 Continuous color observations
January 22, 31, February 2, 6

8 Continuous color observations, additional passes taken in place of Explorer 24
March 1, 2, 3, 4, 5, 6, 7, 8

1 Narrow-band observation (shadow entry)
February 19

6 Polarimetric observations
February 1, 2, 3, 4, 6, 8

Photometric observations of Echo II passes were obtained as follows:

Palomar Mountain, California Summer/Fall 1968

15 Multicolor observations
September 12, 13, 14 (2), 15 (2), 16 (2), 19 (2), 21 (2), 22 (2), 23

3 Continuous color observations
September 12, 24 (2)

Yuma, Arizona Winter 1969

14 Multicolor observations
February 16, 17, 19, 20, 21, 23, 25, March 3, 4, 5, 7, 8, 11, 12

2 Continuous color observations
March 6, 11

3 Narrow-band observations (shadow entry)
February 11 (2), 14

6 Polarimetric observations
February 21, 23, 26, 27, March 1, 2

Photometric observations of Explorer 19 passes were obtained as follows:

Palomar Mountain, California — Fall 1968

12 Multicolor observations
October 16 (2), 17, 18, 22 (2), 23, 24, 25, 26, 27, 28

3 Continuous color observations
October 18, 23, 26

Yuma, Arizona — Winter 1969

2 Continuous color observations
January 29, 30

Photometric observations of Explorer 39 passes were obtained as follows:

Palomar Mountain, California — Fall 1968

17 Multicolor observations
September 29, 30, October 1, 7, 8 (2), 12, 16, 17 (2), 18 (2), 19 (2), 21, 22, 23

4 Continuous color observations
September 28, October 12, 21, 22

Yuma, Arizona — Winter 1969

17 Continuous color observations
January 22, 27, 29 (2), 31 (2), February 2 (2), 5 (3), 6 (2), 7 (2), 8 (2)

DATA REDUCTION AND ANALYSIS PROCEDURE

General

The following steps were employed to prepare the photometric and polarimetric data for analysis:

(1) Analog-to-digital conversion of the photometric and polarimetric data

(2) Placing the digitized data on forms, keypunching, and listing the data

(3) Application of the stellar calibration programs

(4) Application of the satellite data reduction programs to determine orbit geometry, and optical and physical properties

(5) Plotting of data points; satellite magnitudes vs phase angles

(6) Data analysis and establishment of data accuracy levels

The method of data reduction for both photometric and polarimetric modes using the U, B, V, R, I system are as follows:

Photometric

After receipt of the oscillograph charts from the field crew, the analog-to-digital conversion for the stars and satellite of interest was performed. Because this task was performed manually, each photometric point required the following information: filter color, time, intensity height in inches and two or three gain factors. In addition, each star was identified by its Yale Catalog Bright Star (B.S.) number and pair number if the second-order extinction coefficient program was used.

After the analog-to-digital conversion was completed, the data points were placed on special forms for key-punching. The key-punched cards were then submitted to the computer programmer for listing and checking. The stellar transformation and/or calibration programs were first run; plots were then drawn by an automatic X-Y plotter. Printouts and plots were examined for possible errors or unsatisfactory values. In the latter case, the data was analyzed to determine the cause of the discrepancy and reruns performed to obtain satisfactory values.

After the calibration and extinction coefficients had been established for the satellite pass, computer program E-1216, "Satellite Photometer Program: Stellar Magnitudes," was used. This program prints out the satellite extra-atmospheric and normalized magnitudes, slant range, and phase angles, etc., for each data point. These results were then examined for very low altitude points ($\sim$ 10 deg) and clearly spurious magnitude values. These data points were discarded. Computer program E-1214, "Specularity, Radius of Curvature and Reflectance Determinations," was then used for each color. In addition to obtaining these parameters for each pass, combined runs were performed for the satellite in each color. Plots of the data points were then prepared.

A complete description of the theory and computer programs are presented in References 1, 2 and 3.

Data points were removed from these totals for various reasons during the data reduction before definitive values of the optical and physical properties were obtained. Examples of this procedure occurred as a result of low satellite altitude, satellite scintillation, poor extinction determination, etc. The Echo II pass of 19 February 1969 was completely removed because of poor extinction coefficients. Several points were removed from the PAGEOS I data for the Yuma 1969 observation period because of excess scattering, probably from one or more anomalous regions on the satellite.

Polarimetric

The data recorded on the oscillograph charts were converted from analog-to-digital form by manually measuring the filter, gains, and analyzer (Wollaston prism or half-wave plate) positions, the two intensities (I_1 and I_2) and the time for each star or satellite data point. In addition, the Henry Draper (H.D.) catalog number was recorded for each star. After the analog-to-digital conversion was completed, the data were placed on forms. The data were key-punched, and submitted to the computer programmer for listing and checking.

Due to changes in the polarimetric system (photomultipliers, Wollaston prism) and to the bright sky levels present during high phase angle passes (which usually occur near twilight), the polarization data reduction technique was slightly modified from that described in References 2 and 3. The sky readings were subtracted from the satellite plus sky, or the star plus sky level on a one-for-one basis for each position of the half-wave plate or Wollaston prism.

The complete theory and series of computer programs utilized to obtain percent polarization data are given in References 2 and 3.

RESULTS

Analog-to-Digital Conversion

Analog-to-digital data conversion was performed on the photometric satellite passes shown in Tables III to VI, and the polarimetric passes shown in Table VII. The number of photometric data sets and points per satellite pass and total number are also shown in Tables III to VI. Note that only the V20 and V1 band data points were reduced for the continuous type passes.

TABLE III. - PAGEOS I PHOTOMETRIC DATA SETS AND POINTS
(PALOMAR 1968)

Date of Pass		Sets		Points	
		UBV	VRI	V20	V1
9/12/68		35	33	34	34
9/13		54	54		
9/14		46	46		
9/15		56	56		
9/16		48	48		
9/17		27	23		
9/18		59	58		
9/19	(1)	78	78		
9/19	(2)			100	27
9/21	(1)	60	70		
9/21	(2)	34	31		
9/22	(1)	36	36		
9/22	(2)	36	36		
9/23	(1)	48	48		
9/23	(2)	38	38	35	30
9/24	(1)			72	
9/24	(2)			50	50
TOTAL		655	655	91	141

TABLE IV. - ECHO II PHOTOMETRIC DATA SETS AND POINTS
(PALOMAR 1968)

Date of Pass		Sets		Points	
		UBV	VRI	V20	V1
9/12/68		33	35	40	
9/13		30	28		
9/14	(1)	26	26		
9/14	(2)	18	28		
9/15	(1)	37	37		
9/15	(2)	30	29		
9/16	(1)	12	12		
9/16	(2)	5	2		
9/19	(1)	23	22		
9/19	(2)	12	12		
9/21	(1)	16	17		
9/21	(2)	5	5		
9/22	(1)	17	18		
9/22	(2)	5	4		
9/23		5	3		
9/24	(1)			38	
9/24	(2)				42
TOTAL		274	278	78	42

TABLE V. - PAGEOS I PHOTOMETRIC DATA SETS AND POINTS (YUMA 1969)

Date of Pass		Sets		Points	
		UBV	VRI	V20	V1
1/22/69	(1)			56	60
1/22	(2)	16	13		
1/27		23	21		
1/28		39	38		
1/29	(1)	18	18		
1/29	(2)	15	15		
1/30		35	35		
1/31	(1)			65	36
1/31	(2)	26	28		
2/2	(1)			45	30
2/2	(2)	19	16		
2/5	(1)	17	13		
2/5	(2)	18	16		
2/6	(1)			62	37
2/6	(2)	14	13		
2/7	(1)	18	19		
2/7	(2)	22	21		
2/8		34	30		
TOTAL		314	296	228	163

TABLE VI. - ECHO II PHOTOMETRIC DATA SETS AND POINTS
(YUMA 1969)

Date of Pass	Sets		Points	
	UBV	VRI	V20	V1
2/16/69	32	31		
2/17	32	36		
2/19	12	8		
2/21	31	39		
2/25	24	24		
3/3	21	19		
3/4	27	28		
3/5	30	32		
3/6			56	33
3/7	29	30		
3/8	25	24		
3/11 (1)			57	29
3/11 (2)	42	44		
3/12	32	31		
TOTAL	337	346	113	62

TABLE VII. - ECHO II AND PAGEOS I POLARIMETRIC DATA POINTS
(YUMA 1969)

Satellite	No. of Passes	Dates of Passes	U	B	V	R	I
Echo II	5	Feb. 23, 26, 27 March 1,2	17	13	15	0	0
PAGEOS I	5	Feb. 2, 3 4, 6, 8	11	14	18	2	2

Discussion of Results

Stellar Calibration. - Second-order extinction coefficients and scale factors were determined once during each observation period. The values obtained for these parameters are presented in Tables VIII and IX, respectively.

Primary extinction coefficients and zero-point terms are calculated from observations on 5-7 standard stars (References 4 and 5) before and after each satellite pass. These values are then used, along with the second-order extinction coefficients and scale factors, to determine the extra-atmospheric satellite magnitudes in the various spectral regions. Average values for the primary extinction coefficients for the Palomar 1968 and Yuma 1969 missions are presented versus wavelength in Figure 4 along with respective values determined in 1966 and 1967. Note that the Palomar Mountain sky was somewhat more transparent in 1968, while Yuma's sky was more transparent in 1967.

Satellite Results - Photometric. -

PAGEOS I: The optical and physical properties as determined for PAGEOS I during the Palomar 1968 and Yuma 1969 missions are presented in Tables X and XI. Presented in Figures 5 and 6 are the U, B, V20 and V1, R, I data, respectively, for the Yuma 1969 mission.

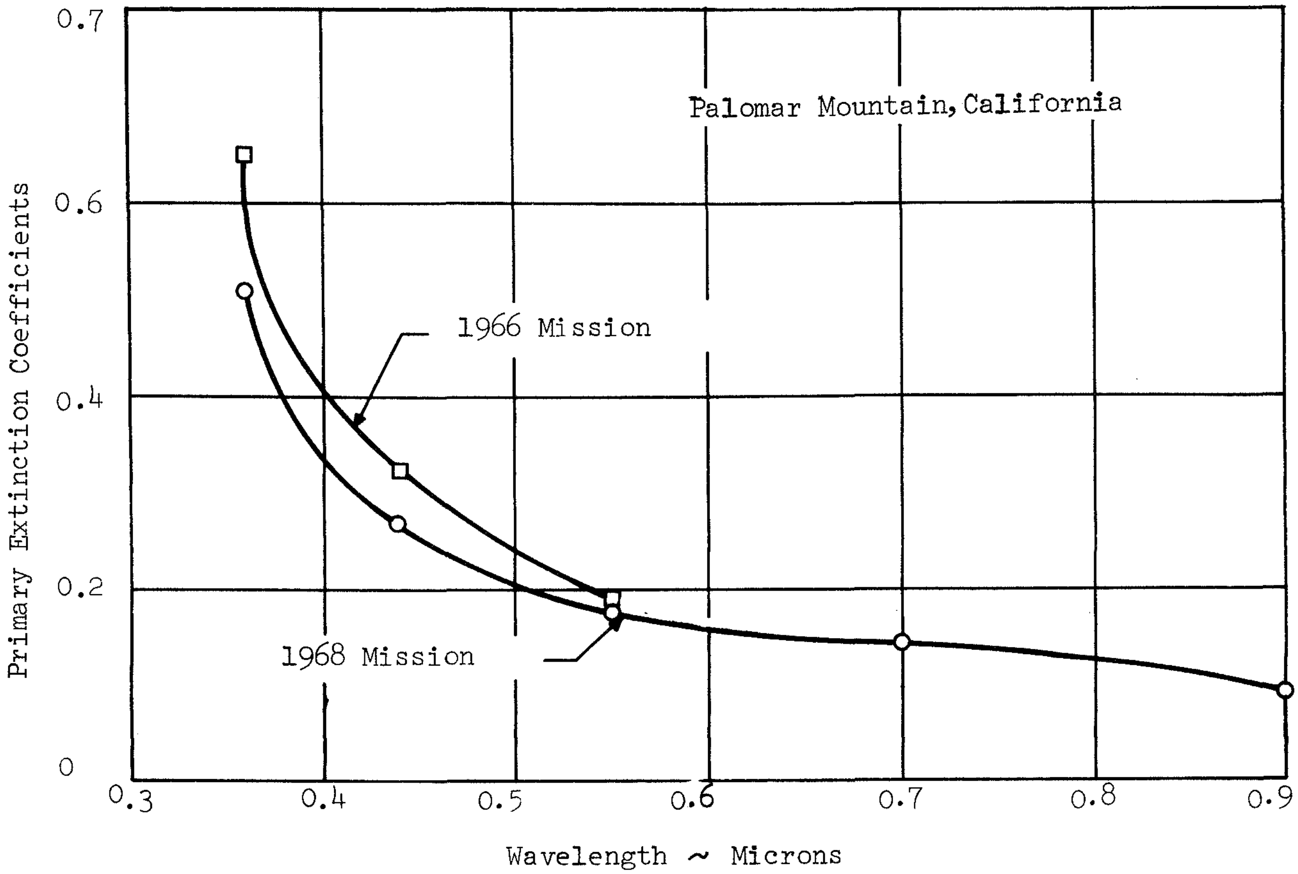
The flat lay of the data points as a function of phase angle indicates a satellite with an extremely high specularity (the calculated specularity of PAGEOS in all spectral bands indicates a nearly complete specular reflector). The fact that the calculated specularity occasionally exceeds 100 percent is believed due to a non-random distribution of observed satellite intensities (macrotexture effects).

TABLE VIII. - SECOND ORDER EXTINCTION COEFFICIENTS

Observation Period/Date	No. of Star Pairs Used	k''_{b-v}	k''_{u-b}	k''_{v-r}	k''_{r-i}
Palomar:					
October 8, 1968	4	-0.007	0.007	0.039	0.008
Yuma:					
February 11, 1969	3	-0.050	-0.010	-0.013	-0.020

TABLE IX. - TRANSFORMATION SCALE FACTORS

Observation Period/Date	No. of Stars Used	$\epsilon_{(V20)}$	$\mu_{(B-V)}$	$\psi_{(U-B)}$	$\rho_{(V1)}$	$\sigma_{(V-R)}$	$\tau_{(R-I)}$
Palomar:							
October 8, 1968	17	0.045	1.083	1.065			
	15				-0.003	1.227	1.220
Yuma:							
February 14, 1969	15	0.049	1.051	1.065	-0.031	1.128	1.123



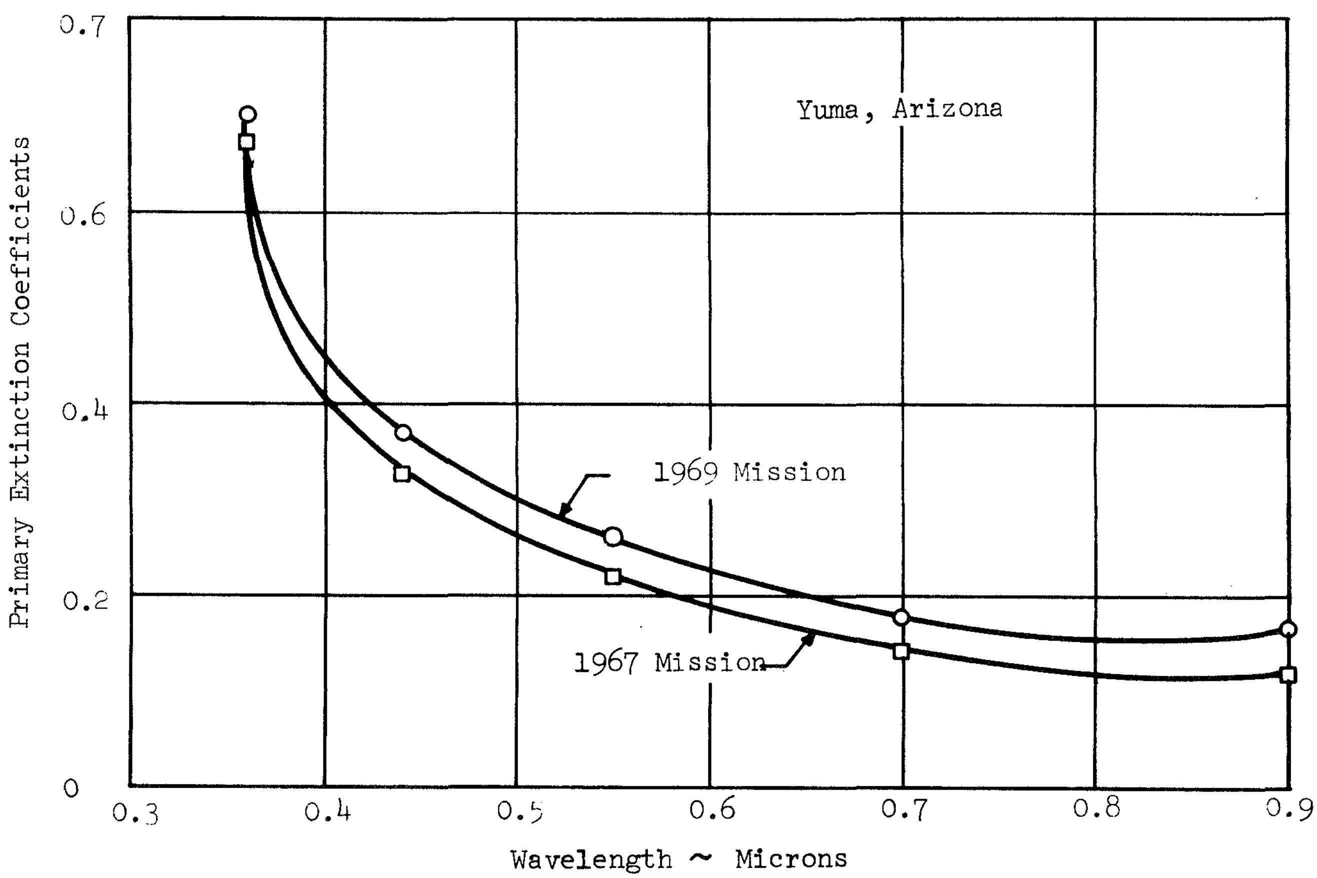


Figure 4. Primary Extinction Coefficients

TABLE X. - OPTICAL AND PHYSICAL PROPERTIES OF THE PAGEOS I SATELLITE - FALL 1968

Parameter	U	B	V20	V1	R	I
Average Normalized Magnitude	2.97	2.74	2.09	2.09	1.60	1.27
Sigma Magnitude	0.26	0.26	0.26	0.23	0.29	0.29
Specularity (%)	99.9	103.6	99.9	101.7	99.7	99.4
Average Radius of Curvature (Ft)	47.2	50.8	50.9	50.9	50.8	52.2
Sigma Radius (Ft)	5.4	5.6	5.6	5.1	6.5	6.8
Total Reflectance	0.78	0.91	0.92	0.92	0.89	0.95
Figure of Merit for Specularity	50.5	51.9	52.1	56.8	44.4	43.6
No. of Data Points	635	634	635	607	607	607

Table XI. - OPTICAL AND PHYSICAL PROPERTIES OF THE PAGEOS I SATELLITE - WINTER 1969

Parameter	U	B	V20	V1	R	I
Average Normalized Magnitude	2.90	2.73	2.10	2.10	1.65	1.24
Sigma Magnitude	0.39	0.29	0.27	0.26	0.36	0.33
Specularity (%)	105.2	99.7	99.0	100.8	98.8	101.6
Average Radius of Curvature (Ft)	48.7	50.2	49.7	49.9	48.9	52.5
Sigma Radius (Ft)	7.9	6.7	6.1	5.8	7.7	7.7
Total Reflectance	0.82	0.89	0.87	0.88	0.82	0.95
Figure of Merit for Specularity	30.9	36.8	39.8	42.2	30.7	33.1
No. of Data Points	306	308	300	290	289	288

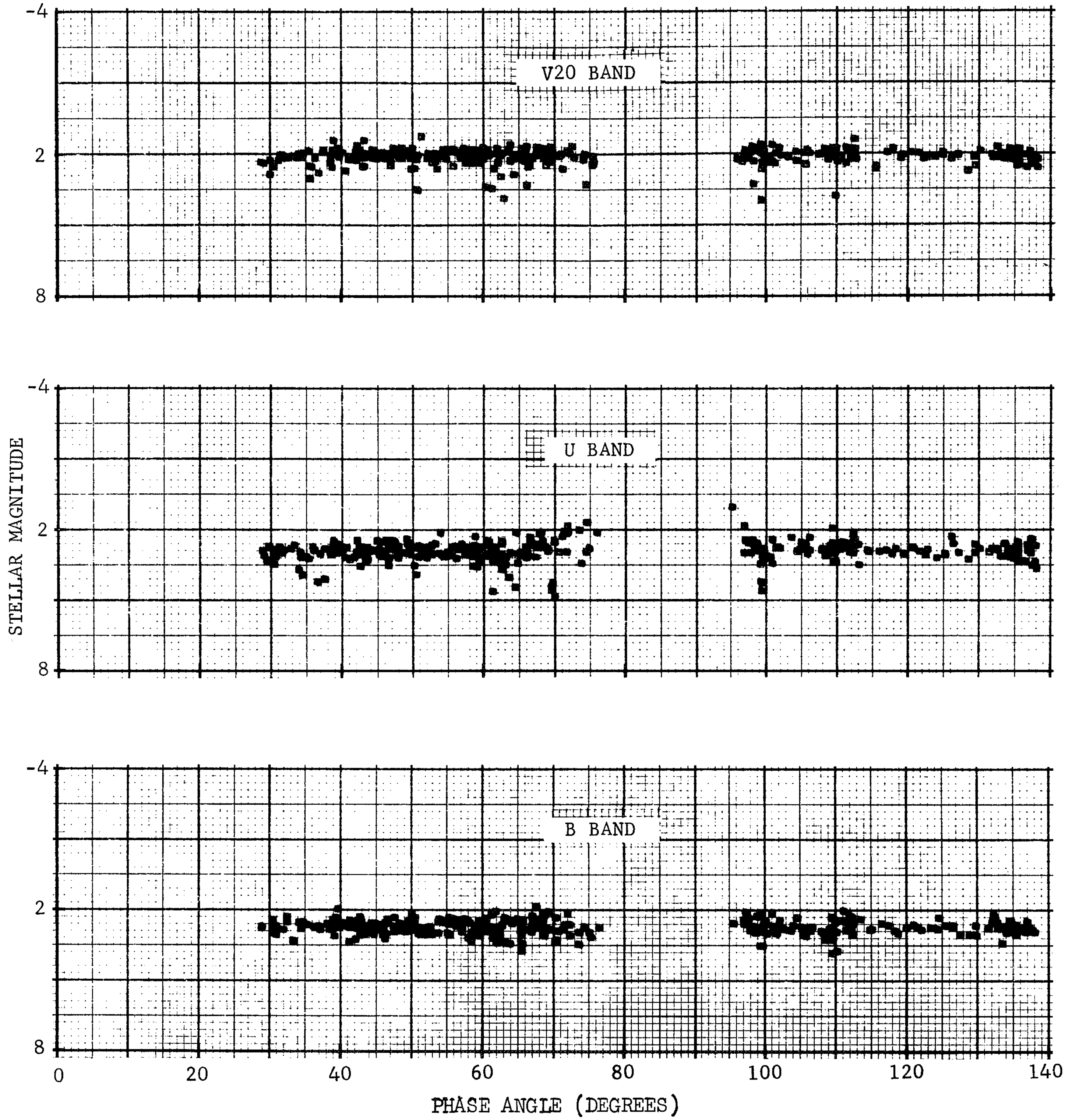


Figure 5. PAGEOS I V20, U, and B-Band Data Points (Yuma 1969)

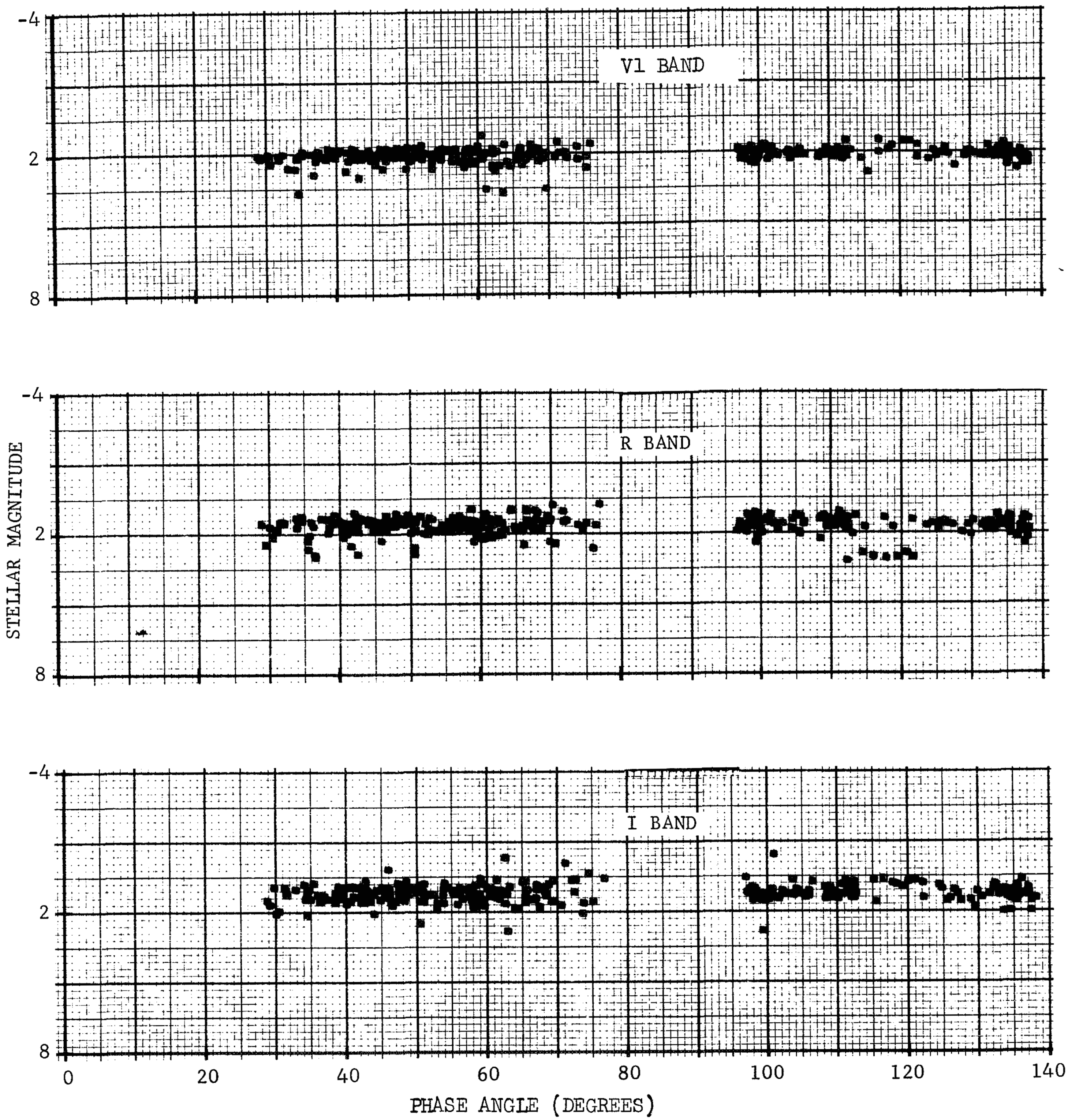


Figure 6. PAGEOS I V1, R, and I-Band Data Points (Yuma 1969)

As may be noted in Tables X and XI, the values of Sigma Magnitude and Sigma Radius are quite high (the Winter 1969 values being much higher), indicating either there are anomalies among the local radii of curvature from wrinkling, or the satellite's surface is optically inhomogeneous through local changes in its specular and/or reflectance properties. The former is believed to be the main cause of the large excursions in intensity levels which were noticed through visual and photometric observations. The data points removed from the Winter 1969 data were as much as 3 magnitudes greater (15 times less intense) than the average.

The large excursions in intensity levels of the PAGEOS I satellite have been attributed to a gross change in the shape of the satellite by K. Kissell and R. Vanderburgh (Air Force Aerospace Research Laboratory, Wright-Patterson Air Force Base, Reference 9). They have suggested PAGEOS I now has the figure of a prolate spheroid. However, since sinusoidal intensity excursions are not seen during each pass, it is believed that the satellite has retained its basic spherical shape, but exhibits local macroscopic anomalies such as a wrinkled polar cap.

The reflectance values remain high indicating little or no degradation (except possibly in the U and I bands) over a 3-year period which included the period of solar maximum for the 20th solar cycle. This will be further discussed in the "Trends" section, later in the report.

Echo II: The optical and physical properties obtained from the combined pass computer analysis of the Palomar 1968 and Yuma 1969 data are presented in Tables XII and XIII.

The V20-band data points for the Palomar 1968 and Yuma 1969 missions are plotted in Figure 7. Also plotted among the 1968 and 1969 data are V20-band data from the Yuma 1967 mission. It is rather difficult to observe any difference in intensity levels between the 1968 and 1969 data; however, linear regressions show the 1969 data to have a slightly higher magnitude (less intense). It is quite clear, however, that the 1967 data lies above the 1968 and 1969 data. The calculated magnitudes at 83.7° phase angle from the linear regressions were as follows:

1967: - 0.38 magnitudes

1968: - 0.20 magnitudes

1969: - 0.17 magnitudes

As may be noted, all optical properties, normalized magnitude at 83.7° phase angle, reflectance, and specularity, are less for the Yuma data than for the Palomar data in all spectral bands, indicating a slight amount of degradation even in the short time period of 5 to 6 months.

TABLE XII. - OPTICAL AND PHYSICAL PROPERTIES OF THE ECHO II SATELLITE - FALL 1968

Parameter	U	B	V20	V1	R	I
Normalized Magnitude at 83.7° Phase Angle	0.74	0.58	-0.20	-0.22	-0.73	-1.17
Sigma Magnitude	0.25	0.21	0.19	0.19	0.20	0.22
Specularity (%)	67.0	65.3	63.7	61.7	64.8	64.4
Average Radius of Curvature (Ft)	54.6	60.7	63.3	64.0	65.1	69.1
Sigma Radius (Ft)	8.0	8.1	7.7	7.9	8.1	8.6
Total Reflectance	0.46	0.51	0.58	0.59	0.59	0.69
Figure of Merit for Specularity	29.0	31.8	34.9	33.5	33.1	33.1
No. of Data Points	272	272	272	278	278	278

TABLE XIII. - OPTICAL AND PHYSICAL PROPERTIES OF THE ECHO II SATELLITE - WINTER 1969

Parameter	U	B	V20	V1	R	I
Normalized Magnitude at 83.7° Phase Angle	0.81	0.66	-0.17	-0.18	-0.72	-1.13
Sigma Magnitude	0.30	0.25	0.19	0.20	0.23	0.22
Specularity (%)	56.7	55.1	55.1	52.9	53.8	62.2
Average Radius of Curvature (Ft)	51.4	57.4	61.3	61.6	63.3	66.9
Sigma Radius (Ft)	10.9	10.0	8.4	9.2	11.0	9.6
Total Reflectance	0.40	0.44	0.54	0.54	0.54	0.64
Figure of Merit For Specularity	18.5	22.3	28.8	26.8	23.2	28.0
No. of Data Points	312	312	312	326	326	326

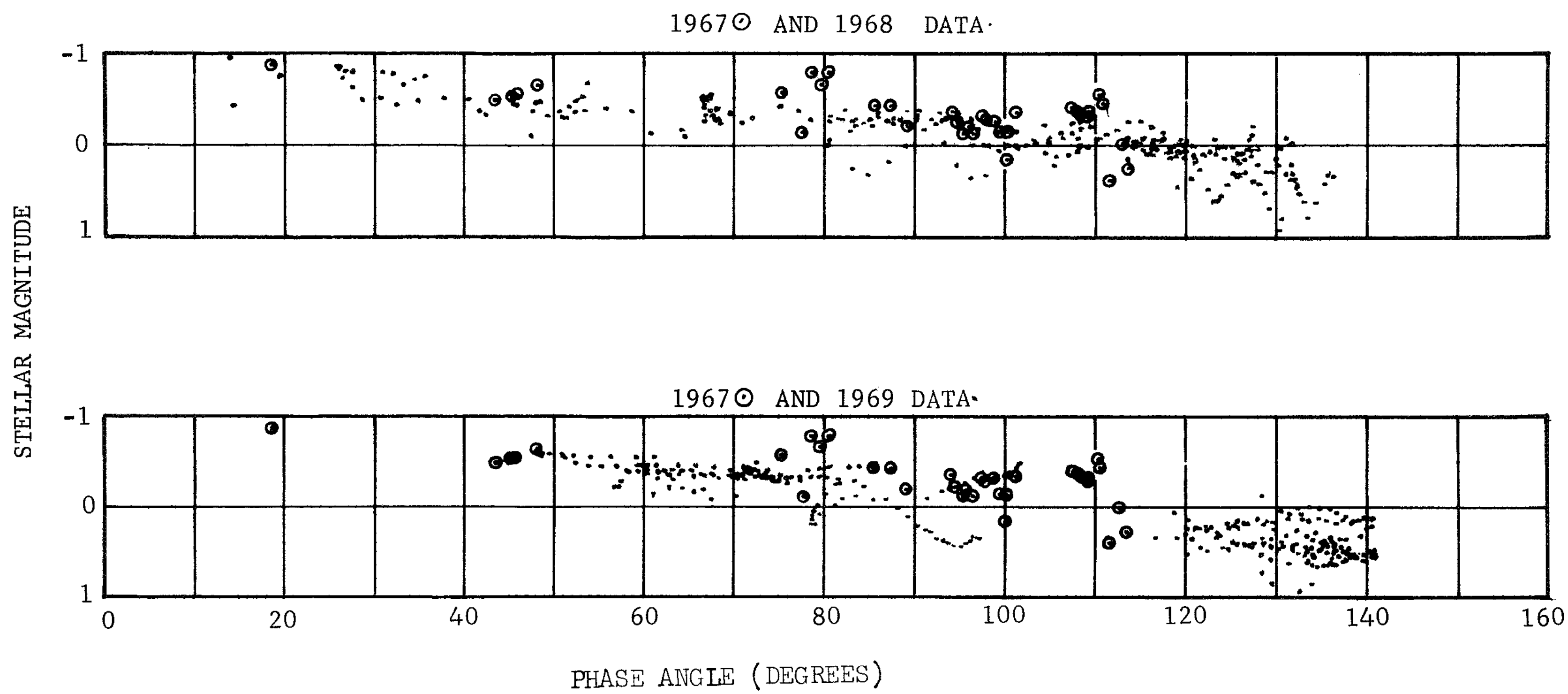


Figure 7. V20-Band Magnitudes for Echo II from 1967, 1968, and 1969 Missions

The reason that a single value of the magnitude taken at 83.7° is accepted as definitive for Echo II rather than an average value such as for PAGEOS I, is that the Echo II satellite is quite diffuse and thus, is phase angle dependent. The magnitude value at 83.7° phase angle (which was derived from a best-fit linear regression of the intensities) is especially significant, since this is the phase angle where the intensity contributions from the specular and diffuse optical components for a spherical satellite intersect.

A striking example of the apparent degradation for this satellite during its orbital lifetime may be seen by comparing laboratory values of the reflectance, and the Yuma 1967 observation period reflectances, with the two observation periods described here. This will be described more fully in the "Trends" section.

This apparent degradation is also seen in the calculation of the average radius of curvature; the determinations in all spectral bands are less than the design value. This determination is not to infer that the satellite has decreased in size, or that the values given in Tables XII and XIII are "true" values of the radius of curvature. The calculations presented in the tables are obtained by using laboratory values of reflectance for Alodine material; since the calculations of the radius of curvature are less than design values, it indicates a decrease in reflectance. This is shown in Tables XII and XIII.

Laboratory absorptance measurements in a solar ultra-violet-vacuum environment performed on Echo II material coated with 185 mg/ft^2 of Alodine 401-45 showed a large increase (40-170%) in absorptance at wavelengths less than 0.45μ (4500 A) with much less effect at longer wavelengths (Reference 10). Absorptance measurements on similar samples but with no ultraviolet irradiation, showed a much smaller (but not insignificant) increase in absorptance. This probably indicates that the very large indicated decrease in reflectance of Echo II (from laboratory values or from the 1967 observations to the 1968 and 1969 observations) in the U and B-bands was caused in large part by solar ultra-violet radiation.

It should be recalled that the solar maximum activity for the 20th solar cycle occurred in the time period of 1967 to 1969. This undoubtedly played a large part in accelerating the apparent degradation of the Echo II optical properties.

Satellite Results - Polarimetric. -

General: Polarimetric observations of the PAGEOS I and Echo II satellites were performed only during passes when the satellites attained phase angles of 120° or higher. Six passes each of the two satellites were taken; however, only five each of these passes provided useful polarization data, mainly due to instrumentation difficulties. These data are plotted in Figures 8 to 13 along with the data obtained during the Yuma 1967 mission.

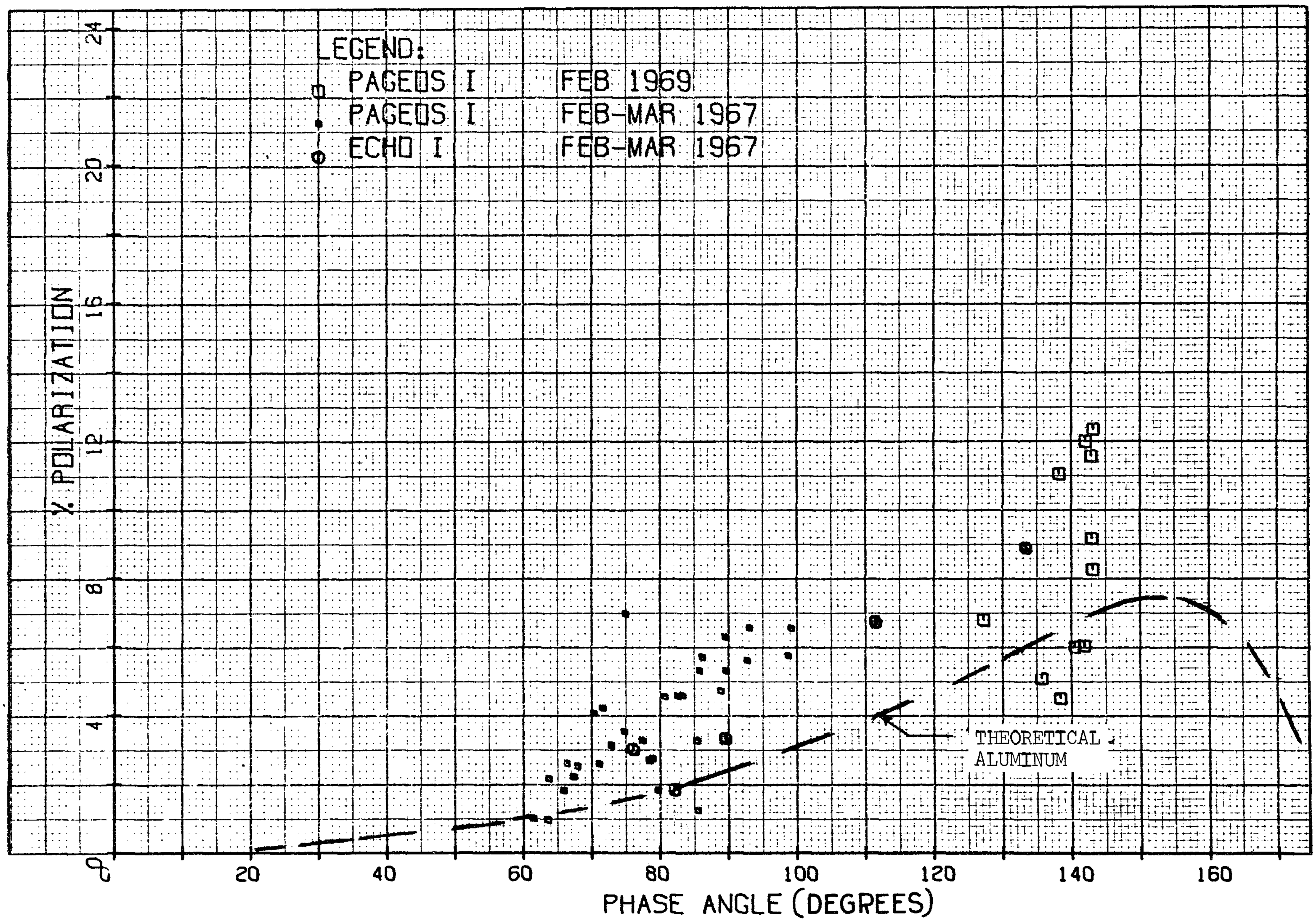


Figure 8 - PAGEOS I and Echo I U-Band Polarimetric Data (1967 & 1969)

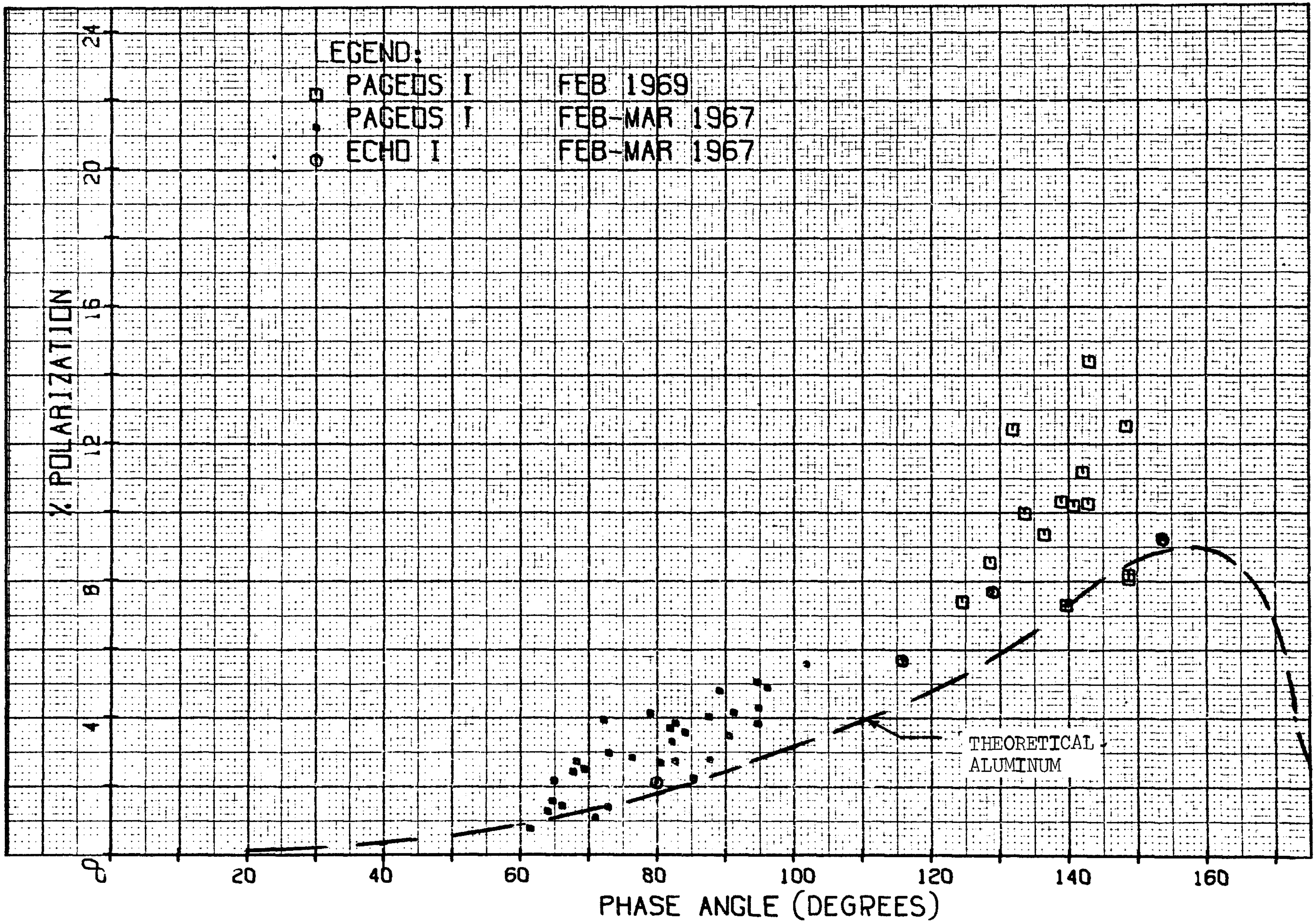


Figure 9 - PAGEOS I and Echo I B-Band Polarimetric Data (1967 & 1969)

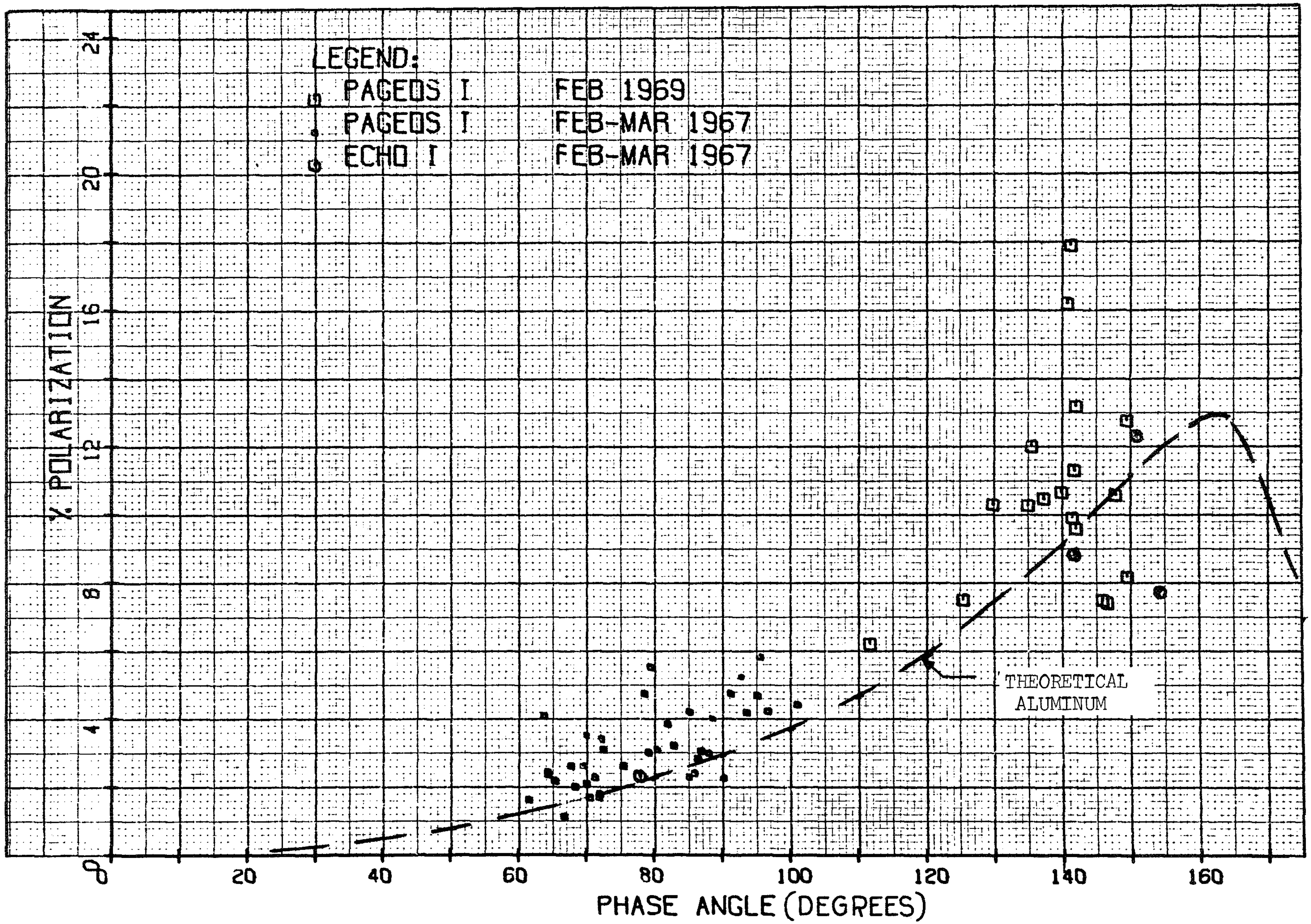


Figure 10 - PAGEOS I and Echo I V-Band Polarimetric Data (1967 & 1969)

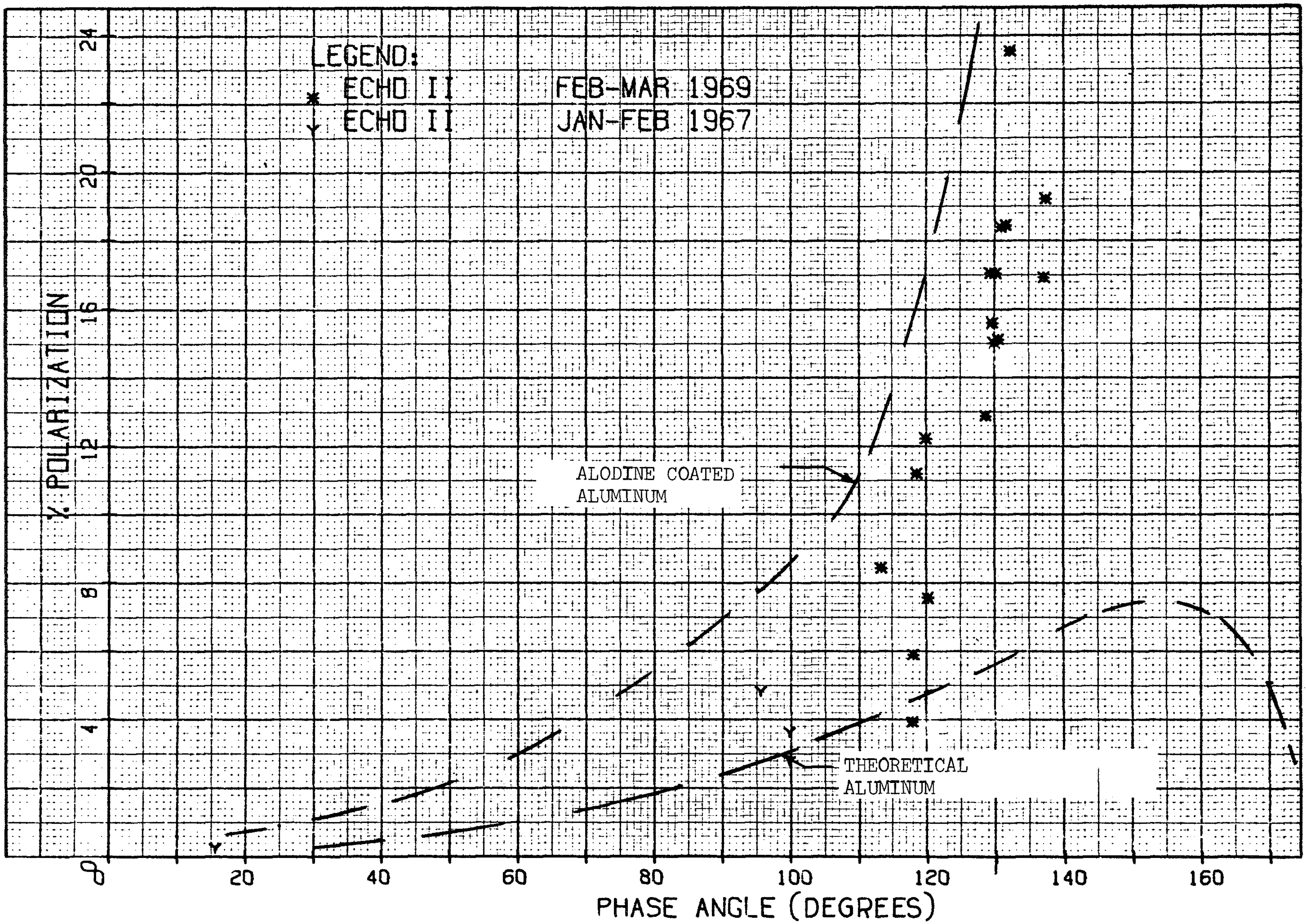


Figure 11 - Echo II U-Band Polarimetric Data (1967 and 1969)

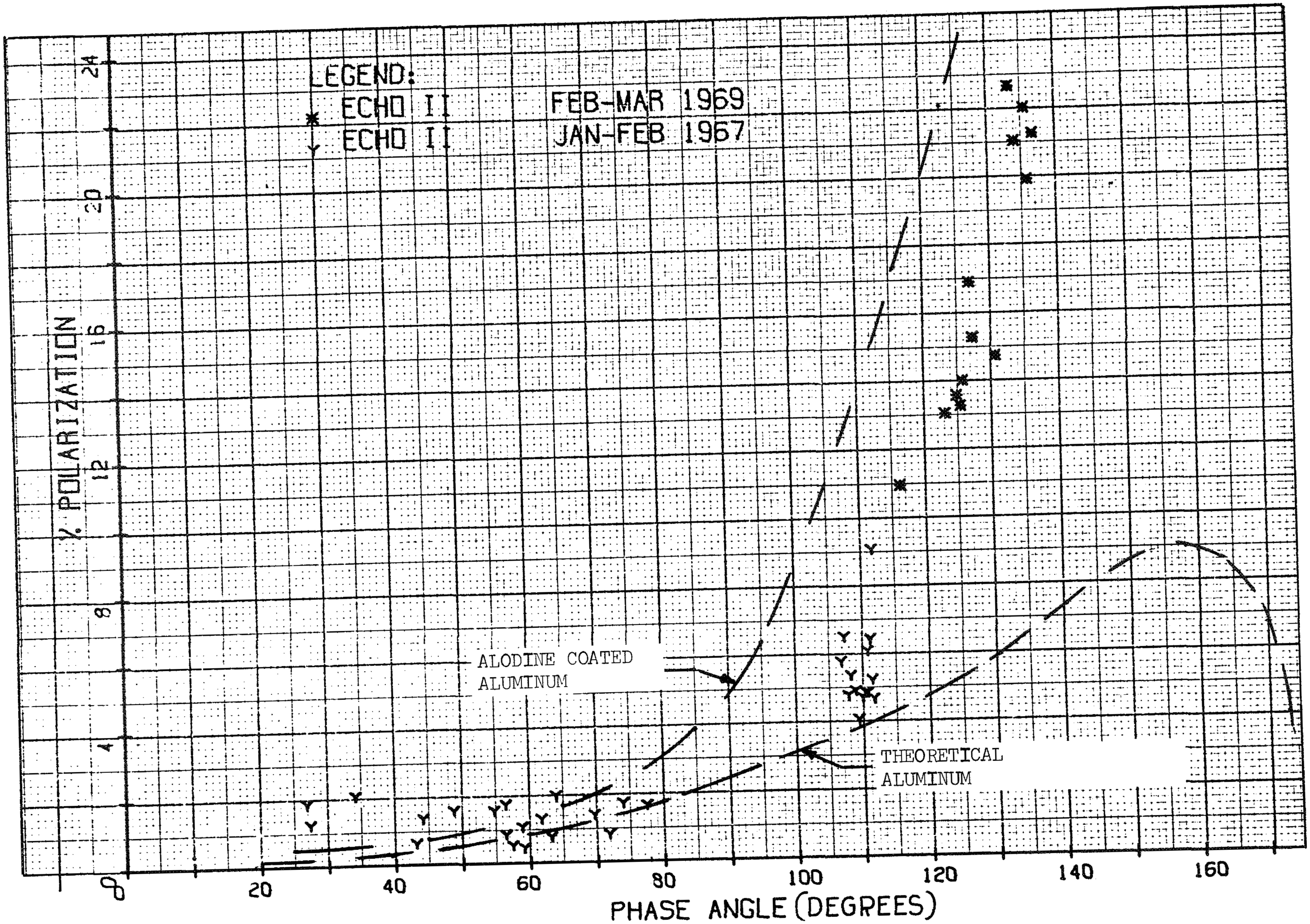


Figure 12 - Echo II B-Band Polarimetric Data (1967 and 1969)

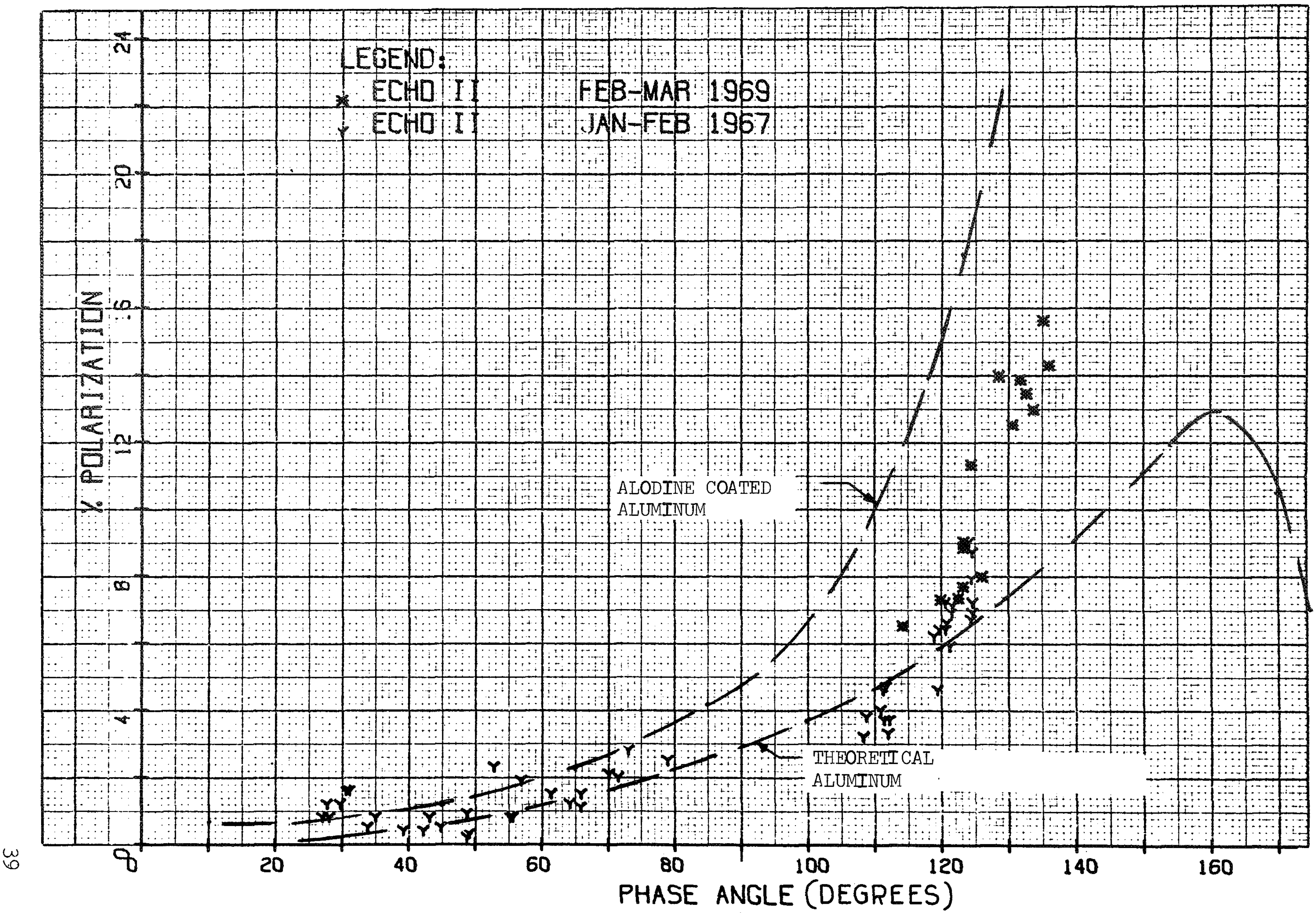


Figure 13 - Echo II V-Band Polarimetric Data (1967 and 1969)

PAGEOS I: Values of the percent polarization data versus phase angles for PAGEOS I for the Yuma Winter 1969 mission in the U, B, V spectral regions are presented in Figures 8 to 10. The R and I-band data are not presented here because of relatively few data points taken in these spectral regions. Shown also in these figures are data for PAGEOS I and Echo I (which was similar to PAGEOS I in size and surface materials) taken during the Yuma Winter 1967 mission. In addition, theoretical curves for bare aluminum for comparison purposes are presented (Reference 11).

It is quite evident that the measured data points lie parallel to and slightly above the theoretical curves in the U, B, and V spectral regions while there were insufficient data taken in the R and I-bands to note any trends. The fact that the percent polarization data points have a similar slope to that of the theoretical curves is an independent indication of the continued presence of aluminum film. That they are not more closely in agreement is not significant since the optical constants used in the theoretical calculations are not those of the PAGEOS I satellite materials.

The fairly large scatter of the polarization data points (as compared with those of Echo II) is probably caused by macroscopic surface effects similar to those observed in the photometric calculations.

Echo II: The plotted values of the percent polarization data for the Echo II satellite during the Yuma 1967 and 1969 missions are presented in Figures 11 to 13 for the U, B, V spectral regions. Presented also are theoretical curves for aluminum as well as experimental values of Alodine measured at NASA-Langley (Reference 12). It is quite evident that the GAC-determined data, while less than the experimental measurements in all spectral regions, has the same general shape as the latter data, and exhibits the same characteristic rise at high phase angles. This probably indicates that most of the original Alodine coating was still present on the satellite at the time of the measurements. If the coating had eroded, it is probable that the polarization would more nearly resemble that of the theoretical aluminum curve (or similar to that of PAGEOS I) since the outermost structural material of Echo II was aluminum foil.

Trends. -

PAGEOS I: PAGEOS I has now been photometrically observed during six observation periods:

(1) Palomar Mountain, California; Summer, 1966

(2) Yuma, Arizona; Winter, 1967

(3) Akron, Ohio; Summer, 1967

(4) Akron, Ohio; Fall, 1967

(5) Mt. Palomar, California; Fall, 1968

(6) Yuma, Arizona; Winter, 1969

while it has been observed polarimetrically during periods (2) and (6).

The determinations of specularity and reflectance for each of these observation periods are shown in Figures 14 and 15, respectively. Similar determinations of these optical properties for Echo I and Echo II as functions of their orbital age are also shown in these figures.

From an examination of the PAGEOS optical properties, it can easily be seen that the satellite remains an almost complete specular reflector. The reflectance values (excepting the U-band) remain at a near constant value during its 3 years in orbit. The lower values for the U-band may be due to poor transparency conditions during those observation periods, although during the Yuma 1967 mission the transparency conditions in all spectral regions were excellent (see Figure 4). The I-band reflectances obtained during the two observation periods of the present contract are higher than those measured in the laboratory. Whether this is a true enhancement due to space environment "polishing" of the film in this spectral region is unknown.

It may be said that the near earth space environment has little or no effect on aluminized surfaces; however, this may not be true of such surfaces which are exposed to high energy particulate radiation in the outer Van Allen belt or outside the magnetosphere (exposed to the solar wind). Button sized samples of aluminized Mylar bonded on a solid surface onboard an ATS satellite in a synchronous orbit were directly exposed to the space environment. These specimens degraded significantly, while similar samples protected by quartz covers did not degrade.

Echo II: Echo II was photometrically observed during periods (2) to (6) and polarimetrically observed during periods (2) and (6). As was stated previously, the specularity and reflectance for the five photometric observation periods for Echo II are presented in Figures 14 and 15. A definite downward trend for both optical properties is apparent for all colors. . It should be stated, however, that the values presented in these figures have widely different confidence levels due to the number of data points obtained and the transparency conditions under which the data was obtained. For instance, during the two Akron observing sessions, few data points were obtained and the sky conditions were rather poor. Few data points were obtained for the first Yuma mission in 1967; however, the reflectance values obtained for this mission had rather a high confidence level (V1-band excepted) because of excellent transparency conditions.

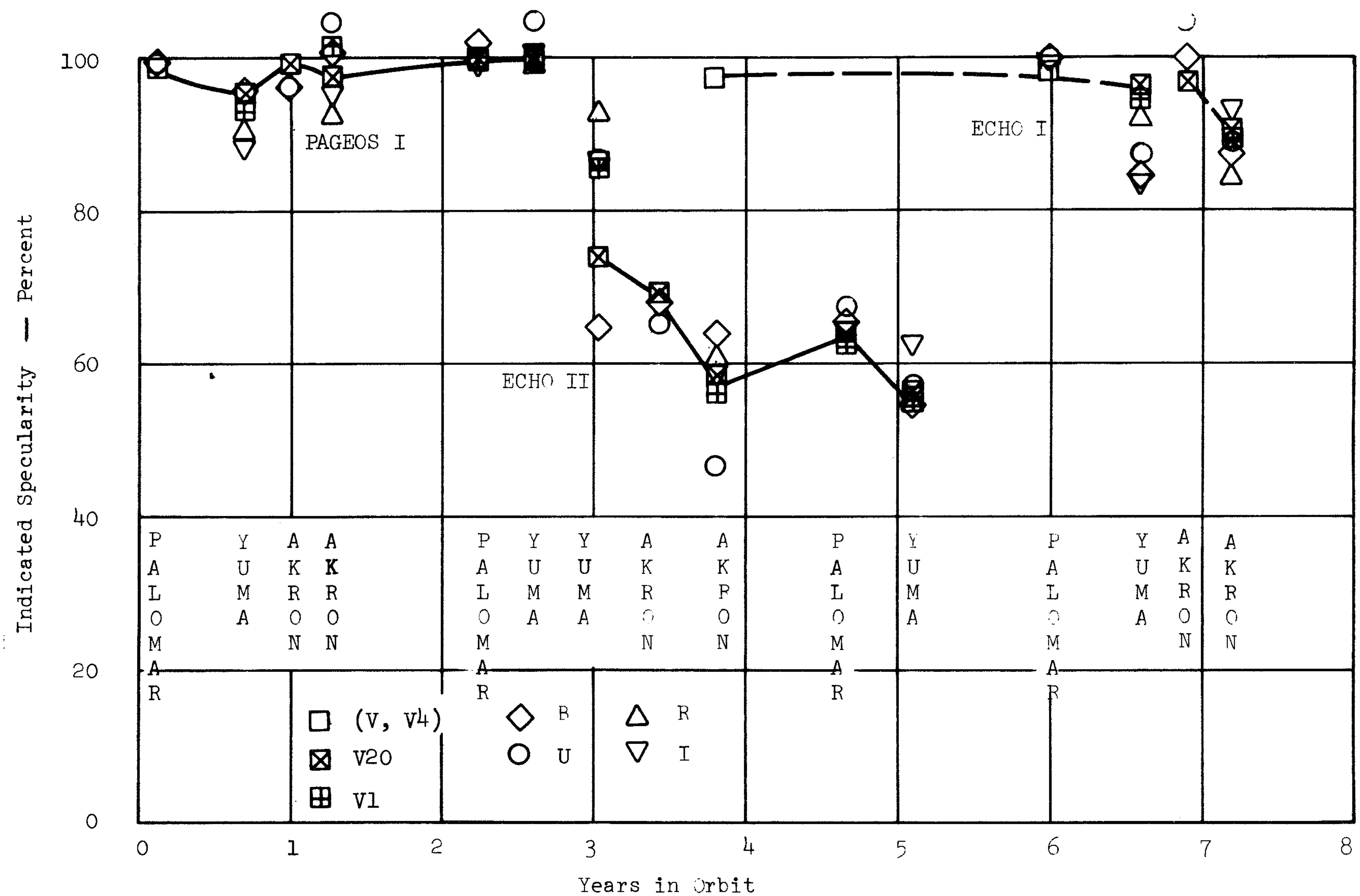


Figure 14. - Specularity Values for PAGEOS I, Echo I, and Echo II Versus Orbital Age

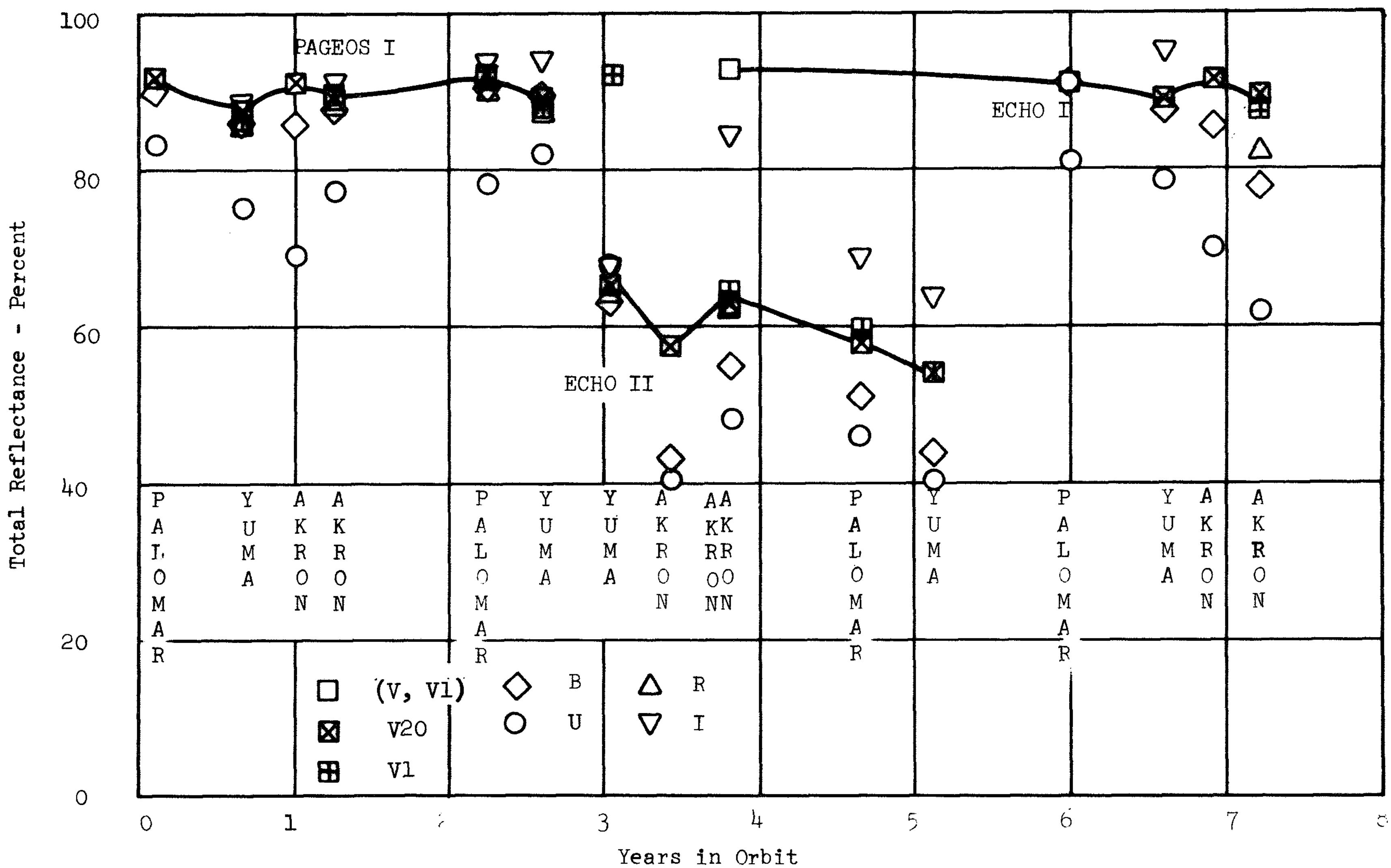


Figure 15. - Reflectance Values for PAGEOS I, Echo I, and Echo II Versus Orbital Age

Shown in Table XIV are reflectance values obtained from the three best observation sessions for Echo II and laboratory measurements on Alodine coating.

TABLE XIV. - ECHO II REFLECTANCE VALUES FROM PHOTOMETRIC OBSERVATIONS AND LABORATORY MEASUREMENTS

DATE	ORBITAL AGE (YEARS)	U	B	V20	V1	R	I
Winter, 1967 Observation Period	3.0	0.68	0.62	0.66	0.91*	0.63	0.68
Fall, 1968 Observation Period	4.6	0.46	0.51	0.58	0.59	0.59	0.69
Winter, 1969 Observation Period	5.1	0.40	0.44	0.54	0.54	0.54	0.64
Laboratory Measurements of Alodine (Ref. 13)	-	0.72	0.64	0.67	0.67	0.64	0.67

*Value Not Considered to be Realistic

If one compares the Winter 1967 observation values to those of the laboratory measurements, it is quite apparent that the reflectance values are comparable. However, the values for the Fall 1968 and Winter 1969 observation periods are completely different. The reflectance values appear to have decreased significantly in all spectral regions. The decrease becomes more significant at the lower wavelengths, with the maximum decrease in the U-band.

Accuracy: Determinations of accuracy for the photometric and polarimetric observations have been calculated from the stellar and/or satellite determinations. Each of these calculations will be discussed in turn.

(1) Photometric Accuracy Determinations

(a) Stellar Accuracy - Magnitude and color index values (V20, B-V, U-V or U-B, V1, V-R, V-I or R-I) of standard stars have been calculated from observations taken during the Palomar Mountain and Yuma observation periods.

The computed values were for stars which were used in the determination of primary extinction coefficients for the Echo II and PAGEOS I passes. Similar determinations were performed after the Palomar Mountain observation period during the Summer of 1966 and the Yuma observation period during the Winter of 1967 (References 1 and 2). The indicated accuracy values for the various spectral regions give an approximate accuracy level for the extra-atmospheric satellite determinations as well as for the two photometric systems.

The average deviations for a single observation, standard deviations for a single observation, and the probable errors for a single observation at the zenith (1.0 air mass) for all observations are presented in Tables XV and XVI. For the probable error determinations, an air mass of 1.5 was used to adjust the values to the zenith. The various parameters are comparable to those obtained previously; the slightly higher values obtained in the U-V (U-B) and V-I (R-I) regions occur because of the inherently lower accuracy in the U and I-band regions, but also because certain of the stars had consistently different color index values than those of Reference 5, which are considered to be "standard".

(b) Satellite Accuracy - The probable error determinations for the Fall 1968 and Winter 1969 observation periods are presented in this section. The theory describing the method of determining these parameters has been presented in Reference 1. The probable error determinations for the Palomar 1968 observations are presented in Tables XVII and XVIII, while those for the Yuma 1969 observations are presented in Tables XIX and XX.

(2) Polarimetric Accuracy Determinations - To obtain an indication of the accuracy of the polarimetric measurements for the PAGEOS I and Echo II satellites, the results obtained for the calibration stars were compared with published catalog values (Reference 14). Forty-six V-band percent polarization determinations of stars of both near-zero and relatively high polarization were compared. The absolute values of deviations (average deviation) was 0.5 percent polarization. The dispersion of these values revealed a standard deviation and probable error in percent polarization values of ± 0.7 and ± 0.5, respectively.

TABLE XV. - ACCURACY DETERMINATION OF MAGNITUDES AND COLOR INDICES OF STANDARD STARS (PALOMAR 1968)

Parameter	V20	B-V	U-V	V1	V-R	V-I
No. of Observations	318	318	318	304	304	304
Average Deviation for a Single Observation (Mag)	0.020	0.029	0.047	0.023	0.033	0.041
Standard Deviation for a Single Observation (Mag)	0.026	0.042	0.063	0.030	0.040	0.053
Probable Error for a Single Observation at 1.0 Air Mass (Mag)	0.012	0.019	0.028	0.014	0.018	0.024

TABLE XVI. - ACCURACY DETERMINATION OF MAGNITUDES AND COLOR INDICES OF STANDARD STARS (YUMA 1969)

Parameter	V20	B-V	U-B	V1	V-R	R-I
No. of Observations	238	237	237	234	235	235
Average Deviation for a Single Observation (Mag)	0.020	0.026	0.040	0.021	0.028	0.032
Standard Deviation for a Single Observation (Mag)	0.027	0.034	0.055	0.030	0.036	0.041
Probable Error for a Single Observation at 1.0 Air Mass (Mag)	0.012	0.015	0.025	0.014	0.016	0.018

TABLE XVII. - PROBABLE ERRORS OF ECHO II PHOTOMETRIC RESULTS (PALOMAR 1968)

SPECTRAL REGION	STELLAR MAGNITUDES	SPECULARITY (PERCENT)	RADIUS OF CURVATURE (FT)	REFLECTANCE (PERCENT)
U	± 0.010	± 1.2	± 0.40	± 1.3
B	± 0.009	± 1.0	± 0.37	± 1.1
V20	± 0.008	± 1.0	± 0.34	± 1.0
V1	± 0.008	± 0.9	± 0.34	± 1.0
R	± 0.008	± 0.9	± 0.34	± 1.1
I	± 0.009	± 0.9	± 0.34	± 1.1

TABLE XVIII. - PROBABLE ERRORS OF PAGEOS I PHOTOMETRIC RESULTS (PALOMAR 1968)

SPECTRAL REGION	STELLAR MAGNITUDE	SPECULARITY (PERCENT)	RADIUS OF CURVATURE (FT)	REFLECTANCE (PERCENT)
U	± 0.007	± 1.0	± 0.15	± 0.7
B	± 0.007	± 1.0	± 0.15	± 0.7
V20	± 0.007	± 0.9	± 0.15	± 0.7
V1	± 0.006	± 0.9	± 0.14	± 0.6
R	± 0.008	± 1.1	± 0.17	± 0.8
I	± 0.008	± 1.1	± 0.18	± 0.8

TABLE XIX. - PROBABLE ERRORS OF ECHO II PHOTOMETRIC RESULTS (YUMA 1969)

SPECTRAL REGION	STELLAR MAGNITUDES	SPECULARITY (PERCENT)	RADIUS OF CURVATURE(FT)	REFLECTANCE (PERCENT)
U	± 0.013	± 1.8	± 0.62	± 1.9
B	± 0.010	± 1.4	± 0.48	± 1.5
V20	± 0.008	± 1.2	± 0.38	± 1.2
V1	± 0.008	± 1.2	± 0.40	± 1.2
R	± 0.009	± 1.6	± 0.47	± 1.5
I	± 0.009	± 1.6	± 0.40	± 1.2

TABLE XX. - PROBABLE ERRORS OF PAGEOS I PHOTOMETRIC RESULTS (YUMA 1969)

SPECTRAL REGION	STELLAR MAGNITUDE	SPECULARITY (PERCENT)	RADIUS OF CURVATURE(FT)	REFLECTANCE (PERCENT)
U	± 0.015	± 2.3	± 0.31	± 1.4
B	± 0.011	± 1.3	± 0.26	± 1.1
V20	± 0.011	± 1.1	± 0.24	± 1.0
V1	± 0.010	± 1.0	± 0.23	± 1.0
R	± 0.014	± 1.4	± 0.31	± 1.4
I	± 0.013	± 1.1	± 0.29	± 1.3

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. The specularity of PAGEOS I has not measurably degraded. The calculated value of specularity indicates a near mirror-like reflector.

2. There is no clear evidence that the brightness or color of PAGEOS I have changed since August, 1966. Reflectances inferred for the blue, visual (yellow), and red regions of the spectrum are in close agreement with laboratory values. Either the laboratory value of the ultra-violet reflectance is too high or there was a "sudden" degradation in this parameter soon after launching (June 1966). The measured laboratory infra-red reflectance is lower than that obtained through I-band photometry of the satellite. This suggests that exposure to the space environment may have enhanced the I-band reflectance.

3. The average radius of curvature of PAGEOS I remains 50 feet, as designed. One or more significant surface anomalies have developed since August 1966, causing the satellite to now occasionally fade through several stellar magnitudes. The general macro-texture, however, has not appreciably changed. The standard deviation of the stellar magnitudes remains about 0.2 to 0.3.

4. Since the observed intensity excursions of PAGEOS I are not generally sinusoidal, the suggestion elsewhere in the literature that its figure is that of a prolate spheroid is not supported.

5. The similarity of the percent polarization data of PAGEOS I to that of the theoretical curves for bare aluminum (although they are slightly above and parallel to the theoretical curves) is an independent indication of the continued presence of the aluminum film. The larger scatter of the polarization data points (as compared to the Echo II) is undoubtedly caused by macroscopic surface effects similar to those observed photometrically.

6. The continuous decrease in the normalized magnitudes at 83.7° phase angle, reflectance, and specularity for Echo II in all spectral regions from 1967 to 1969 indicates a substantial degradation of the Alodine surface coating. It is believed that degradation is caused more by surface discoloration than by erosion of the coating.

7. The determination of percent polarization for Echo II indicated that a substantial amount of Alodine coating remains on the satellite. The percent polarization data points as a function of phase angle, resembles more closely laboratory measurements of Alodine rather than theoretical calculations of bare aluminum. (The structural surface material of Echo II was aluminum foil.)

8. The feasibility of performing eclipse entry observations of Echo II and PAGEOS I was established during this contract period. These observations may be used to determine ozone concentration over various areas of the earth.

9. The 5-color system operated satisfactorily throughout the two field missions conducted under this contract. Required maintenance to maintain proper operating capabilities was about normal for the complexity of the equipment involved. The cryogenic system also functioned satisfactorily throughout the mission with a minimum of maintenance.

10. The new type Wollaston prism (new adhesive) appears to demonstrate satisfactory operation, and it is expected that it will have eliminated the temperature excursion survival problem it was designed to correct, and continue to give satisfactory service over the temperature range specified for the overall observatory system.

11. The new FM magnetic tape data recording system operated satisfactorily from the time the installation was completed and de-bugged to the end of the mission with a minimum of maintenance attention.

Recommendations

1. Further photometric and polarimetric surveillance of the PAGEOS I satellite is desirable to determine its continued suitability as a geodetic satellite. These observations should be performed on an approximately twice-yearly basis throughout the useful lifetime of the satellite. The Explorer 19 and 39 satellites should be photometrically observed coincidentally to obtain knowledge of degradation (if any) of their surface materials and thermal coatings.

2. Since the feasibility of observing narrow-band eclipse entry passes of Echo II and PAGEOS I has been established during the two observation periods described in this report, further observations (of PAGEOS I)of this type as well as development of programs to determine ozone concentration appear to be desirable. One of the admirable characteristics of the present system is the ease of transformation from the broadband to the narrow-band system, thus allowing the user to obtain either/or both types of observations during a single satellite pass.

3. Development of methods of data reduction and analysis to determine the degree of degradation of the Explorer 19 and 39 satellites (combinations of aluminum foil and S-13 and S-13G white paint polka dots) should be pursued. This data reduction may be performed in several ways:

(1) Calculate the average reflectance and specularity of the satellites using the present theories; this may indicate the degradation rate of the white paint if it is known that the aluminum foil does not degrade.

(2) Calculate the optical properties of the white paint independently of the aluminum foil background. The isolation of intensities returned from individual polka-dots has not been definitely established within the data. Preliminary examination of the recordings indicates deep trough readings which are believed to be the integrated intensities returned from illuminated diffuse regions on the satellites.

4. Missions should be planned to ensure that the system has all required maintenance completed before the start of each mission, or other means provided to handle the resulting backlog.

5. Since the major data-taking capabilities have now been provided in the Mobile Observatory (including FM magnetic data recording), it would seem advisable to make those relatively minor remaining additions that would yield the greatest increase in system capability and operating efficiency. These would include (in the order listed):

(1) Automatic gain level control in both channels.
Very simple signal monitoring logic could generate the gain level increase or decrease signal pulses for this.

(2) Logarithmic signal amplifier.
Under some circumstances with very rapidly changing signal level (as during eclipse measurements), this would greatly increase operating effectiveness at very low cost.

(3) The time-code generator should be modified to extend its time-code range.

(4) Tracking improvement.
To a large extent, operating capability (small field stop for good S/N ratio, etc.) is proportional to tracking capability. This could be substantially improved by any or all of the following.

(a) TV link (image orthicon or SEC vidicon) from guide scopes to operating console (installation provisions are already available) with general monitoring by present vidicon cameras.

(b) Connection of currently installed angular position feedback pots to instrument room circuits and integration with sidereal tracking control.

(c) Auto-track by time shared use of light from main scope, or from auxiliary scopes.

(d) Replace unused 4-minute arc aperture with 3-minute aperture (for bright targets).

Any of these provisions would be quite worthwhile, and easily provided.

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