SMITHSONIAN INSTITUTION
ASTROPHYSICAL OBSERVATORY

OPTICAL SATELLITE-TRACKING PROGRAM

Grant Number NGR 09-015-002

Semiannual Progress Report No. 20

1 January 1969 to 30 June 1969

Project Director: Fred L. Whipple

Prepared for

National Aeronautics and Space Administration
Washington, D. C. 20546

Smithsonian Institution
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INTRODUCTION

In support of the scientific and operational requirements under the Satellite-Tracking Program grant, the following progress report is made. This report is somewhat different from previous ones in that these past six months mark the beginnings of a transition from a program that has primarily used data collected by the Baker-Nunn cameras augmented by other data such as laser, to a program that will emphasize laser ranging instrumentation augmented by the Baker-Nunns.

Several intensive international observing campaigns on satellites with retroreflectors have already been coordinated by the Smithsonian Astrophysical Observatory (SAO). These are forerunners of the programs SAO hopes now to embark upon. To this end, fabrication is proceeding on schedule on three laser units planned for deployment in the first half of calendar 1970. We expect that this laser network will provide data for valuable new insights into the study of the earth as a planet. Later, data will be obtained from long-baseline interferometry and from ranging to the moon and to synchronous satellites with a next-generation laser. All these data should permit significant progress on such topics as earth tides, polar motion, rotation of the earth, and continental drift.

Another factor that altered the course of the program was the notification from the National Aeronautics and Space Administration's Office of Tracking Data Acquisition (NASA/OTDA) of a substantial budget reduction in FY 1970. This fact, coupled with the changing emphasis on the type of science and instrumentation, has caused a reevaluation of the overall mission of the program. The conclusions reached form the basis of the proposal for renewal of the grant for FY 1970 and are incorporated in a scientific planning paper presented to NASA in early August.

RESEARCH PROGRAMS

GEODETIC INVESTIGATIONS

Geopotential and Geophysical Studies

A principal objective of the satellite geodesy program, determination of the gravity field of the earth, has been completed under the guidance of Dr. E. M. Gaposchkin. The representation has been expanded to 281 parameters through the use of satellite observations acquired by the SAO Baker-Nunn network, cooperating optical cameras, laser tracking systems, and other electronic range and range-rate systems. Station coordinates have been obtained by orbital methods for 30 sites; combination of these coordinates with geometrical observations has resulted in the determination of more than 40 distinct coordinate sets. The accuracy is estimated at approximately 10 m in the station coordinates for those sites with adequate data. Furthermore, from a comparison with 1-m laser data, it has been determined that the accuracy of satellite ephemerides are now approaching 10 m. Further refinements of geopotential coefficients are continuing in the current year.

The successful completion of entirely new computer programs and of the gravity-field determination system is demonstrated by the above results. The internal accuracy of the programing system has been specified at 0.5 m. The programs will be used to continue refinement of these geodetic parameters as well as to study geophysical and astronomical topics such as earth tides, polar motion, and rotation of the earth.

A program for performing literal algebra on the computer was developed largely by Gaposchkin and Mr. J. R. Cherniack; its results provide a verification for parts of the orbital theory used in the above analysis. This programing system can be used to verify and extend all parts of the satellite theory.

Dr. P. A. Mohr is investigating local geological effects on station coordinates.

Geometric and Classical Geodesy

Dr. K. Lambeck, assisted by Mr. A. Girnius, has successfully determined, using the geometrical method, the coordinates of 40 stations. For scaling purposes, he employed optical direction data from the SAO Baker-Nunn, NASA, and several European stations as well as laser data from SAO and the French Centre National d'Etudes Spatiales (CNES). This geometric solution, presented at the American Geophysical Union meeting in Washington in April 1969, has been combined with Gaposchkin's dynamical determination; the results disclose improved geocentric positions for 48 stations. These results were presented at this year's Committee on Space Research (COSPAR) meeting in Prague.

Lambeck has also examined the relationships between various important geodetic datums, including those of North America, South America, and Europe, and studied the prospects for a geocentric reference system determined from satellites. The appropriate transformations have been solved.

Preliminary tests have been made to combine surface-gravity measurements with the geopotential derived by Gaposchkin from simultaneous observations. Other investigations have been conducted regarding the application of satellite-borne altimeters to geodesy, geophysics, and oceanography.

Laser and Interferometer Systems

Experimental data from the prototype laser ranging system at Mt. Hopkins have been analyzed and compared with theoretical calculations. The maximum range of the system is somewhat less than anticipated, although the precision of the range measurement appears to be consistent with expectations. Mr. C. G. Lehr and Dr. M. R. Pearlman collaborated with others to present four papers on the SAO laser ranging systems.

Dr. N. C. Mathus is examining atmospheric propagation effects on electromagnetic radiation in relation to corrections required for satellite-tracking data. The Environmental Science Services Administration (ESSA) ray-tracing program has been selected for a computer study of the effects of earth's atmosphere on radio waves received from radio stars and artificial earth satellites. Modifications and testing of this program continue.

International Cooperation

Mr. J. Rolff has continued to monitor international cooperation on satellite observations. With his assistance, the Russian tracking station in Mirny, Antarctica, has been included in the Geos 2 flash observation program coordinated by NASA. Rolff has attended meetings in Europe and has visited optical tracking stations in Zimmerwald, Switzerland; Nice, France; Oporto, Portugal; Ondrejov, Czechoslovakia; and Madrid and San Fernando, Spain. Through correspondence, contacts with many other agencies and tracking stations have been maintained. Rolff has provided liaison between SAO and the French Institute Géographique National (IGN) in the reduction of Pageos data.

ATMOSPHERIC INVESTIGATIONS

Dr. L. G. Jacchia, in collaboration with Mr. I. G. Campbell and Mr. J. Slowey, has continued to investigate the upper atmosphere through drag analysis of artificial satellites. Eight satellites have been regularly tracked by the Baker-Nunn cameras to provide data for these investigations. The different types of recognized atmospheric variations, i. e., solar-activity effect, geomagnetic effect, diurnal and semiannual variation, and helium migration, are the object of individual studies covering 11 years of recorded observations encompassing a complete cycle of sunspot activity.

This group has discovered the shape of the diurnal density-variation curve to be variable with height. To discover this, sunspot areas were used to separate the disk and spot components of the flux over a considerable interval. They found that the disk component is highly correlated with the mean flux in a linear manner.

Jacchia and his colleagues also devoted considerable effort to the construction of new semiempirical models of the upper atmosphere. From ground-based observations of solar and geomagnetic effects, these models are capable of representing with a maximum of accuracy the variations of atmospheric density above any geographic locality. COSPAR will use these models for its International Reference Atmosphere to be published in 1970 or 1971.

Using a three-dimensional model of the upper atmosphere, Dr. M. P. Friedman has continued his study of winds in the altitude range 120 to 800 km. A report on the results of this study is now being prepared.

He has also investigated the effect of solar-radiation pressure on satellite orbits. The theory that radiation reflected from the earth also exerts pressure on satellite orbits is now being developed. Eventually, this theory will be combined with that of direct solar radiation in a computer program to be used for satellite-orbit analysis.

DATA ACQUISITION

SATELLITE-TRACKING AND DATA-ACQUISITION DEPARTMENT

Special Observations

In March, the Baker-Nunn stations in Maui, Hawaii, and Mt. Hopkins, Arizona, successfully photographed the Saturn 4B rocket of the Apollo 9 spacecraft as it apparently released residual fuel several hours after it had been boosted into a solar trajectory (Plates 1 and 2). Part of the photography, of about three hours total duration, was simultaneous between the two stations.

In May, the Baker-Nunn network was assigned tasks for the Apollo 10 space mission. The station in Argentina recorded images 29 hours after translunar injection. Analysis is now proceeding to determine whether the images are of the spacecraft or of the Saturn 4B. During the mission, the network was also requested to photograph waste-water dumps from the spacecrafts's Environmental Control System. No successes were reported, and the films are being analyzed to determine the limiting magnitude of the photographs under the conditions prevailing at the time of the observations. This will provide an estimate of the upper limit of the brightness of the waste-water dump.

On March 18, the SAO stations in Arizona, Brazil, and Peru photographed a barium ion cloud release from the Heos 1 satellite as part of a program undertaken by NASA's Goddard Space Flight Center (GSFC) and the European Space Research Organization (ESRO) (Plate 3). The photographs will provide data for study of the earth's magnetic field, and SAO is currently analyzing the cloud in terms of density, size, and position as a function of time.

During March, April, and May, SAO participated in a cooperative observational effort with CNES. Simultaneous optical and laser observations of the six retroreflector-equipped laser satellites were conducted between the SAO station in Dionysos, Greece, and the CNES station in Haute Provence,

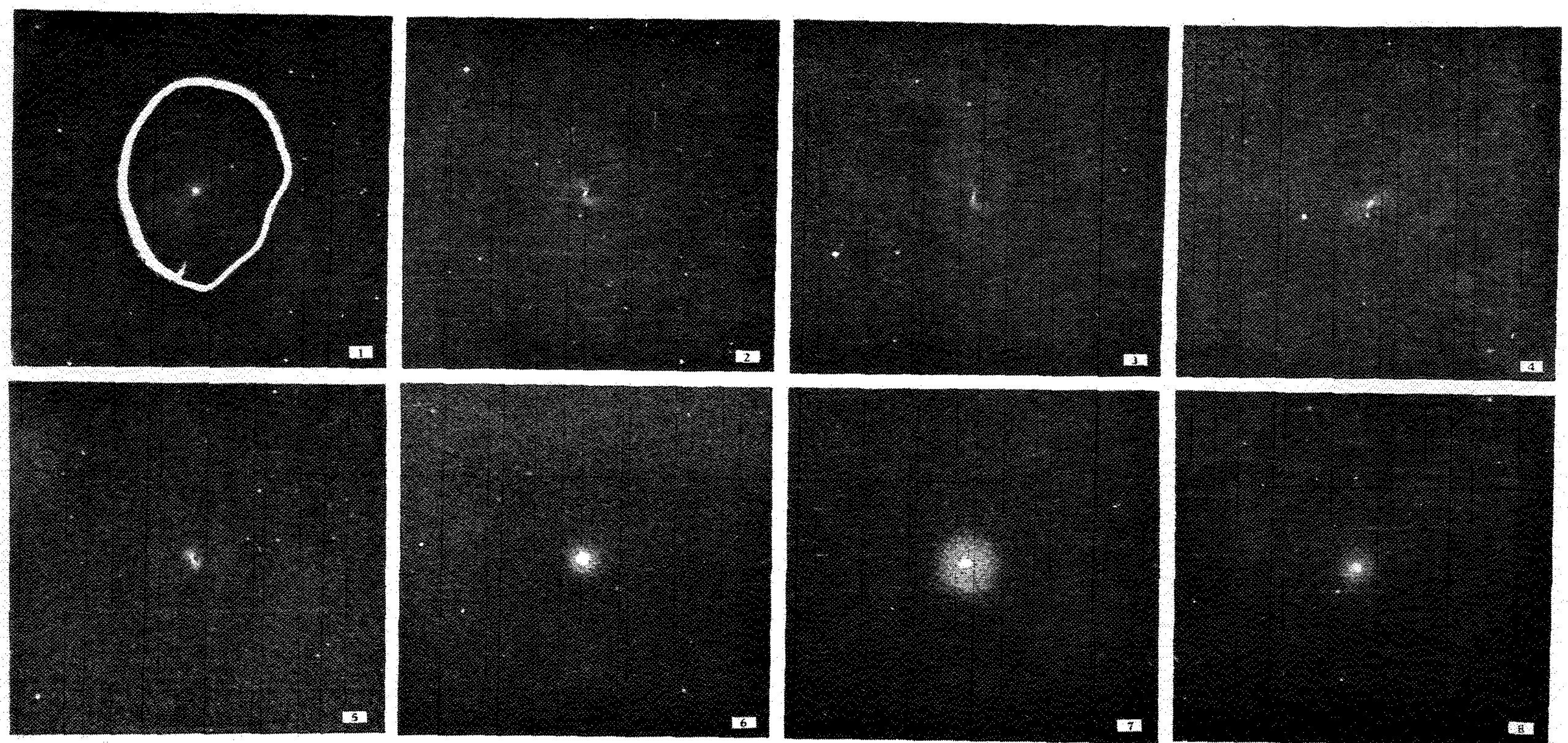

Plate 1. Dumping of residual fuel from Saturn 4B rocket during *Apollo 9* mission. Photographed by Baker-Nunn at Mt. Hopkins, Arizona, on March 3, 1969. The photographs were taken at:

1.	02h 59m 59.3s,	range: 70,000 km;	2.	03h 11m 37.2s,	range: 73,000 km;
3.	03h 36m 37.5s,	range: 78,000 km;	4.	03h 43m 24.3s,	range: 79,000 km;
5.	04h 05m 38.8s,	range: 83,000 km;	6.	04h 41m 38.5s,	range: 90,000 km;
7.	05h 01m 58.2s,	range: 94,000 km;	8.	05h 21m 31.1s,	range: 98,000 km.

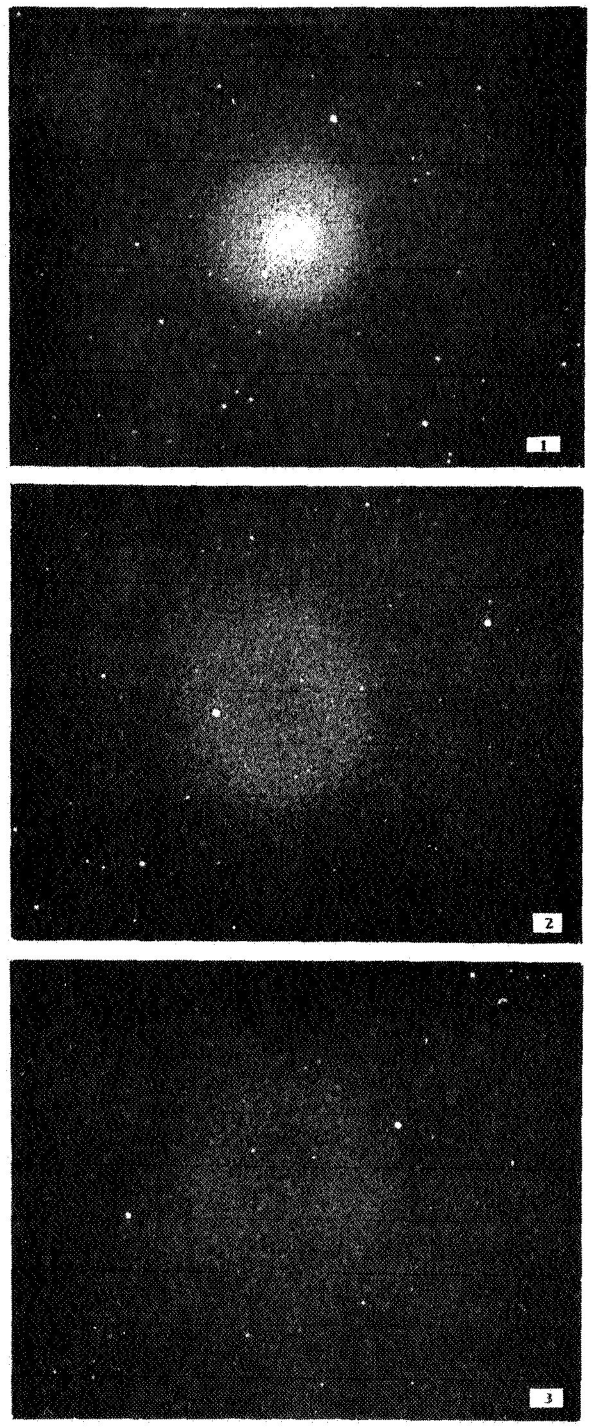

Plate 2. Dumping of residual fuel from Saturn 4B rocket during Apollo 9 mission. Photographed by Baker-Nunn in Hawaii on March 3, 1969. The photographs were taken at:

1. 05h 28m 45.5s, range: 96,000 km;
2. 05h 49m 31.2s, range: 100,000 km;
3. 05h 58m 39.9s, range: 102,000 km.

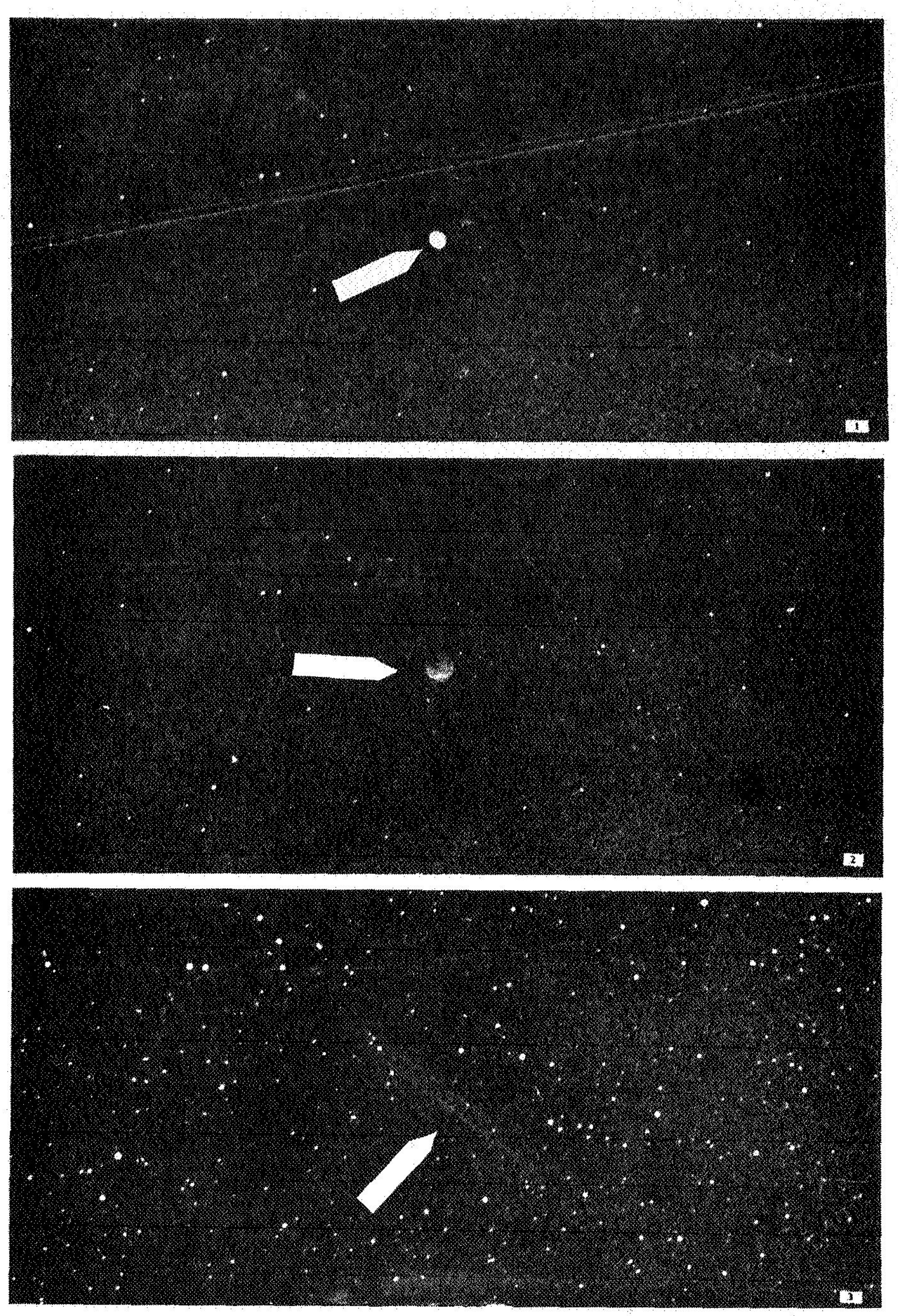

Plate 3. Barium ion cloud photographed by Baker-Nunn camera in Arizona on March 18, 1969. The cloud was released at a height of 75,000 km from the Heos 1 satellite. Prints 1 and 2 show the expanding cloud, and 3 shows how the ionized particles have aligned with the lines of force in the earth's magnetic field. The lines in print are blemishes. The release initiation time was 07h 20m 52s. The photographs were taken at:

1. 07h 21m 13.9s; 2. 07h 21m 42.0s; 3. 07h 31m 10.5s.

France. This program overlapped the saturation tracking program of Geos 1 by the entire Baker-Nunn/laser network, which extended from March 7 through April 18. Thus, the CNES observations will contribute data to SAO's dynamic geodesy studies. Efforts such as these are forerunners of major international cooperative ventures using lasers and Baker-Nunn cameras.

In addition to satellite range measurements, the SAO laser systems have been obtaining atmospheric profiling measurements. The results were presented by Pearlman and others of the SAO scientific staff at the Lidar Conference at Brookhaven Institute, Long Island, New York.

The high-power prototype laser system at Mt. Hopkins was frequently employed in special studies, such as analysis of telescope-photoreceiver operation and checks of prediction accuracy, to provide design ideas for the new generation of ruby lasers being built for SAO.

Oscilloscope photographs have been obtained of pulses resulting from internal photomultiplier-tube noise, sky-background light levels, and laser returns to evaluate the structure and accuracy of the laser return signals. This information provided data for several papers by Lehr, Pearlman, and associates of the scientific staff.

The cooperative simultaneous observation program on the Pageos satellite with African and European cameras in cooperation with SAO's stations ended on February 15, as scheduled. This program, which began December 1, was coordinated by IGN under the overall direction of the CNES.

In January, the stations in Maui, Hawaii, and Mt. Hopkins, Arizona, reported observations of Geos 2 in which 8 flashes occurred. By March, a sufficient number of reports had been received from the Baker-Nunn network to confirm that Geos is flashing 8 times during many scheduled sequences. The extra flash always occurs 4 sec earlier than the programed first flash and is usually 2 to 3 mag fainter than the normal flashes. This information was reported to Geos Operations Control Center.

SAO stations ceased photography of the UK-E satellite in February. For almost 2 years, the Baker-Nunn system had provided observations to determine the orientation of the satellite's spin axis; however, the rate of spin had become too slow to warrant further effort. Dr. R. Bent, for whom we had performed these observations under assignment from NASA/OTDA, visited SAO during January. He reported that the SAO Baker-Nunn observations have more than satisfied his requirements and helped to prove the feasibility of optically determining a satellite's orientation.

Astronomical Observations

In April, while responding to a request from the International Astronomical Union (IAU) to confirm a reported supernova, the Baker-Nunn stations in Australia, Spain, and South Africa discovered that variable star DW Geminorum was 1 mag brighter than usual.

In cooperation with the IAU, the Baker-Nunn stations observed flare stars YZ Canis Minoris in January and AD Leo in February. The observing periods, two weeks around the new moon, were scheduled to avoid interference with routine tracking.

Operational Statistics

Table 1 provides monthly statistics on Baker-Nunn observations for the first half of 1969 compared with the first half of 1968. Successful observations from individual stations for the same period are presented in Table 2. During this time, the three SAO ruby laser systems made over 1800 range measurements on six satellites equipped with retroreflectors.

Engineering Support

Precision Timing System and Associated Electronics. Average maximum possible timing uncertainty at Smithsonian Astrophysical Observing Stations as of June 30, 1969, was ± 93 μsec. Thirteen comparisons with portable clocks

TABLE 1

COMPARISON OF BAKER-NUNN OPERATIONAL RESULTS

January to June 1968 and 1969

		Number of Predictions	
Month		1968	1969
January		8097	9195
February		9190	7496
March		5641	8562
April		6243	9623
May		7091	9306
June		6423	8492
	Total	42685	52674

		Number of Successful Observations	
Month		1968	1969
January		3601	3128
February		3534	2763
March		3081	3448
April		3144	4265
May		4621	4458
June		3879	3286
	Total	21860	21348

TABLE 2

SUCCESSFUL BAKER-NUNN OBSERVATIONS BY INDIVIDUAL TRACKING STATIONS

January to June 1968 and 1969

Station	Number of Successful Observations	
	1968	1969
New Mexico (SC-1)[1]	919	—
South Africa (SC-2)	1802	1336
Spain (SC-4)	2656	2131
Mitaka, Japan (SC-5)[2]	700	—
India (SC-6)	2224	2318
Peru (SC-7)	995	731
Hawaii (SC-12)	1546	1961
Mt. Hopkins, Arizona (SC-21)[3]	—	2624
Australia (SC-23)	2613	2442
Dodaira, Japan (SC-25)[4]	201	1128
Ethiopia (SC-28)	1591	1595
Brazil (SC-29)	1400	1069
Argentina (SC-31)	2677	2671
Greece (SC-91)	2532	1907
Total	21860	21348

[1]Closed March 19, 1968.

[2]Closed May 6, 1969.

[3]Opened April 1, 1969.

[4]Opened May 15, 1969.

were made at field stations during this period, nine with SAO portable clocks. Three time comparisons with the National Bureau of Standards (NBS) and the U.S. Naval Observatory (USNO) were made. SAO's timing facility in Cambridge maintained time to ± 5 μsec of UTC (USNO).

A Loran-C receiver was on loan to SAO by Aerospace Research, Inc., for an initial experiment using Loran-C to increase timing accuracy and reliability for the new SAO laser ranging systems. Testing was concluded at Woomera, Australia; Dionysos, Greece; Maui, Hawaii; and Mt. Hopkins, Arizona. Preliminary results indicate that this method can be used to increase timing accuracy to the 10-μsec level at a majority of SAO field stations. A final report giving detailed results of the experiment is in preparation.

The Cambridge monitoring equipment is being used to investigate possible uncertainties in timing data resulting from use of different VLF stations and/or VLF receivers for time reference.

Normal maintenance of the EECo timing system and associated electronics was carried out at Cambridge and at all field stations. Major maintenance was required only at Mt. Hopkins, in May, as a results of a nearby lightning strike.

Camera Maintenance and Development. The twelfth and last system for transport of short-frame film was installed, in camera No. 6, Naini Tal, India, on December 31, 1968. The camera transmission was replaced on the South Africa camera. All other maintenance was routine.

Photographic testing was conducted to determine the improvement in the refigured backup plate installed in the Mt. Hopkins, Arizona, camera in November 1968. A significant improvement was noted over approximately 85% of the long-frame film size. Star-image diameters have been determined to be within 20 to 25 μ at best focus. A final report on these results is in preparation.

Final laboratory testing of instrumentation for an investigation of timing errors in the Baker-Nunn camera shutter mechanism has been postponed pending return of the camera transmission from the South Africa station.

Volume II of the Baker-Nunn Camera Manual was published in the early part of June.

Laser Development. The major goal of the Laser Field-Unit Acquisition Program has been to obtain three laser satellite-ranging systems based on experience with the existing prototype. The simple, rugged design will be capable of reliable operation on a routine basis at the remote sites of SAO's worldwide tracking system. The main components consist of a laser transmitter system (LTS), a static-pointing pedestal, a telescope photoreceiver, and a ranging and data-recording electronics system.

In operation, the laser transmitter head, which is a portion of the LTS, and the telescope photoreceiver are pointed by the static-pointing pedestal to the altitude and azimuth coordinates predicted in advance by computer from data obtained by photographic and laser observations. The LTS is then pulsed, under electronic or manual control, at the appropriate epoch, and a very short pulse of light in a narrow beam is projected from the laser transmitter head toward the satellite. The light is reflected back from the satellite and detected photoelectrically by the telescope photoreceiver. The intensity of the light returned from the satellite is vastly enhanced if the satellite carries cube corner reflectors. The range from the laser system to the satellite is then calculated from the elapsed time, with due corrections for atmospheric and other effects.

After negotiations, a fixed-price contract was awarded to Spacerays, Inc., for the following: (1) the fabrication, assembly, factory acceptance testing, installation, and field acceptance testing of the first LTS; and

(2) the fabrication, assembly, and factory acceptance testing of the second and third LTS. The preliminary and detail design reviews were held, and the fabrication and assembly of the first LTS have been successfully completed.

The LTS consists of a laser transmitter head and its associated cables and cooling hoses, a power supply and control electronics section, a cooling system, an alignment instrument, and a boresighting device. The LTS has an oscillator-amplifier configuration and uses ruby rods. The peak power, Q-switched, will be 500 Mw; the pulse width, Q-switched, will be 15 nsec or less; the energy output, Q-switched, will be 5 J; the pulse repetition rate will be 4 pulses per minute; and the beam divergence will be continuously adjustable from 0.5 mrad, or less, through 6.0 mrad.

A fixed-price contract was also awarded to Tinsley Laboratories, Inc., for the fabrication, assembly, and factory acceptance testing of three semiautomatic static-pointing pedestals. The preliminary design review was held, and authorization to purchase long lead time items was granted to the vendor.

The static-pointing pedestal is of an altitude-over-azimuth biaxial configuration. The overall accuracy of the pedestal will be within 0.°008 (great-circle error of 0.5 arcmin or less). The pedestal will be set by means of reversible continuous rotation drive systems utilizing integrally mounted digital stepping motors and compatible motor control units; these features will enable the pedestal to be run by local operation, open-loop semiautomated remote operation, and open-loop fully automated remote operation. The Gurley Unisec goniometers will be retained as reference standards and as emergency readouts for manual operation.

A third fixed-price supply contract was awarded to Tinsley Laboratories, Inc., for the fabrication, assembly, and factory acceptance testing of three telescope photoreceivers. The detail design review was held, and the fabrication and assembly were begun.

The telescope photoreceiver consists of a main optical system, a photomultiplier-tube optical system, an auxiliary-viewing optical system, and a mechanical structure to support all the optical components. It will have an overall light-gathering efficiency of 60% or greater when expressed as the total light contained within the spot at the photomultiplier-tube focal plane divided by the total light incident on the entrance aperture at 6943 Å and exclusive of any filters; this system has a clear aperture of at least 20 inches in diameter. A set of field stops will provide fields of 2, 4, 8, 12, 16, and 20 arcmin diameter.

The fourth major component of the laser ranging system, the ranging and data-recording electronics, is being built inhouse. The specification and major design of this package have been completed. The procurement and construction of the system components have almost been finished, and assembly, testing, and mating of the subsystems have begun.

The ranging and data-recording electronics system will provide semiautomatic control and operation of the LTS, automatically record the range and epoch data, and perform other miscellaneous functions associated with the laser field unit.

The control portion of the system will be operated from the precise time signals generated by the station clock; when enabled by the operator, it will provide signals to charge the energy storage capacitors in advance of the laser pulse, provide a signal to operate personnel warning devices, and, at the appropriate epoch, provide a trigger signal to pulse the laser. This sequence of events can be switch-selected to trigger the laser on the even minute, at +15 sec, +30 sec, and +45 sec in any combination.

The data-recording portion of the system will consist of two major components: a time-storage buffer to present visually and in digital format the epoch of the laser output pulse; and a range counter, operating from the station clock, to present the range time, with a resolution of 1 nsec, visually and in digital format. An interface unit will convert these electrical data from parallel to series form. They will then be recorded on punched paper tape in a format suitable for transmission over a standard teletype circuit.

The system's range gate will effectively activate the range counter only when a return is expected in order to reduce the probability of triggering phototube noise pulses. Other miscellaneous features of the data-recording system include provision of power for the phototube, monitoring of the phototube current, controls for operation of the semiautomatic pedestal, intercommunications between the laser operating crew and other station personnel, various safety interlocks, and a high-frequency oscilloscope for visual observation of system performance.

The manual Laser Safety Regulations for SAO Astrophysical Observing Stations was published in May.

Moonwatch

The SAO Moonwatch network has 175 stations, of which 145 observe routinely and 30 can be called upon in support of special events, such as the Apollo missions and reentering satellites. The network made 14,650 observations in the period January 1 to June 30, 1969. This number is higher than that for the same period last year and indicates the yearly total will exceed last year's record high. Almost half of these observations are equal in accuracy to Baker-Nunn field-reduced positions.

The Moonwatch network participated in Apollo 9 and 10 missions, providing both visual and photographic support. Special ephemerides were calculated and distributed to teams having possible visibility of the missions. Using these predictions, the Townsville, Australia, Moonwatch team successfully photographed the translunar injection burn of the Saturn 4B booster rocket of Apollo 10 (Plates 4 and 5). Moonwatch also received two reports of visual observation of the reentry of Apollo 10 from several airline pilots of the Moonwatch Volunteer Flight Officer Network (VFON).[1]

The Moonwatch network also provided observations of the NASA/GSFC and European Space Research Organization high-altitude barium ion experiment.

Predictions for 58 reentering satellites were calculated and sent to stations having visibility.

The low-perigee program remains an important part of Moonwatch. Satellites with low perigee are maintained on the Moonwatch observing list to fulfill investigative requirements of many U.S. and foreign scientists.

During this period, the Chief of Moonwatch visited teams in Arizona, California, Colorado, and Florida to discuss the addition of photography to the regular Moonwatch program and to consider the use of larger telescopes for Moonwatch support of the Apollo missions.

Moonwatch assumed the administrative support of the VFON project. A field office is maintained in Denver, Colorado, under the direction of Mr. H. Roth, who previously managed the project.

Other Activities

Members of the Observatory's technical staff, including the Satellite-Tracking and Data-Acquisition Department (STADAD), have continued to participate in the development of a VLBI system.[2] This radio-interferometer system will operate in conjunction with the Observatory's Satellite Laser Ranging Program to make coordinated baseline measurements. Eventually, measurements may be possible using satellites as both laser targets and interferometer sources.

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[1]Supported by Air Force contract FO 5603-69-C-0270.

[2]Supported under NASA contract no. NSR 09-015-079.

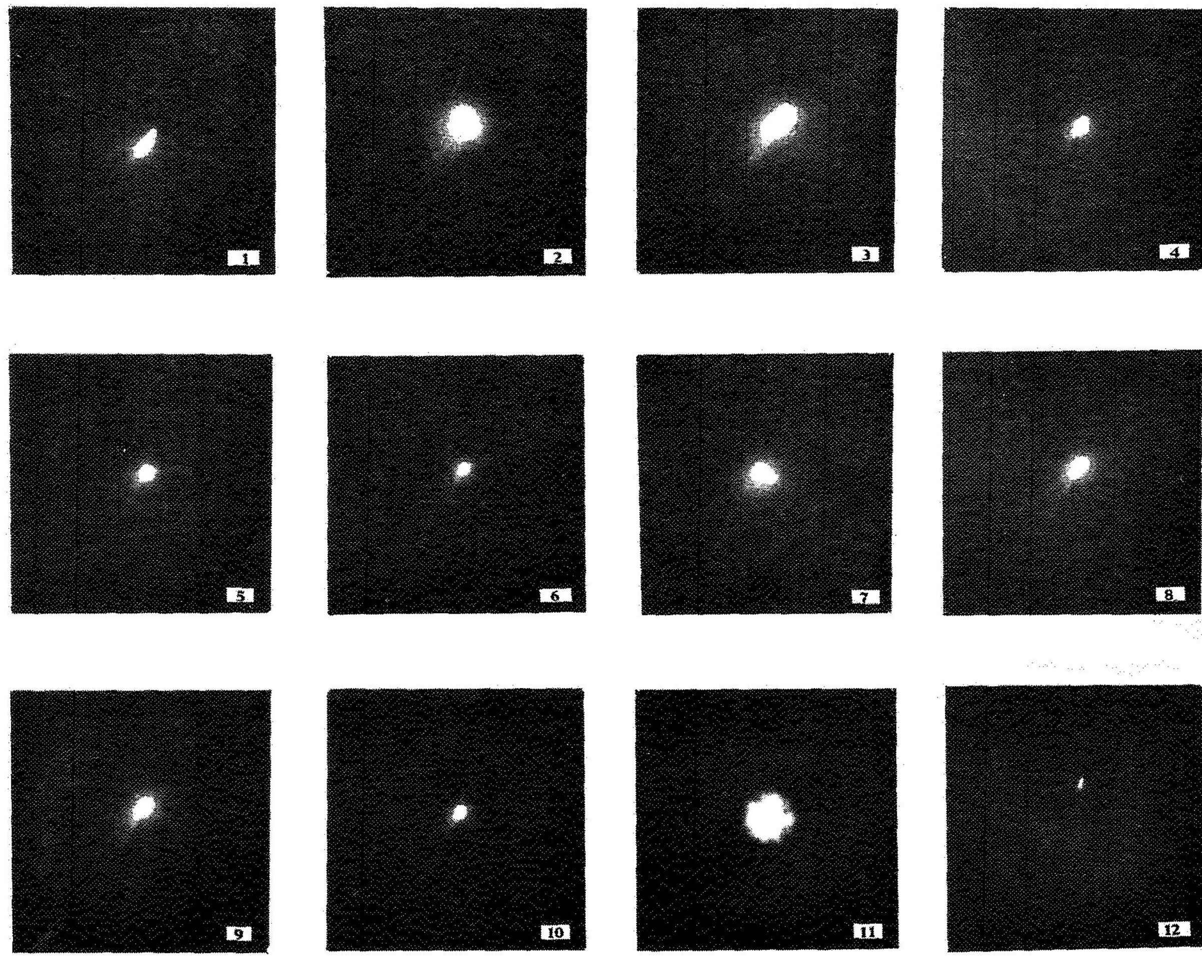

Plate 4. Translunar injection burn of Saturn 4B rocket of Apollo 10 mission photographed by the leader of the Townsville, Australia, Moonwatch team. Photographs were taken with a Nikon camera with a Nikkor 200-mm f/4 lens, Tri-X film, and one second exposures. The photographs were taken at:

1. 19h 26m 16s;	2. 19h 26m 36s;	3. 19h 26m 44s;	4. 19h 26m 52s;
5. 19h 26m 58s;	6. 19h 27m 12s;	7. 19h 27m 25s;	8. 19h 27m 31s;
9. 19h 27m 37s;	10. 19h 28m 05s;	11. 19h 28m 12s;	12. 19h 28m 19s.

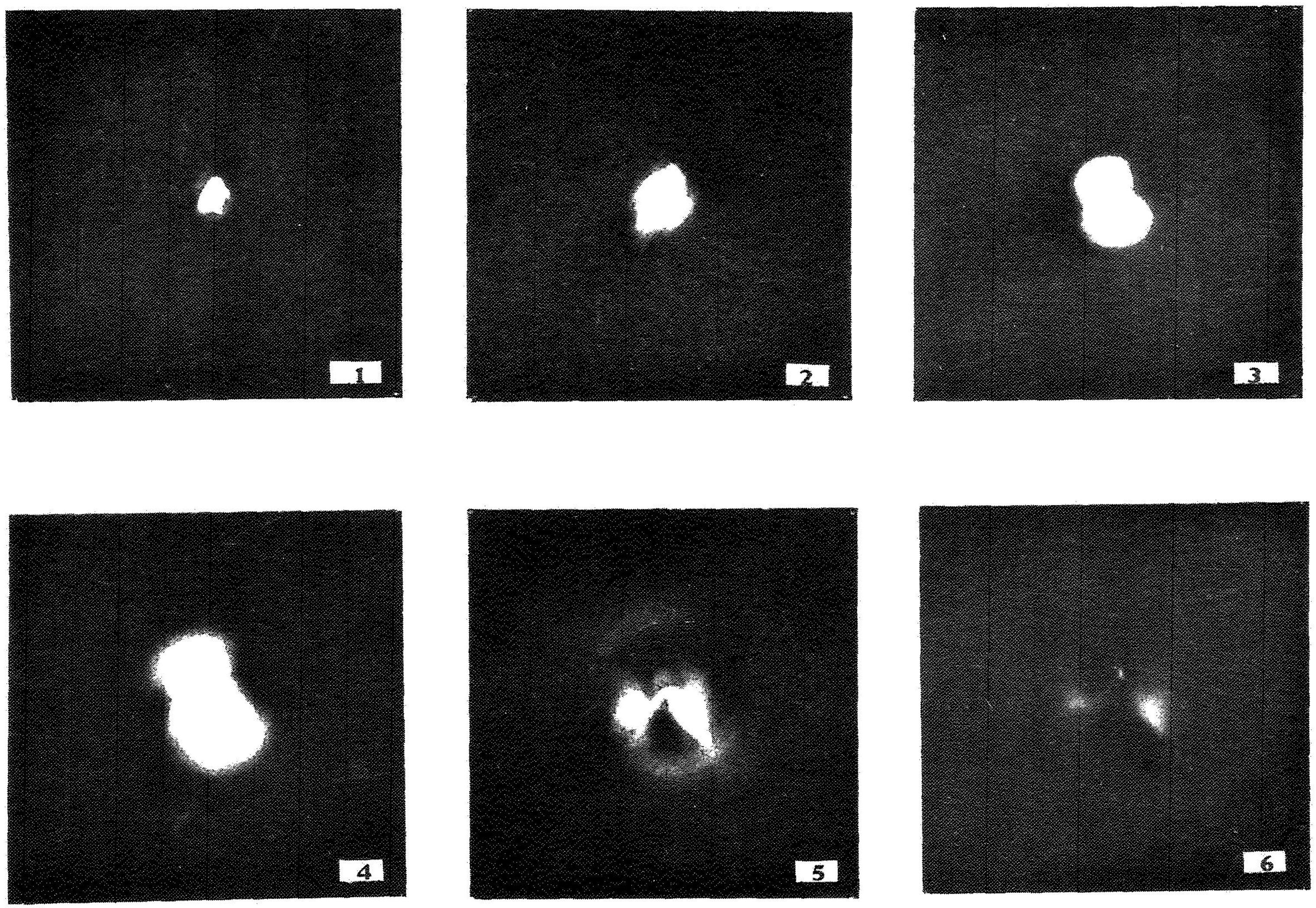

Plate 5. Translunar injection burn photographic sequence continued from previous plate. These prints were enlarged three times. The photographs were taken at:

1. 19h 28m 38s; 2. 19h 28m 43s; 3. 19h 28m 49s;
4. 19h 28m 54s; 5. 19h 29m 01s; 6. 19h 29m 07s.

Antenna and radiometer modifications have begun, and two instrumentation systems will be completed in August. Timing subsystems are being provided by STADAD.

Arrangements have been made for VLBI observing sessions in August, September, and late November of this year.

STADAD continues to provide on a noninterference (no out-of-pocket cost) basis, logistical and operational support for scientific and technical groups, including our cooperating agencies. Some of the groups supported during this report period include the following:

1. Peabody Museum of Archaeology and Ethnology, Harvard University — cultural and historical research on a nomadic group in Ethiopia. Telegraphic communications and shipping support provided.

2. Optical Physics Laboratory, Air Force Cambridge Research Laboratory (AFCRL) — observations for determination of tropical atmospheric dust concentration. Photographic support provided with equipment supplied by AFCRL.

3. Smithsonian Institution Center for Short-Lived Phenomena — collection and dissemination of information on short-lived events to the international scientific community. Telegraphic communications support provided.

4. Geophysical Observatory of Haile Selassie I University, Ethiopia — geophysical research. Mail and telegraphic communications support provided.

5. Paris Institut d'Astrophysique — airglow observations at various wavelengths at the magnetic equator. Site facilities provided at the Ethiopia station.

6. University of Hawaii, Institute of Astronomy — Baker-Nunn photographic support was completed on photography of comet orbits for a search for residual comet debris.

7. University of Hawaii Zodiacal Light Observatory — Baker-Nunn photographic support of lunar libration-point photography was completed.

COMMUNICATIONS

The Communications Department handled more than the usual number of messages during this recent reporting period. The increase was due to several factors. One was that both the Astrophysical Observing Stations and the Moonwatch teams were hoping to observe the decay of Echo 2. Because of its unpredictable orbit, revised predictions were continually being sent out and observations received for a span of many weeks until the balloon finally reentered the earth's atmosphere on June 7. The Apollo missions also contributed to the increase of traffic. A third factor was the ever increasing amount of data in the form of the North American Air Defense (NORAD) bulletins, NASA equatorial crossings and orbital elements received over the NASCOM circuit. This particular circuit requires practically constant attention by an operator since it is in almost continual use.

Once again, on the basis of an error-free performance of 99% or better from January through June 1969, the Department received an outstanding proficiency rating while operating on the NASCOM network.

The crypto operations on the Department of Defense Autodin system was without fault for this period. Recognition for this achievement was given to us by the U.S. Naval Communications Unit, Syracuse, New York. This is based on immediate responsiveness and completion of assigned duties within ten minutes or less.

With the installation of radio teletype equipment at the Brazil station, we expect that messages will be routed via Goddard and NASA's Eastern Test Range station in Antigua. This will result in a substantial saving by eliminating commercial cable costs to and from Brazil.

Five members of the department attended a special evening course on telecommunications at Boston State College from January through April. The purpose of the course was to show communicators how to provide economical and efficient services and to increase their understanding of modern-day complex circuitry. The New England Telecommunications Association sponsored and gave instructions in the course.

Owing to recent reductions in the budget for the Satellite Tracking Program, the Department is reducing the working force. Termination notices were given to three full-time teletype operators, and a fourth was transferred to part-time status. The expected elimination of part-time and WAE teletype operators will make it necessary for personnel to work evenings and weekends on permanent or rotating shifts.

DATA PROCESSING

DATA PROCESSING

Data Division

Weekly predictions on a total of 37 satellites (Table 3) were supplied to the Astrophysical Observing Stations and Moonwatch sites by Data Division. Selections for tracking were made at the direct request of NASA, by SAO's scientific staff in order to fulfill its research commitments under the Satellite-Tracking Program grant, and at the request of NORAD. Simultaneous predictions were generated for the Air Force Baker-Nunn sites and for the modified K-50 at Villa Dolores, Argentina, operated by our cooperating agency the Comision Nacional de Investigaciones Espaciales (CNIE).

Laser predictions were provided for three SAO stations: Mt. Hopkins, Arizona; Maui, Hawaii; and Dionysos, Greece. During a special period of cooperative high-density tracking of Geos 2 from March 7 through May 31, predictions were also provided for the Australian laser developed by the Weapons Research Establishment.

Orbital elements, predictions, field and precisely reduced observations, and long-range forecasts were provided on a request basis to the Tokyo Astronomical Observatory, the University of California, the University of Texas, the U.S. Coast and Geodetic Survey, the Department of Defense, Langley Research Center, Bell Telephone Laboratories, the University of London, Raytheon Corporation, GIMRADA, CNES in France, Aerospace Corporation, Weapons Research Laboratory in Australia, and the Uttar Pradesh State Observatory, India.

TABLE 3

SATELLITES TRACKED BY SAO

1 January to 30 June 1969

Tracked on Request from NASA

Satellite	Name
5900101	Vanguard 2
6000902	Echo 1 Rocket
6305301	Explorer 19
6400401	Echo 2
6508901	Geos 1
6605601	Pageos
6704201	UK-E
6707301	OGO 4
6800201	Geos 2
6806601	Explorer 39
6905101	OGO 6

Tracked for SAO Geodesy and Earth Physics Investigations

5900101	Vanguard 2
6000902	Echo 1 Rocket
6001301	Courier 1 B
6102801	Midas 4
6400401	Echo 2
6406401	BE-B
6503201	BE-C
6507801	
6508901	Geos 1
6600501	
6605601	Pageos
6701101	D1C
6701401	D1D
6800201	Geos 2
6805501	Explorer 38
6810601	Cosmos 256

Tracked for SAO Atmospheric Investigations

5800101	Explorer 1
5900101	Vanguard 2
6001401	Explorer 8
6305301	Explorer 19
6400401	Echo 2
6604401	Explorer 32
6806601	Explorer 39
6900901	ISIS-A

Launch Backup Provided

1969 6 A	OSO-F
1969 9 A	ISIS-A
1969 16 A	TOS-G
1969 18 A	Apollo 9
1969 18 B	S 4B
1969 37 A	Nimbus B-2
1969 37 B	EGRS 14-19
1969 43 A	Apollo 10
1969 43 B	S 4B
1969 51 A	OGO 6

Tracked on Request from the Air Force

1967 95 A	Molniya I-6
1967 95 D	Rocket Body

Pageos and Geos 2 continued to be used in a cooperative observing program with the Royal Radar Establishment at Malvern, England, and the European WEST network of stations.

Simultaneous observation of Explorer 38 (1968-55A) yielded a number of successful long ties between stations not possible before. Owing to the high altitude of this object, simultaneous observations between Australia and Japan have become feasible. These observations are extremely valuable since the Australia station is the only SAO site whose coordinates have not yet been determined geometrically.

Data Division maintained orbits on Satellite OAO 2 (1968-110A) and its rocket, the former carrying the Observatory's Celescope experiment.[1] A special program was run to safeguard the telescopes from glints when the rocket approached the OAO.

Solar-flux, planetary-index, polar-motion, and precise-timing data were received, tabulated, and distributed to interested persons in the scientific community.

Star Catalog

Inquiries on and sales of the Star Catalog tape continue to be handled routinely. Cape Catalog -64° to -90° was put into the FK4 system and merged for comparison with the SAO Star Catalog. The annual tape for photoreduction is being updated to 1969. 5.

Star Charts

The MIT Press has the final introduction for the Star Charts, which should be published in September 1969.

SAO ceased to provide Geos flash predictions to CNIE, since they temporarily suspended operations at the Villa Dolores site.

[1]Supported by NASA/GSFC under contract NAS 5-1535.

PHOTOREDUCTION DIVISION

A total of 8,332 precise reductions of satellite positions were completed, a 3.6% increase in production over the previous period. The Division has now completed 226,630 precise reductions.

The film Control Section received and cataloged 18,710 films from Smithsonian stations and 309 films from Air Force stations.

Photometric reductions were performed on photographs of Apollos 7, 8, and 9. These data were used for a paper presented at the XII Plenary Meeting of COSPAR, in Prague, in May 1969.

Beginnings have been made on a pilot photometry project using the microdensitometer in conjunction with the data-handling equipment of Project Celescope in support of Apollo missions and for analysis of future barium-cloud photography.

Table 4 gives a breakdown of the job orders completed by the Division during the reporting period.

TABLE 4.

JOB ORDERS COMPLETED BY PHOTOREDUCTION

1 January to 30 June 1969

Object	Period	Program	Images
63 053 01 Exp 19	July 1967	Atmospheric Studies	217
64 076 01 Exp 24	July 1967	Atmospheric Studies	231
63 053 01 Exp 19	Aug. 1967	Atmospheric Studies	434
68 002 01 Geos 2	Feb. -May 1968 (SIMOBS)	Geometric Geodesy	84
64 076 01 Exp 24	Aug. 1967	Atmospheric Studies	51
63 053 01 Exp 19	Sept. 1967	Atmospheric Studies	107
64 076 01 Exp 24	Sept. 1967	Atmospheric Studies	19
63 053 01 Exp 19	Oct. 1967	Atmospheric Studies	189
64 076 01 Exp 24	Oct. 1967	Atmospheric Studies	234
63 053 01 Exp 19	Nov. 1967	Atmospheric Studies	174
68 118 01 Apollo 8	Dec. 1968	Apollo	
68 118 02 Apollo 8	Dec. 1968	Apollo	
68 118 03 Apollo 8	Dec. 1968	Apollo	
68 118 04 Apollo 8	Dec. 1968	Apollo	88
64 076 01 Exp 24	Nov. 1967	Atmospheric Studies	63
63 053 01 Exp 19	Dec. 1967	Atmospheric Studies	146
64 076 01 Exp 24	Dec. 1967	Atmospheric Studies	82
63 053 01 Exp 19	Jan. 1968	Atmospheric Studies	99
64 076 01 Exp 24	Jan. 1968	Atmospheric Studies	171
63 053 01 Exp 19	Feb. 1968	Atmospheric Studies	163
68 076 01 Exp 24	Feb. 1968	Atmospheric Studies	30
68 002 01 Geos 2	10 June-24 July 1968	Geopotential and Geophysical Studies	1943
Misc. SIMOBS	Jan. 1967 - Aug.1968	Geometric Geodesy	380
66 056 01 Pageos 1	4 Sept. 1968	Geometric Geodesy	18
68 002 01 Geos 2	April-May 1968 (SIMOBS)	Geometric Geodesy	21
67 073 01 OGO 4	July 1967-Jan 1968	OGO	87

PROGRAMMING DIVISION

The Programming Division is responsible for the development of computer programs for all phases of the Satellite-Tracking Program, for the operation of existing computer programs, and for development work in applied mathematics required to achieve these objectives. The computer programs now use (almost exclusively) a Control Data 6400 system funded under this grant and located at 185 Alewife Brook Parkway. During the reporting period the following has been accomplished:

SCROGE. SAO's principal prediction program has been extended to handle the hyperbolic and parabolic orbits of the Apollo flights. GETCE, which converts a geocentric radius vector and a velocity vector to the orbital elements of an earth satellite, has also been incorporated into this program. Other new features include the ability to suppress combinations of a satellite with three stations, of satellites and two stations with polygon restrictions, etc.

GRIPE. This program is used for the investigation of a wide variety of parameters influencing the motions of satellites. The Library of the GRIPE preprocessing program to the GRIPE master has been organized. An ANNAL program can now be used to process ANNA doppler data. Included among other revisions of GRIPE has been the incorporation of multiple-reel file routines.

DOI. The first draft of the comprehensive DOI 6400 program writeup has been completed. The program continues to be modified and updated.

EPHEMERIS. Several new versions of EPHEMERIS have been added to the system. Also, five versions of the updatable EPHEMERIS for nonelliptical orbits have been developed.

COMETS. A program has been written to determine a comet's position from head and tail measurements.

SAOCATG. Work has continued on the SAO Star Catalog and the Cape Annal Catalogue and these projects are near completion.

EDITORIAL AND PUBLICATIONS

EDITORIAL AND PUBLICATIONS

Listed below are papers and Special Reports of this period that relate to results from the Satellite-Tracking Program.

Papers

Benima, B., Cherniack, J. R., Marsden, B. G., and Porter, J. G., "The Gauss Method for Solving Kepler's Equation in Nearly Parabolic Orbits." _Publ. Astron. Soc. Pacific_, vol. 81, pp. 121-129, 1969.

Brownlee, D. E., Hodge, P. W., and Wright, F. W., "Upper limits to the Micron and Submicron Particle Flux at Satellite Altitudes." _Journ. Geophys. Res._, vol. 74, pp. 876-883, 1969.

Cherniack, J. R., and Gaposchkin, E. M., "Computer Derivation of Short-Lived Lunar Perturbations." Presented at the XII Plenary Meeting of COSPAR, Prague, May, 1969.

Gaposchkin, E. M., "Improved Values for the Tesseral Harmonics of the Geopotential and Station Coordinates." Presented at the XII Plenary Meeting of COSPAR, Prague, May, 1969.

__________, and Sehnal, L., "Air Drag and Solar Radiation Pressure Effects on Close Earth Satellites." Presented at the XII Plenary Meeting of COSPAR, Prague, May, 1969.

__________, and Wright, J. P., "Measurable Effect of General Relativity in Satellite Orbits." _Nature_, vol. 221, p. 650, 1969.

Jacchia, L. G. "Recent Advances in Upper Atmosphere Structure." Presented at the XII Plenary Meeting of COSPAR, Prague, May, 1969.

__________, Slowey, J W., and Campbell, I. G., "A Study of the Semi-Annual Density Variation in the Upper Atmosphere from 1958 to 1966, Based on Satellite Drag Analysis." _Planet. Space Sci._, vol. 17, pp. 49-60, 1969.

Lambeck, K., "Comparisons and Combinations of Geodetic Parameters Estimated from Dynamic and Geometric Satellite Solutions and from Mariner Flights." Presented at the XII Plenary Meeting of COSPAR, Prague, May, 1969.

__________, "A Spatial Triangulation Solution for a Global Network and the Position of the North American Datum within It." Presented at the Annual Meeting of the AGU, Washington, D. C., April, 1969.

Lehr, C. G., "Geodetic and Geophysical Applications of Laser Satellite Ranging." Presented at the IEEE Symposium on Geoscience Electronics, Washington, D. C., 1969.

__________, and Pearlman, M. R., "Laser Ranging to Satellites." Presented at the XII Plenary Meeting of COSPAR, Prague, May, 1969.

__________, Pearlman, M. R., Salisbury, M. H., and Butler, T. F., Jr., "The Laser System at the Mount Hopkins Observatory." Presented at the International Symposium on Electromagnetic Distance Measurement and Atmospheric Refraction, Boulder, Colorado, June, 1969.

__________, Pearlman, M. R., Scott, J. L., and Wohn, J., "Laser Satellite Ranging." Symposium on Laser Applications in the Geosciences, Douglas Advanced Research Laboratories, Huntington Beach, California, June, 1969.

Lundquist, C. A., "Photometry from Apollo Tracking." Presented at the XII Plenary Meeting of COSPAR, Prague, May, 1969.

Marsden, B. G., "Comets and Nongravitational Forces. II." Astron. Journ., vol. 74, pp. 720-734, 1969.

Pearlman, M. R. and Grossi, M. D., "The Long Base Radio Interferometer and Methods for Refractive Corrections." Presented at the International Symposium on Electronic Distance Measurement and Atmospheric Refraction, Boulder, Colorado, June, 1969.

__________, and Salisbury, M. H., "The SAO Facilities." Presented at the 2nd Conference on Lidar Probing of the Atmosphere, Brookhaven, New York, April, 1969.

Special Reports

No. 294 Possible Geopotential Improvement from Satellite Altimetry, by C. A. Lundquist and G. E. O. Giacaglia; Numerical Definition of Localized Functions on a Sphere, by K. Hebb and S. G. Mair.

No. 295 Revised Values for Coefficients of Zonal Spherical Harmonics in the Geopotential, by Y. Kozai.

No. 298 Apollo 7 Retrofire and Reentry of Service Propulsion Module, by M. Grandfield, D. Hanlon, K. Hebb, E. Jentsch, and R. Yorke.

No. 299 Influence of a Cometary Belt on the Motions of Uranus and Neptune, by S. E. Hamid.