SAO ISAGEX EXPERIENCE. I. DATA ACQUISITION

Edited by E. M. Gaposchkin

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Smithsonian Institution
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ABSTRACT

The International Satellite Geodesy Experiment (ISAGEX) has completed the data acquisition phase. This report describes the contributions and methods of the Smithsonian Astrophysical Observatory to the program. The report will provide users of the data with necessary supporting information. A sequel will be prepared when the analysis of the ISAGEX is completed.

INTRODUCTION

E. M. Gaposchkin

The ISAGEX program is the third in a series of cooperative satellite-tracking campaigns. The first in 1967 and the second in 1968, organized by SAO, were primarily camera tracking programs. There were, respectively, four and five laser tracking instruments operating during those intervals. Where possible, the tracking schedules were established to accommodate these systems. In 1967, there were five satellites and in 1968, there were six satellites suitably equipped with corner reflectors. However, three of them were in almost identical orbital configurations, so for some purposes the number was, in reality, three and four.

ISAGEX was initiated in 1969 by the French CNES with its "Proposition for an International Laser and Photographic Observation Campaign on Satellites Equipped with Laser Reflectors." ISAGEX took on added importance with the increased number of laser systems (10) and of precision satellite-tracking cameras (30) and the launch of a seventh retroreflector satellite (Peole), by France.

There are many purposes of a tracking campaign, and the archives of data will be useful for applications not envisaged at the inception of the program. The cooperating groups proposed the following three broad objectives, which gave shape to the program:

A. To organize a well-coordinated tracking campaign of the seven satellites equipped with laser retroreflectors in such a way that its contribution to our knowledge of the gravity field of the earth and other geodetic parameters will be significant.

B. To collect the set of observations made by the different participating agencies and to make those data available to the scientific community with all information necessary for use in computations.

C. To further research and development of instrumentation and operations of high-precision tracking systems for future space experiments.

ISAGEX is primarily a program of coordinated observations and data exchange. The data are to be distributed to all participants as per the operations plan, and subsequent analysis is largely at the option of the individual agencies. The analysis objectives of the participants and others are given in the International Satellite Geodesy Experiment Plan, published by CNES on November 10, 1970.

The planning and execution of the program has been documented in several CNES reports. The program ran from January through August 1971 and, broadly speaking, all the objectives were met. The data reduction has been completed for the laser data, which have been forwarded to the CNES data bank. The reduction of photographic observations is now under way. Therefore, the first objective and part of the second have been achieved.

The purpose of this report is to describe SAO's experience and methods. Included are the information necessary to use the laser data and descriptions of the observing system, the calibration methods, the reduction methods, and the process of data validation. In addition, there is a discussion of the various aspects of data acquisition. We hope that with such a document, improvement of the data systems will be furthered. We have concentrated on the technological and operations aspects of ISAGEX and on laser tracking in general. Within the next year, a sequel will be prepared, on the scientific results to come from the ISAGEX data. Some results already in hand are reported here and elsewhere (Gaposchkin, Kozai, Veis, and Weiffenbach, 1971).

There were substantial objectives for camera observations during the campaign. Since the SAO Baker-Nunn data have already been discussed in considerable detail, this report is restricted to the SAO laser systems.

In addition to the above objectives, ISAGEX was a test bed. We have seen how successfully a multinational observing program can be carried out. This success, in the absence of any more than informal agreements, is due to the good faith and mutual interest of all parties concerned. This sort of cooperation is enormously important for the future. With scientific objectives becoming ever more ambitious, the requirements for tracking data become more demanding. It is apparent that several groups pooling resources can achieve much more than can individuals alone. The future programs of all groups will be materially advanced by such cooperation, and it can even be argued that some programs are not feasible without it.

SAO agreed to participate with laser units that were in the process of construction. The fielding of these units and their subsequent operation taxed the resourcefulness of the whole organization. Indeed, it had to be considered an experiment to see whether such a program of fabrication, field installation, and immediate data acquisition in amounts and with a necessary precision could even be accomplished. The statistics attest to the increased volume of data as the program progressed.

ISAGEX was used as a period for improvement of the accuracy and reliability of the laser network under routine field operation. We faced the difficulties of repairing malfunctions and detecting operating problems while the observing program was continuing. This was a completely different situation from operating one or two systems, under essentially laboratory conditions, with all SAO technical personnel available at a domestic site. We had a mixed record as a result. Some problems slipped through the system until the validation process. Needless to say, the system has since been modified. In addition, studies were begun to improve the system's accuracy. Photographing the oscilloscope waveform for centroid detection was attempted on a routine basis. Analysis of these data is in progress, and preliminary results are reported here. This experiment will lead to improved signal detection and analysis in future operation.

ISAGEX was intended to provide a framework for individual agencies developing laser tracking to take data in an organized program. They could have routine predictions and an immediate evaluation of their data. This situation is very helpful for new systems. In the final accounting, only a few such new systems participated. However, they did have the benefits described, although on the whole, the data taken were too few to be geodetically significant. These systems have been in operation, and we hope they will be able to participate in a more substantial way during future programs such as EPSOC, currently being conducted by SAO.

The ISAGEX program has ushered in a new era of cooperative tracking programs. We have every indication that the laser data taken are of 1-m accuracy with 60-cm noise. We have good confirmation of the 10-m accuracy of our current geodetic tools, as well as the very real opportunity to obtain 1-m geodesy using these and other data.

Everyone at SAO and many individuals at CNES, NASA, and other organizations contributed in a substantial way. It is impossible to acknowledge them all. The contributors of this report join me in expressing our gratitude to these people. The program has achieved what it has only through such cooperation.

REFERENCE

GAPOSCHKIN, E. M., KOZAI, Y., VEIS, G., and WEIFFENBACH, G.
1971. Geodetic studies at the Smithsonian Astrophysical Observatory. Presented at the XVth IUGG General Assembly, Moscow, August.

SAO NETWORK DESCRIPTION

J. M. Thorp and M. A. Bush

Fifteen years ago, SAO conceived the idea of a worldwide network of photographic observing stations to track the artificial satellites proposed for the International Geophysical Year (IGY). Since the United States planned to launch its IGY satellites from Cape Kennedy into orbits with low inclinations, the original locations of the astrophysical observing stations were selected to obtain the best practical coverage of such orbits. Later, the low-latitude network configuration was modified to recognize the existence and importance of high-inclination satellites, which allow analysis of atmospheric and geodetic conditions at high latitude.

The ISAGEX network configuration is depicted in Figure 1, showing the locations of 11 astrophysical observing stations and the station in Dakar, Senegal, which was operated in cooperation with CNES. Each site is equipped with a Baker-Nunn tracking camera and a highly precise timing system. In addition, five stations have been augmented with laser ranging systems. Table 1 lists the COSPAR number and the location of the sites used in the ISAGEX program.

Figure 2 shows the Baker-Nunn camera at San Fernando, Spain, and Figure 3, the new SAO laser ranging system at Natal, Brazil.

The Baker-Nunn camera is a modified Super-Schmidt f/1, of 500-mm focal length (20 inches) and 500-mm aperture. A pyrex spherical mirror 760 mm (30 inches) in diameter and three corrector elements, two positive and one negative, constitute the optics, designed by J. G. Baker. The focal surface is approximately spherical, and the film is stretched under tension on a specially designed pyrex spherical surface. The field is 30° along the tracking axis and 5° along the perpendicular one. When the satellite position is fairly well known, the field along the tracking axis can be reduced to 15°, resulting in a considerable savings in film usage.

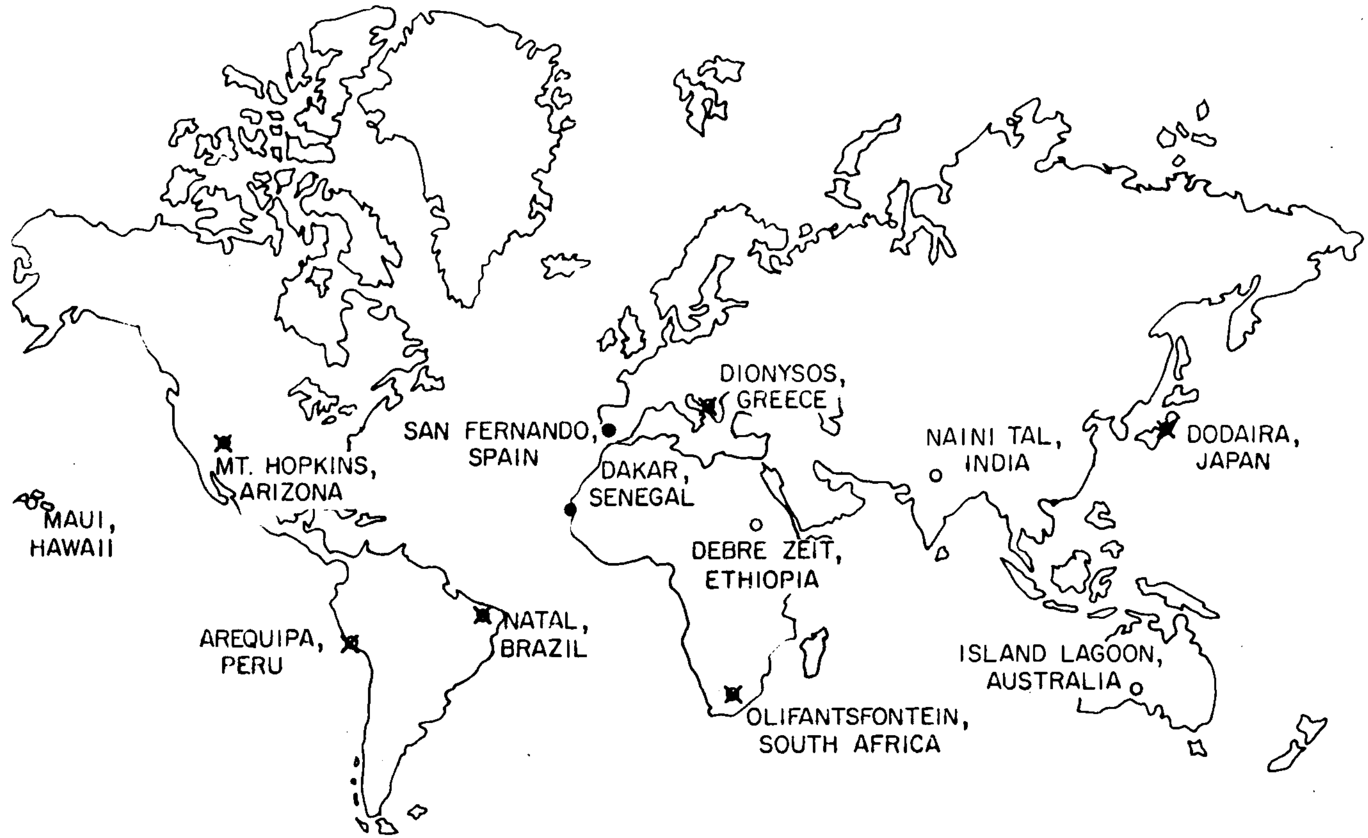

Figure 1. Configuration of the Baker-Nunn ISAGEX network.

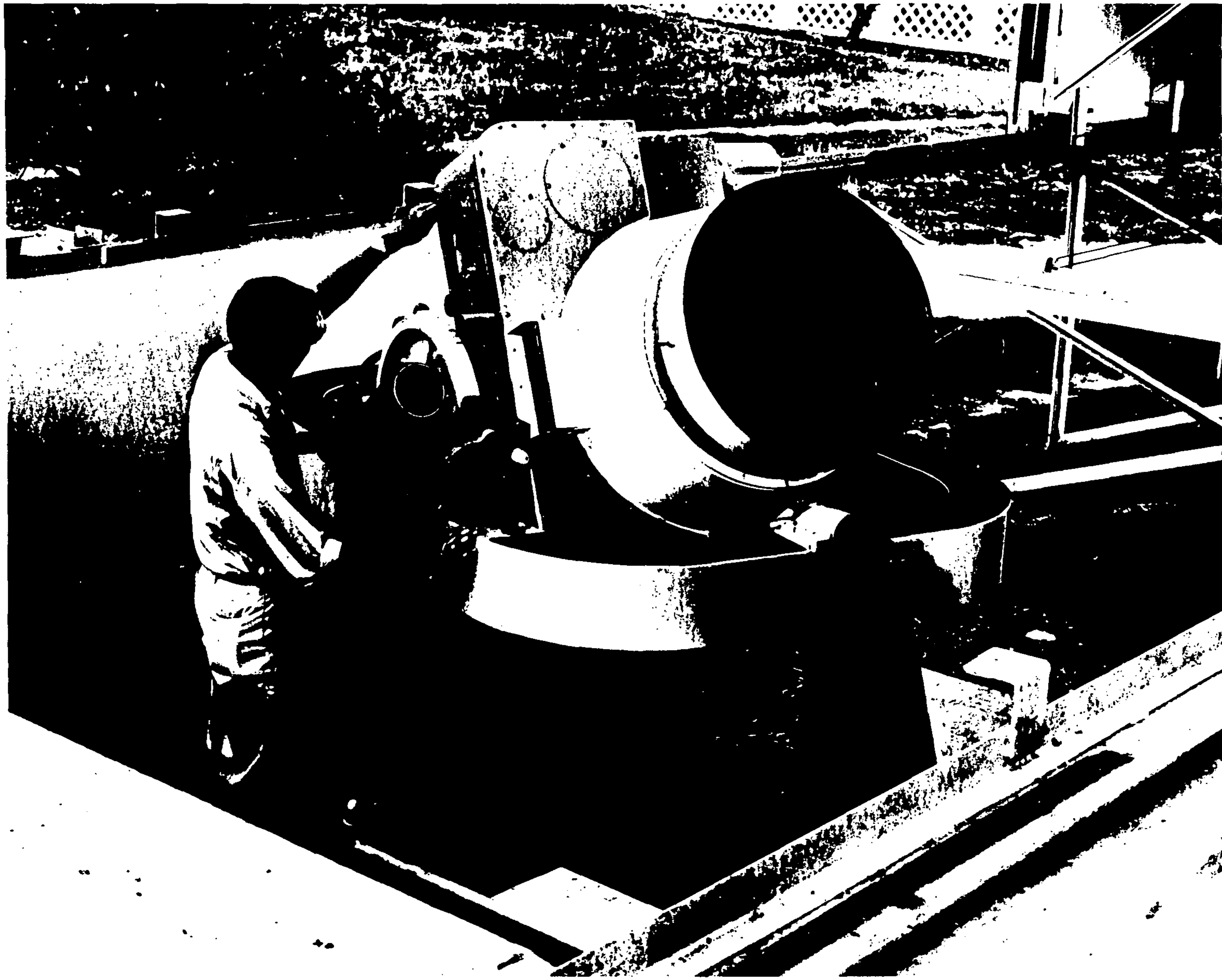

Figure 2. The Baker-Nunn camera at San Fernando, Spain.

Figure 3. The new SAO laser ranging system at Natal, Brazil.

Table 1. Sites used in the ISAGEX program.

Station		
Location	COSPAR number	Equipment
San Fernando, Spain	9004	Baker-Nunn
Naini Tal, India	9006	Baker-Nunn
Maui, Hawaii	9012	Baker-Nunn
Mt. Hopkins, Arizona	9021	Baker-Nunn
Mt. Hopkins, Arizona	7921	Laser
Olifantsfontein, South Africa	9022	Baker-Nunn
Olifantsfontein, South Africa	7902	Laser
Island Lagoon, Australia	9023	Baker-Nunn
Dodaira, Japan	9025	Baker-Nunn
Arequipa, Peru	9027	Baker-Nunn
Arequipa, Peru	7907	Laser
Debre Zeit, Ethiopia	9028	Baker-Nunn
Dionysos, Greece	9030	Baker-Nunn
Dionysos, Greece	7930	Laser
Natal, Brazil	9039	Baker-Nunn
Natal, Brazil	7929	Laser
Dakar, Senegal	9020	Baker-Nunn
Dakar, Senegal	7820	Laser

The standard film is Kodak Royal-X pan-recording 2475 (extended red) emulsion on a 4-mm estar base. The scale on the film is 2.46 μ $arcsec^{-1}$, and 80% of the light is placed on a 20-μ-diameter disk. The camera can photograph stars of 14th mag with a 20-sec exposure. A barrell-type shutter, rotating in front of the focal surface at a precise angular velocity, chops the trails of the stars (or of the satellites, if the camera is stationary) and provides the breaks that are used as references for the reduction of the film. The shutter (or chopper) rotates five times, making five breaks per exposure. When the shutter is in the middle of the central break, an electrical contact strobes a flashing tube that records the time from a slave clock in the camera. Time is thus recorded on the same film on which the satellite and stars appear. With the use of a phase shifter, the shutter can be synchronized to time signals so as to produce the middle of the central break at a predetermined time. This method can be used to perform simultaneous observations from several stations whose shutters are in full synchronization.

The Baker-Nunn can be operated in two basic modes, stationary and tracking. In the first, more simple mode, the camera is held stationary while the images of the satellite trail along the film. In the tracking mode, the body of the camera is driven at the same rate as the apparent angular velocity of the satellite, holding the image of the satellite to a point of light on the film.

The precision timing system is composed of an EECo clock that utilizes a 5-MHz Sulzer crystal oscillator as its frequency standard, a high-frequency receiver to monitor the WWV signal, and a VLF receiver. The VLF receiver monitors the very accurate frequency tones transmitted by various VLF stations around the world. The frequency of the crystal oscillator is continuously compared with these frequency tones, and the difference is displayed on both a chart recorder and an accumulated time-deviation counter. The oscillator can therefore be adjusted periodically by means of a tuning capacitor. As a further aid to more accurate timekeeping, a portable clock is carried from station to station to measure the relative settings of the clocks. Timing to within 100 μsec is routinely achieved at all camera stations. At the laser sites, timing is maintained to within 50 μsec, an accuracy necessary for laser ranging.

Since 1966, SAO has been improving the accuracy of its tracking technique by installing laser tracking systems at several of its camera locations. The Baker-Nunn provides very accurate directional data, and the laser provides the added dimension of range or the accurate determination of a satellite's height above the earth. The increased accuracy of the Smithsonian tracking program as a result of the addition of lasers has innumerable research benefits.

SAO currently operates five laser tracking systems collocated with Baker-Nunn cameras at tracking stations in Mt. Hopkins, Arizona; Natal, Brazil; Arequipa, Peru; Olifantsfontein, South Africa; and Athens, Greece. With the exception of the last, which was assembled and operated in cooperation with the NTU of Athens, all systems were designed and built to SAO specifications and represent near state-of-the-art ruby-laser technology.

The following characteristics apply to the four systems operated by SAO: The type is ruby Q-switched; the peak power is 400 Mw; the pulse width is 18 nsec; the energy output is 7 J; the maximum pulse repetition rate is 4 pulses $\min^{-1}$; the beam divergence can be varied from 0.5 to 6 mrad (or from 2 to 20 arcmin); the pointing is automatic-static, which permits day and night ranging and does not require that the satellite be sunlit; and the range resolution of the counter is 1 nsec. The laser transmitter utilizes two ruby rods, one for the oscillator and one from the amplifier stage. The rods are stimulated by the discharge of xenon high-voltage lamps. At lasing, some of the output energy is sampled by a photodetector that triggers the range measuring counter. The pulse, after traveling in space from the transmitter to the satellite, is reflected back from the retroreflectors mounted on the spacecraft and is focused by a 20-inch Cassegrain telescope onto a photomultiplier tube. The signal generated by the photomultiplier stops the counter, which then displays the elapsed time.

One of the problems encountered in laser ranging is the variation in signal strength of the pulse reflected from the satellite. This variation is due in part to the fact that the signal varies inversely as the fourth power of the satellite range and in part to an observed "scintillation," or random effect. The variations in signal strength affect the range measurements. As we said, satellite range is obtained from a time-interval counter that is started by the transmitted pulse and stopped by the receiving pulse. The resolution of the counter is 1 nsec, but the duration of the pulse is 18 nsec. Hence, the counter reading changes significantly if it stops at different points on the pulse's leading edge. The counter stops when it reaches a threshold that has been set near the half-amplitude point of a weak return pulse. Since the system is calibrated for such a pulse and setting, errors are introduced when the return pulse varies from its average value. These errors, however, can be corrected if a photograph of each return pulse displayed on an oscilloscope is obtained. An automatic recording system capable of doing this for every pulse has been devised and is currently being field-tested. This correction can reduce the error in range measurements to 1 ft or less.

DESCRIPTION OF THE SAO LASER SYSTEM CURRENTLY DEPLOYED IN BRAZIL, PERU, AND SOUTH AFRICA

P. W. Sozanski

The main components of SAO's laser system are the laser transmitter, the static-pointing pedestal, the telescope photoreceiver, the data system, and the epoch timing system (see Figure 1).

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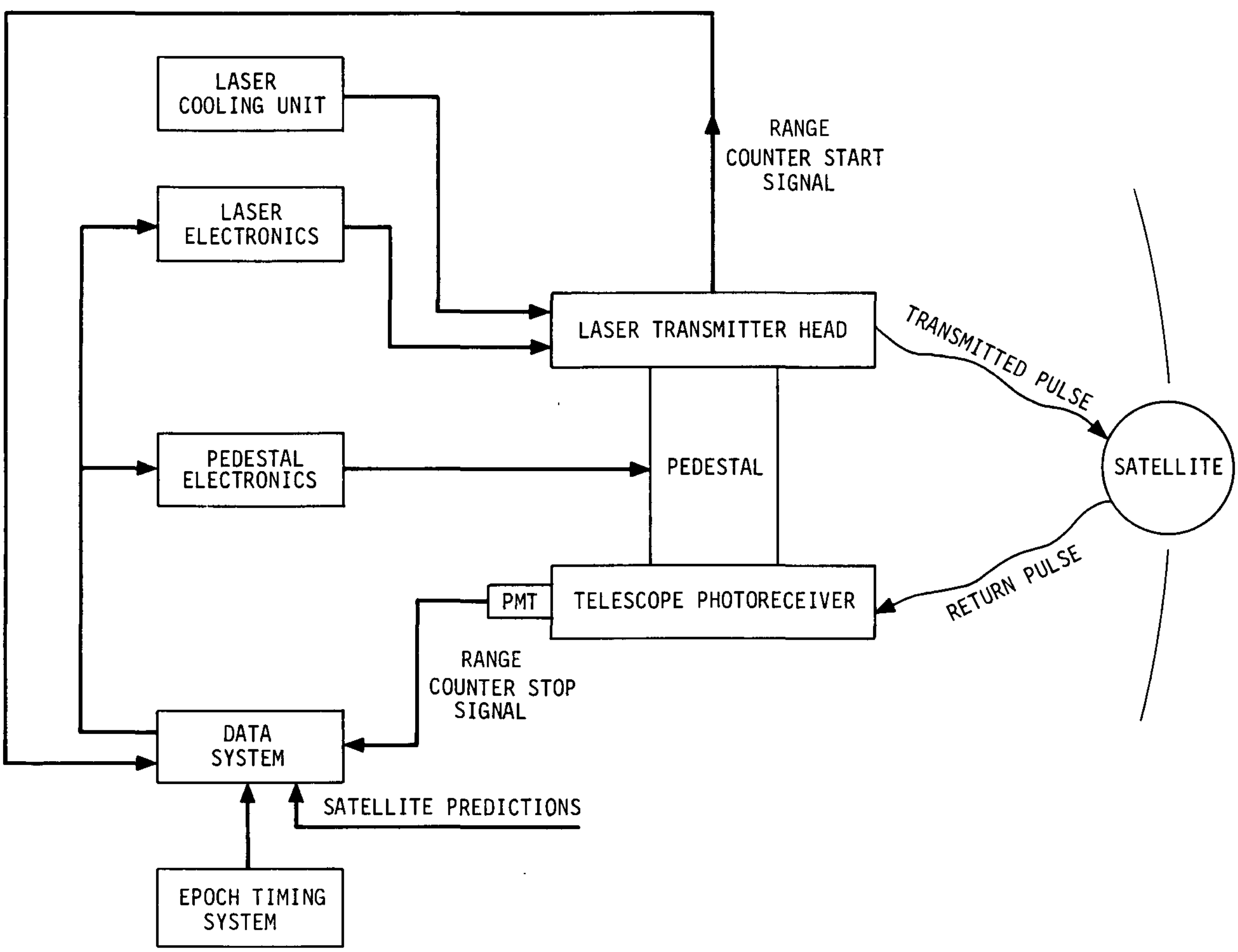

Figure 1. Laser ranging system.

To describe the operation of the laser system in simple terms, the laser transmitter head and the telescope photoreceiver are pointed by the static-pointing pedestal (see Figure 2) to the altitude and azimuth coordinates in accordance with predictions generated in Cambridge. The laser is then pulsed, under electronic or manual control, at the appropriate epoch, and a very short pulse of monochromatic light in a narrow beam is projected from the laser transmitter head toward the satellite. The transmitted pulse is detected at the transmitter by a photodiode whose output is an electrical pulse that starts the range interval counter and reads out the station clock to mark epoch. The light is reflected back from the satellite by its cube-corner reflectors and is detected photoelectrically by the telescope photoreceiver whose output is an electrical pulse that stops the range interval counter. The range from the laser system to the satellite is then calculated from the elapsed time, with due corrections for atmospheric and other effects.

Procurement started in early 1969, and the systems were fielded in late 1970.

A detailed description of the SAO laser system components follows:

1. LASER TRANSMITTER

The laser transmitter was purchased in March 1969 from:

Spacerays, Inc.
Northwest Industrial Park
Burlington, Massachusetts 01803
(617)272-6220

The system is a flash-pumped, Q-switched ruby system with an oscillator and one amplifier stage. The output is a 4- to 5-J pulse 18 nsec wide. The beam is collimated with a Galilean telescope with an aperture of 12.7-cm diameter, the beam divergence is variable from 0.3 to 6.0 mrad (measured at full width, half-power points), the repetition rate is 4 ppm, and the wavelength of the output is 694 nm.

The laser transmitter system consists of three major units: the laser transmitter head, the power supply and control electronic units, and the cooling unit.

Figure 2. Laser transmitter head (right) and telescope photoreceiver (left) mounted on static-pointing pedestal.

2. PEDESTAL

The pedestal was purchased in May 1969 from:

Tinsley Laboratories, Inc.
2448 Sixth Street
Berkeley, California 94710
(415)843-6836

This pedestal is a static-pointing, open-loop unit of an altitude-over-azimuth biaxial configuration. Its overall accuracy is within 0°.008 (great circle error of 0.5 arcmin or less).

The pedestal is a static-pointing unit, i.e., it moves to a given pointing direction, waits for the satellite to pass through that direction, and then moves on to the next such static point.

The unit is of the open-loop type, i.e., it does not operate as a servomechanism and does not require a feedback error signal. It relies instead on starting at a known pointing direction of two orthogonal axes and on simple addition and subtraction of known increments of motion about those axes to arrive at a new predetermined pointing direction. The known increments of motion are provided by reliable, precision, incremental-stepping motors fed by precomputed number-of-steps input data. The initial starting position is established by optical goniometers, and the continuous addition and subtraction is maintained by solid-state arithmetic units, counting registers, comparison logic circuitry, and visual displays.

The pedestal is positioned by manual decade-switch selection or by using a pre-punched paper-tape input.

3. TELESCOPE PHOTORECEIVER

The telescope photoreceiver was purchased in May 1969 from several vendors (see below). It contains three subsystems (see Figure 3). The first, the main subsystem, contains two components, a 53-cm-diameter f/4 paraboloidal primary and a

14.6-cm-diameter flat secondary. The primary has at least a 50-cm-diameter clear aperture and when combined with the secondary produces a field greater than 20 arcmin in diameter, an overall accuracy of better than 1/4 wave; after aluminizing and SiO overcoating, the primary has a minimum combined reflectance greater than 60% between 400 and 700 nm.

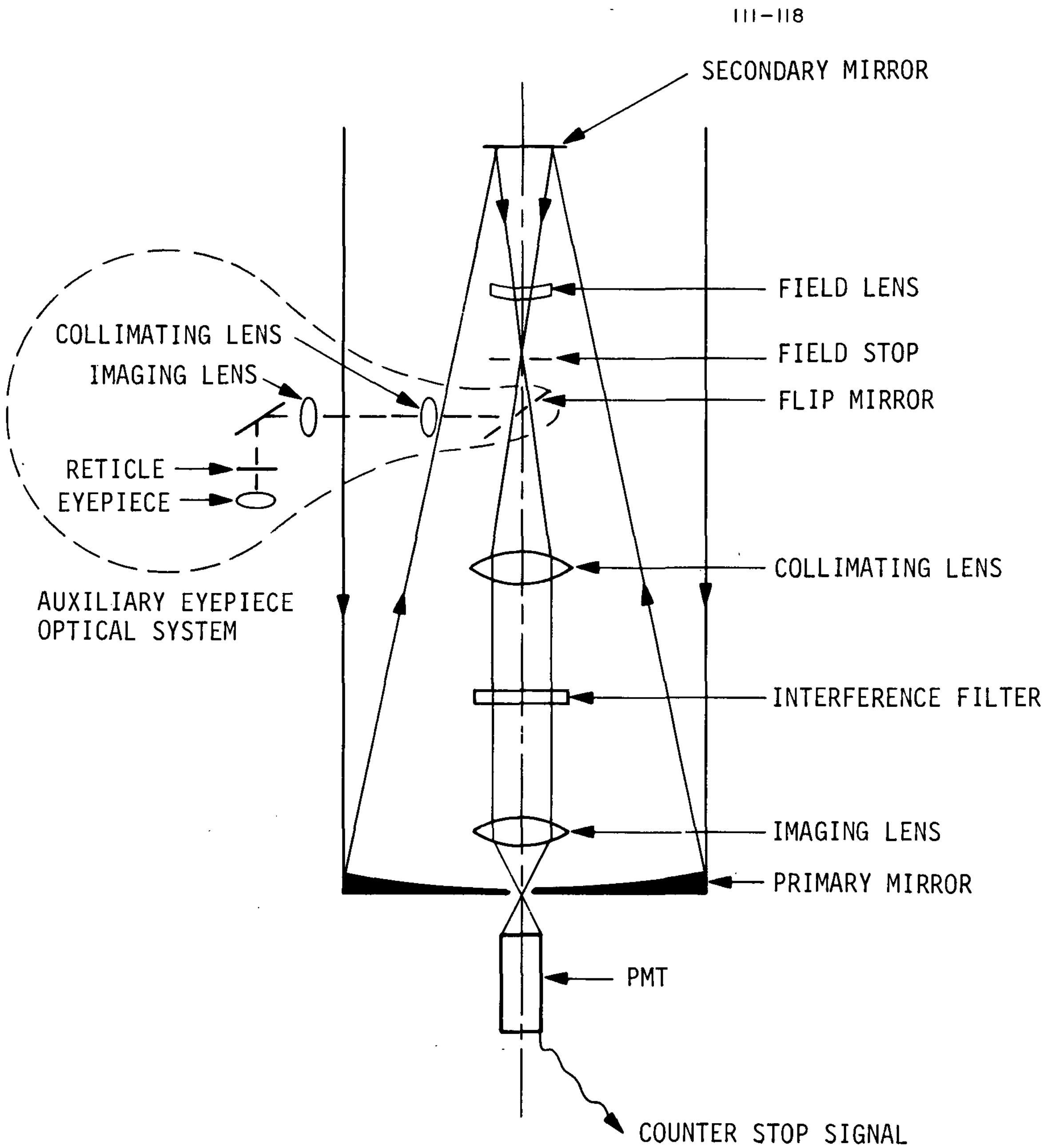

Figure 3. Telescope photoreceiver.

The second subsystem, the photomultiplier tube (PMT) optical subsystem, transfers the beam reflected by the main optical system through its components and onto the face of the PMT. The beam passes through a holder for a stack of gelatin filters, then through a field lens that directs the beam through the field stop wheel containing six apertures. These apertures are sized to produce fields of 2, 4, 8, 12, 16, and 20 arcmin in diameter. The diverging beam passes next through a collimating lens and then through a tiltable interference filter, a final imaging lens, and onto the face of the PMT. This system is designed to produce a 3.8-cm-diameter spot on the face of the PMT independent of field stop settings.

The third subsystem, the auxiliary viewing subsystem, consists of 1/4-wave flat flip mirror that, when inserted into the beam, directs the beam through the exit lenses onto a front surface diagonal mirror that reflects the beam through an illuminated reticle and out to the eyepiece for visual viewing.

A detailed breakdown of the photoreceiver is as follows:

Telescope. A 50-cm telescope is used to detect the laser return and was bought from:

Tinsley Laboratories, Inc.
2448 Sixth Street
Berkeley, California 94710
(415)843-6836

Photomultiplier Tube. A RCA Model 7265, selected for a quantum efficiency of 4.5% or greater at 694 nm and a gain of 2×10^7 or greater at 2400 v, is used to trigger the counter. It was purchased from:

Radio Corporation of America
Industrial Tube Division
New Holland Pike
Lancaster, Pennsylvania 17604
(717)397-7661

Photomultiplier Tube Housing. A Products for Research Model PR 2100 (modified) housing, used to hold the PMT, was purchased from:

Products for Research
78 Holten Street
Danvers, Massachusetts 01923
(617)774-3250

Interference Filters. A 20 Å interference filter and a 7 Å interference filter were purchased from:

Thin Films Products Division
Infra-Red Industries
80 4th Avenue
Waltham, Massachusetts 02154
(617)894-8410

4. DATA SYSTEM

The data system was purchased during the interval from March 1969 through September 1970 from several vendors (see below). The system (Figure 4) consists of the measurement instrumentation as well as the digital-control and data-handling systems for the laser transmitter. The four functional subsystems are described below.

Counter. An Eldorado ElectroData Model 796 (modified) counter with a 1-nsec resolution is used to obtain the satellite range times. This unit was purchased from:

Eldorado ElectroData Corporation
601 Chalomar Road
Concord, California 94520
(415)686-4200

Oscilloscope. A Tektronix Type R454 oscilloscope with modification 163D and a Tektronix Model C-40 oscilloscope camera are used to provide a means for visual monitoring and photographic recording of the laser transmitter output and the laser return pulses. The oscilloscope and camera were purchased from:

Tektronix, Inc.
P. O. Box 500
Beaverton, Oregon 97005
(503)644-0161

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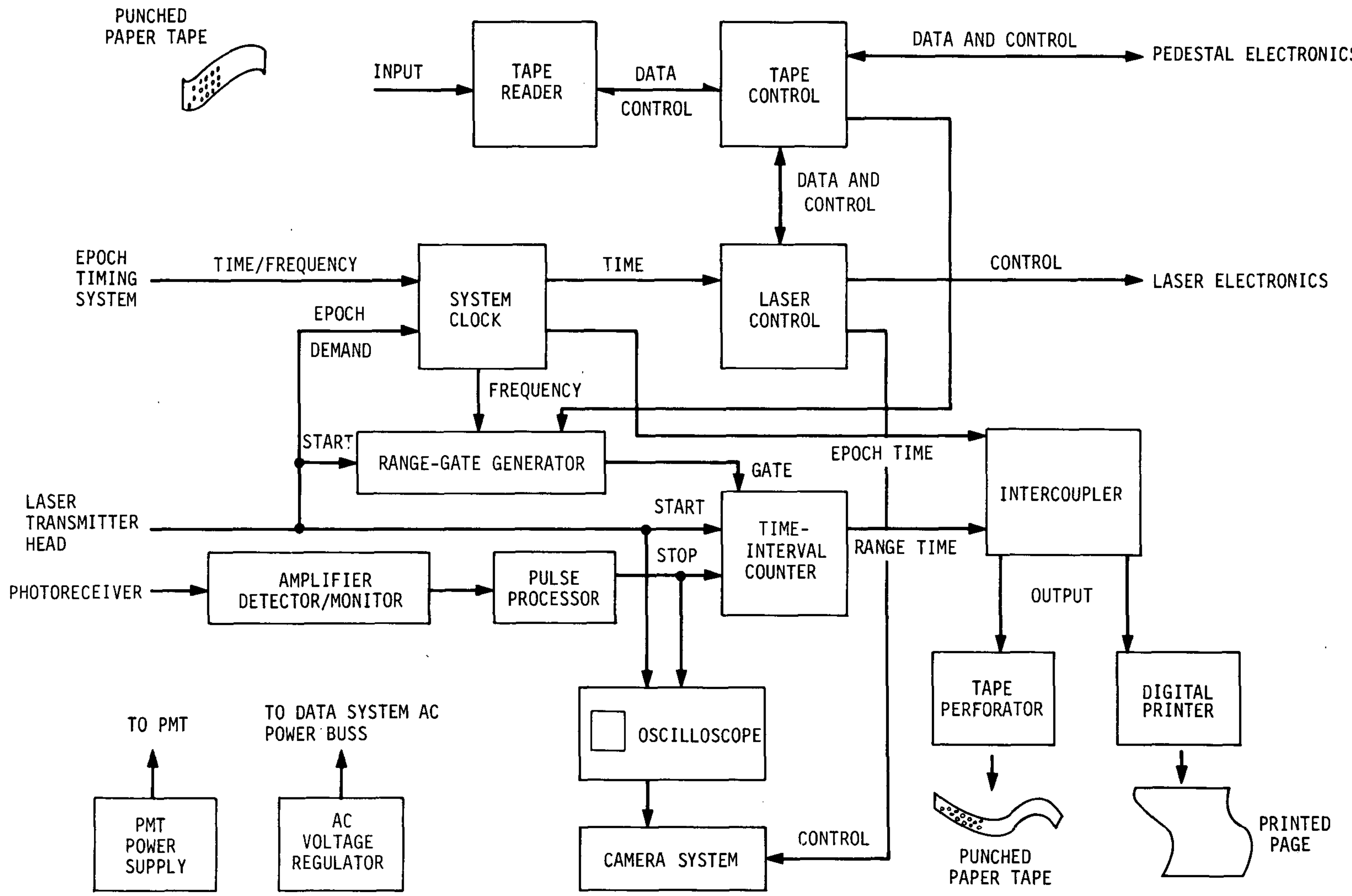

Figure 4. Laser data system.

Control System. In addition to providing the basic time-interval measurement for satellite ranging, the laser data system must also record the observation epoch time (system clock); program the operating sequence of the laser transmitter unit, the pedestal, and the data system itself (tape reader, tape control, and laser control); condition the stop channel and the return pulse (range-gate generator and amplifier detector/monitor); and print out the digital data (intercoupler, digital printer, and tape perforator). All the control-system components with the exception of the digital printer and tape perforator were built by SAO. The digital printer and tape perforator (Model ASR-32, modified by SAO) were purchased from:

The Teletype Corporation
5555 Touhy Avenue
Skokie, Illinois 60076
(312)982-2000

Racks, Power, and Cabling. A Western Devices rack and blower unit, used to hold most of the data system, was purchased from:

Zero Manufacturing Company
1121 Chestnut Street
Burbank, California 91503
(213)849-5521

A Bud Radio Company Model 2707 Series 60 rack is used to hold the tape-reader system and was purchased from:

Gerber Electronics
852 Providence Highway
Dedham, Massachusetts 02026
(617)329-2400

A General Radio Model 1581-ALR2 voltage regulator is used to supply regulated AC power to the data system. It was purchased from:

General Radio Company
300 Baker Avenue
West Concord, Massachusetts 01781
(617)369-4400

A Northeast Scientific regulated high-voltage power supply Model RQE-3001-21230 provides high voltage to the photomultiplier tube. It was purchased from:

Northeast Scientific Corporation
30 Wetherbee Street
Acton, Massachusetts 01720
(617)263-7706

5. EPOCH TIMING SYSTEM

The epoch timing systems, a Model ZA 34675 single-channel unit and a Model ZA 34685 dual-channel unit, were purchased in March 1965 from:

Electronic Engineering Company of California
1601 East Chestnut Avenue
Santa Ana, California 92700
(714)547-5651

The EECo timing system (see Figure 5) is used to provide epoch. It has a display resolution of 10 μsec and an electrical resolution of 1 μsec. The single-channel unit consists of a crystal oscillator, accumulator, oscilloscope, VLF receiver, chart recorder, WWV receiver, and a battery backup system. The dual-channel unit consists of the above plus an additional crystal oscillator, accumulator, and VLF receiver.

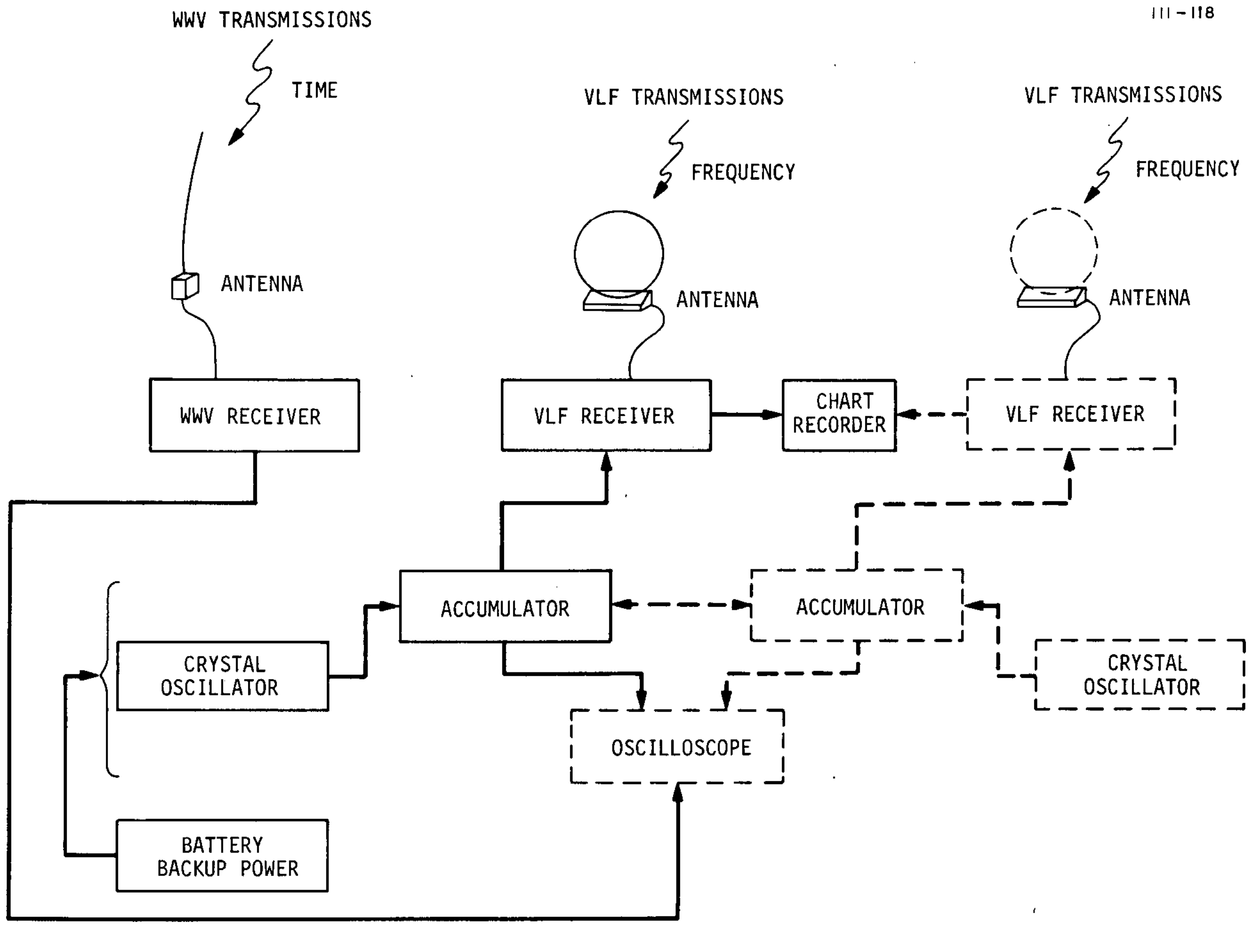

Figure 5. Epoch timing system (EECo). Solid lines show single-channel unit, while the dual-channel unit is represented by the solid lines and the dotted lines.

CALIBRATION

C. R. H. Tsiang

The ranging accuracy of the laser system is calibrated through a procedure of ranging on a fixed land-based target at a surveyed distance, generally on the order of 0.25 to 1 mi. A calculation can be made to obtain the expected range time based on the surveyed distance and the atmospheric refractivity. Once an average range time is obtained from a series of target measurements, it is possible to compute a calibration number τ_c, which can be reported along with the satellite range times. This number covers delays in the range counter, cabling, telescope, output detector, photomultiplier tube, and signal amplifier. It does not provide a means for obtaining a calibration factor for atmospheric delays, but otherwise accounts for all components in the range measuring path to and from the satellite.

The following formula can be used in computing the atmospheric refractivity N:

$$N = 80.29 \frac{P}{T} - 11.9 \frac{e}{T} \quad ,$$

where P is the measured barometric pressure (in millibars), e the partial pressure of water vapor, and T the temperature (K). The calculation for two-way range time has been based on

$$\tau_s = \frac{R_s}{0.15} (1 + N \times 10^{-6} + 6.917 \times 10^{-4}) \quad ,$$

where τ_s is the calculated range time (nsec) for a surveyed distance of R_s (m). After noting that local temperature and pressure variations at any one location never change N by more than ±10% and that the range equation gives subnanosecond variations in τ_s for such changes, we decided that fixed values of N could be determined for each station. Rather than each station calculating its mean barometric pressure, we prepared a chart, which gives a direct conversion from the station altitude above the geoid in kilometers to values of N (see Figure 1).

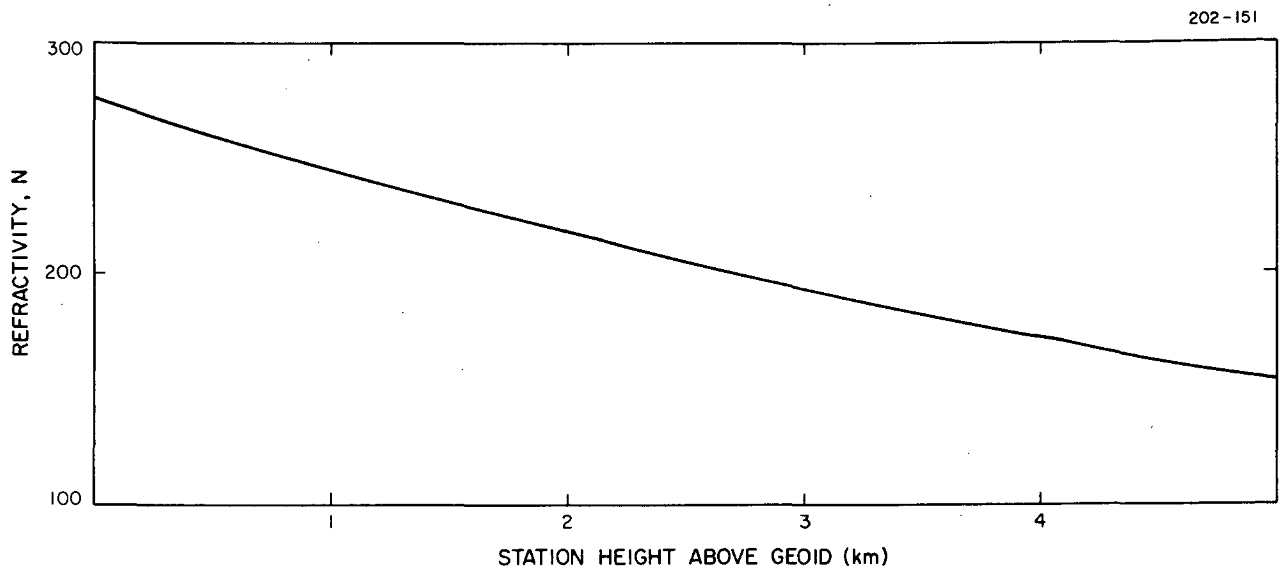

Figure 1. Atmospheric refractivity as a function of station height for an ambient temperature of 15°C at 6943 Å.

The system-calibration number reported in word eight of the 33333 observation message is obtained by subtracting the observed range time τ_m from τ_s, the range time calculated from the surveyed laser-to-target range:

$$\tau_s - \tau_m = \tau_c \quad .$$

The resulting system-calibration number τ_c is reported as a signed quantity, which is added to all range measurements in the 33333 message. Generally, τ_c is negative in the SAO laser systems.

In theory, the calibration of the instrument should change only if its components are changed, moved, or affected by environmental fluctuations or aging. By using the whole system to range on a fixed land-based target, we hoped that all such factors could be covered by the single system-calibration number. Attempts were made to simulate real operational conditions by regulating the pulse-repetition rate, photomultiplier-tube voltage, counter thresholds, amplifier gain, return signal level, output power level, etc. Several unavoidable differences existed between the ranging measurements on the satellites and those on the target — viz., corner cubes vs. nonspecular reflecting surface of the target; small solid angle subtended by the satellite vs. full-beam reflection by the target (8-ft × 8-ft wooden surface painted flat white); point-source satellite image vs. off-axis, near-field reflection by the target; short air-path length to ground-based target vs. full atmosphere to satellite, etc. None of these differences is trivial, but for operation of the laser at the original design levels (0.5-m resolution and 1-m accuracy), the calibration procedure and results appear to be satisfactory.

For the three stations with the new lasers, the variations in the reported calibration number over the course of most of ISAGEX did not exceed 15 nsec. All the new stations did experience some problems with calibration ranging when first set up, but they were confined to the first week of operations and apparently were cleared up by the beginning of the second ISAGEX period. For the most part, the variations in the reported calibrations were due to the following:

A. Replacement or relocation of components in the laser head, photoreceiver, or data system.

B. Readjustment of signal operating levels in the target-ranging procedure.

C. Readjusted survey figures for the laser-to-target distance.

Attempts at standardizing and improving the reliability of the calibration tests were made throughout ISAGEX as more experience and knowledge of the instrumentation was gained. During investigations into the error-reducing capabilities of photographically determined range-time corrections, certain observations led to the establishment of procedures that would minimize the effects of variations in signal level during target observations. These effects — the most detrimental ones for satellite ranging — were reduced to a level so that the most significant systematic error component of the calibration lay in the accuracy of the ground-survey information. Therefore, where survey information was questionable, additional measurements were made in an attempt to allow no more than a 4-cm error.

Unfortunately, this has led to the establishment of more than one survey target distance at two of the South American stations. Table 1 shows the results obtained by local surveyors using conventional techniques. Note that certain sites have been measured to greater resolution than others. Only where special comments are included should this be considered significant. Ultimately, corrections will be applied to all ISAGEX calibration data when the stations are resurveyed with a laser geodimeter.

Apart from the systematic error contributed by the differences in survey results, the net range-time uncertainty introduced by the calibration should generally be better than ± 2 nsec. Photographic reduction of pulse images offers the possibility of decreasing the error to less than ± 1 nsec for many of the periods after May 1971. Reduction of these photographic data and distribution of the results will be made in 1972.

Table 1. ISAGEX target range history: Effective dates of change to new values of survey distance and refractivity constant N.

Station				
Location	COSPAR number	Date (1971)	Survey distance (m)	Refractivity constant N
Arequipa, Peru	7907	January 5	313.135	250
		October 1	312.844	250
Mt. Hopkins, Arizona	7921	January 5	776.329	172
Olifantsfontein, South Africa	7902	February 12	404.48	290
Natal, Brazil	7929	January 5	316.08	248
		April 28	316.08	340
		April 29	314.67	340
		September 23	315.62	340
Dionysos, Greece	7930	January 5	327.25	0
		April 9	327.973*	0
		April 28	327.973	340

*Measurement made by laser geodimeter.

TIMING (EPOCH)

D. A. Arnold and J. M. Thorp

Epoch time is maintained at each station by use of the EECo precision time system (see Thorp and Bush, this volume) and by reference to UTC(USNO). A portable clock is used to set the station clock, which is then maintained by referencing the frequency of a 5-MHz Sulzer oscillator to a known frequency, broadcast by one of the various VLF stations. Each observing station maintains an estimate of its timing uncertainty in two ways: First, the accuracy of the original clock set from a portable clock is expressed as an uncertainty (usually ±5 μsec). Time is maintained at each station on one main channel, with one or more alternate channels keeping time independently for backup. If the main channel has to be reset to one of the backup channels, an additional uncertainty is added (usually ±5 μsec). The second uncertainty is the deviation of the oscillator caused by its drift in frequency. The oscillator drift is determined by comparing the phase of the VLF station with that of the oscillator at a particular time each day. Each station steers or guides its oscillator to keep its time-drift uncertainity as small as possible (usually ±50 μsec).

In addition to the above uncertainties, two sets of time corrections are added in order to have time equivalent to UTC(USNO). One set consists of corrections of hours, minutes, seconds, or parts of seconds when a failure has occurred in the main timekeeping channel. These corrections are confirmed by referring to the alternate timekeeping channel and the WWV time signals. If all channels fail, time reference is lost and a reset is necessary. The second set of corrections is added in Cambridge; this consists of the computed phase differences between the average VLF phase for a period (usually a month) and the phase of the VLF at the time the clock is set. These corrections, determined from data published in USNO time-service bulletins, are generally on the order of < 20 μsec.

Two files of time corrections are maintained by the Data Services Division at SAO. The first gives the difference between A.S and UT1, and the second, the difference between A.S and the clocks at the observing stations. The time system A.S is related to UTC(USNO) by the expression

$$A.S - UTC(USNO) = 6^{s}.140768 + 0.002592000(T - 39856.0)$$

for the period February 1, 1968, to January 1, 1972; T is the time in Modified Julian Days; 39856.0 is January 1.0, 1968; and the difference is given in seconds. The A.S - A.1 difference is about 0.8983 msec.

UT1 data are obtained from "Circular D," published monthly by the BIH. Values of UT1 - UTC(BIH) and AT - UTC(BIH) are listed at 5-day intervals. The difference A.S - AT is currently 35.3 msec. A.S - UT1 is calculated by the relation

$$A.S - UT1 = (A.S - AT) + [AT - UTC(BIH)] - [UT1 - UTC(BIH)] \quad .$$

A second-order polynomial is fitted to the A.S - UT1 values, and the coefficients are punched on cards. Usually, each polynomial covers a 50-day period. If the values change too rapidly, the interval can be reduced to 25 days.

The difference between the station clocks and UTC(USNO) is recorded by STADAD as described. The corrections are added to the A.S - UTC(USNO) difference to obtain the correction from the station clock to A.S time. Cards are punched giving these corrections as a series of straight-line segments specifying the values of the corrections at the beginning and end of each interval. A new card must be used whenever there is a gap, discontinuity, or change of slope in the time correction.

ATMOSPHERIC REDUCTION OF LASER DATA

C. G. Lehr

Laser ranges determined by using the value of the velocity of light in a vacuum must be corrected for the fact that the laser pulse travels at a lower velocity during its passage through the earth's atmosphere. The correction is currently made by means of the following formula (obtained in a personal communication from Gordon D. Thayer):

$$r_m = r_v - \frac{2.238 + 0.0414\, PT^{-1} - 0.238\, h_s}{\sin \alpha + 10^{-3} \cot \alpha} \quad ,$$

where r_v is the uncorrected range (m), r_m is the corrected range (m), P is the atmospheric pressure (mb) at the laser station, T is the temperature (K) at the laser station, h_s is the laser's elevation above mean sea level (km), and α is the altitude angle of the satellite. The formula holds for a ruby laser, which operates at 694 nm. It should be used only when $\theta_0 > 5°$, where θ_0 is the apparent altitude angle (i.e., the altitude angle uncorrected for atmospheric bending).

PULSE ANALYSIS

C. R. H. Tsiang and C. G. Lehr

The effects of variations in pulse amplitude and shape must be carefully considered in attempting to reduce the noise and bias in laser range measurements. The simplest mode of operation in making time-interval measurements employs only a fixed-voltage threshold discriminator. Range times obtained this way are susceptible to errors caused by phenomena such as leading-edge walk and leading-edge pulse distortion. Attempts were made during operations to keep these effects to a minimum, and further work was done to record some of the laser passes on film. Errors on the order of ±5 nsec can be expected when point-to-point amplitude changes affect the fixed threshold counter triggering circuit. Reduction of the photographic images of the outgoing- and return-pulse oscilloscope traces may produce range-correction figures to decrease the net range-counter errors to about ±1.7 nsec. No work has yet been done to evaluate fully the accuracy of the photographic data collected during ISAGEX, and further study is necessary to substantiate empirically the estimated accuracy of ±1.7 nsec. The process of photoreduction of the data and discussion of the system-accuracy potential is given in Lehr, Pearlman, and Scott (1970a). Early attempts at testing the effectiveness of this technique are presented in Lehr, Pearlman, and Scott (1970b).

Table 1 lists the satellite passes covered by photography. Most returns were obtained on Polaroid film, rather than on 35-mm film, because of the former's quick developing process. This rapid feedback was advantageous to the laser operator for adjusting the amplification level in the return-signal circuitry. Saturation of the amplifier, the limited resolution range of the oscilloscope at a fixed gain, and the minimum voltage imposed by the counter threshold were the constraints that had to be satisfied. Returns were photographed successfully at all three new laser stations in spite of early problems, such as signal adjustment and operation of the laser with new procedures and with an already heavily burdened crew of observers.

The listing of satellite passes gives some information of the quality and quantity of the data, even though little has been done so far to reduce the images for range correction factors. The column marked "Total reported observation points" refers to the number of range measurements reported by the station for each pass, and the next column gives the number of attempted photographic images. The actual number of traces of return or noise pulses is given in the column labeled "Images." Of these frames, only a few are of sufficient quality that they could be measured reliably. Those of reduction quality should produce measurements of at least ±3-nsec consistency, and probably no worse than 1.5 nsec rms. Those images that do not qualify to be counted in the "Reduction quality" column are usually very irregularly shaped, low-level returns or extremely strong returns that go off the oscilloscope screen or are distorted by the saturation of the amplifier. In some cases, there are images of noise pulses that have falsely stopped the range counter. Even in these rejected images, there is useful information about the behavior of the return-signal circuitry under extreme amplitude conditions. Aside from the measurement of the images for range correction figures, the most important additional data come from the cataloging of return-pulse amplitudes and shapes photographed under routine laser tracking procedures. These data can be applied to studies on the scintillation of returns and to the calculation or prediction of return amplitudes. The amount of photographic data amassed during the last part of ISAGEX is insufficient in itself to have much value. Some reduction work is planned, however, so that the results can be used to evaluate the effectiveness of the photographic technique and to improve the operational procedures of the data-recording system.

REFERENCES

LEHR, C. G., PEARLMAN, M. R., and SCOTT, J. L.

1970a. A photographic technique for improved laser-ranging accuracy. In Laser and Radar Investigations, ed. by Computer Sciences Corp., NASA, Washington, vol. III, pp. 51-56.

1970b. Range corrections from oscilloscopic displays of laser returns. Smithsonian Astrophys. Obs. Laser Rep. No. 4, 27 pp.

Table 1. Satellite returns.

Date	Time (UT)	Satellite	Total reported observation points	Number of frames: Total	Number of frames: Images	Number of frames: Reduction quality
			Brazil			
June 17	22^h53^m	7010901	7	4	4	0
June 18	08 23	6800201	9	2	2	0
June 19	06 06	7010901	3	2	2	0
August 5	22 34	6508901	39	45	17	0
August 11	20 53	6508901	31	24	12	0
August 11	21 22	6508901	11	15	7	0
August 13	23 14	7010901	1	3	1	1
August 14	08 03	6508901	20	15	10	4
August 14	22 20	6508901	13	3	3	3
August 22	02 14	6503201	5	3	1	0
August 22	06 32	6508901	19	9	6	0
August 23	21 33	6800201	10	15	3	0
August 24	03 28	6503201	1	2	1	0
August 31	03 53	6503201	7	6	4	1
September 1	05 56	7010901	9	4	3	1
September 23	22 27	6508901	25	22	11	3
September 27	23 31	6800201	18	18	15	8
October 1	22 58	6800201	20	21	15	3
October 1	22 59	6508901	20	9	2	1
October 3	22 24	6503201	15	9	7	0
October 4	21 11	6508901	15	3	3	0
October 16	06 58	6508901	14	3	3	3
October 24	05 22	6508901	15	7	6	2

Table 1 (Cont.)

Date	Time (UT)	Satellite	Total reported observation points	Number of frames: Total	Number of frames: Images	Number of frames: Reduction quality
			Peru			
May 19	17^h59^m	6508901	41	26	25	9
May 19	22 09	6800201	33	26	26	8
May 20	17 55	6508901	16	28	28	6
May 22	02 53	6508901	8	2	2	0
May 28	03 23	6508901	17	1	1	1
June 3	01 36	6508901	31	20	20	0
June 8	13 01	6508901	60	35	27	5
June 8	23 01	6800201	17	16	14	0
June 8	23 58	6508901	34	28	21	1
June 9	00 13	6701101	16	5	5	0
June 9	13 04	6508901	49	14	14	7
June 10	00 01	6508901	43	29	20	7
June 10	11 20	6800201	21	14	12	0
June 10	13 10	6508901	45	13	9	2
June 11	00 06	6508901	31	15	13	0
June 11	13 16	6508901	55	48	37	22
June 11	22 08	6800201	4	3	2	0
June 12	13 20	6508901	51	39	33	20
June 13	13 24	6508901	29	17	12	0
June 13	22 16	6508901	22	15	15	0
June 13	22 47	6800201	32	20	19	0
June 15	22 22	6508901	26	12	9	0
July 6	17 35	6508901	20	18	16	7
August 17	21 21	6508901	14	6	9	0

Table 1 (Cont.)

Date	Time (UT)	Satellite	Total reported observation points	Number of frames: Total	Number of frames: Images	Number of frames: Reduction quality
		South Africa				
August 19	00^h08^m	6508901	45	60	33	5
August 20	00 11	6508901	28	44	27	4
August 23	00 24	6508901	42	54	22	10
August 24	00 26	6508901	31	56	12	1
August 24	07 16	6800201	5	31	8	1
August 24	17 52	6800201	12	25	3	0
August 25	06 07	6800201	9	36	16	0
August 26	00 37	6508901	28	49	20	7
August 26	22 36	6508901	12	41	8	0
August 26	22 39	6508901	14	4	3	0
August 27	17 19	6508901	15	24	14	2
August 27	22 40	6508901	29	49	16	0
August 28	00 47	6508901	10	32	20	0
August 29	22 48	6508901	40	57	15	0
August 30	18 15	6800201	14	23	14	0
August 30	22 53	6508901	37	55	36	0
August 31	06 10	6800201	3	32	17	0
August 31	22 56	6508901	41	56	35	0
September 1	17 06	6800201	10	16	7	0
September 4	21 90	6508901	35	47	24	0

STATISTICS: RETURNS AND FAILURES

B. R. Miller

The following statistics represent the SAO and Air Force Baker-Nunn optical and the SAO laser returns during the months of intensive tracking on the individual satellites.

The first 2 months' predictions were generated with a paucity of observations, which may account for the sparse number of returns. During the rest of ISAGEX, as more observations became available for use in predicting orbits, the number of returns increased also.

The numbers here reflect the data collected during ISAGEX after gross errors were removed in the orbit computations for predictions.

The data were processed for validation purposes before being used in analysis. Therefore, there is a discrepancy in these figures and the final data used in the analysis.

BE-B (6406401)

Station Location	COSPAR number	January	March	April	Total
		Optical Returns			
San Fernando, Spain	9004		10	5	15
Naini Tal, India	9006		6	6	12
Maui, Hawaii	9012		5	7	12
Mt. Hopkins, Arizona	9021	6	3	13	22
Olifantsfontein, South Africa	9022	5			5
Island Lagoon, Australia	9023	13	8	5	26
Dodaira, Japan	9025	8	1	9	18
Arequipa, Peru	9027			1	1
Debre Zeit, Ethiopia	9028			2	2
Dionysos, Greece	9030		7	13	20
Natal, Brazil	9039	1		5	6
Rosamund, California	9113	5	1		6
Cold Lake, Canada	9114	2	16		18
Johnston Island	9117	1			1
Mt. John, New Zealand	9119	9	21	1	31
San Vito, Italy	9120		2	13	15
Total		50	80	80	210
		Laser Returns*			
Arequipa, Peru	7907			6 (18)	6 (18)
Mt. Hopkins, Arizona	7921		1 (3)	6 (21)	7 (24)
Natal, Brazil	7929	1 (1)		3 (8)	4 (9)
Dionysos, Greece	7930		3 (5)		3 (5)
Total		1 (1)	4 (8)	15 (47)	20 (56)

*The first number is the number of passes of the satellite; the number in parentheses is the total number of points in those passes.

BE-C (6503201)

Station					
Location	COSPAR number	February	March	August	Total
		Optical Returns			
San Fernando, Spain	9004	6	1	30	37
Naini Tal, India	9006	14	3		17
Maui, Hawaii	9012	12	2	42	56
Mt. Hopkins, Arizona	9021	8	5		13
Olifantsfontein, South Africa	9022	20	3	21	44
Island Lagoon, Australia	9023	47	6	11	64
Dodaira, Japan	9025		8	7	15
Arequipa, Peru	9027	2		8	10
Debre Zeit, Ethiopia	9028	3		1	4
Dionysos, Greece	9030	2	2	44	48
Natal, Brazil	9039	5		5	10
Rosamund, California	9113	2	3		5
Cold Lake, Canada	9114	5	3	20	28
Johnston Island	9117	10		3	13
Mt. John, New Zealand	9119	34	4	26	64
San Vito, Italy	9120			68	68
Total		170	40	286	496
		Laser Returns			
Olifantsfontein, South Africa	7902	4 (6)	1 (2)		5 (8)
Arequipa, Peru	7907	2 (9)	11 (30)	25 (181)	38 (220)
Mt. Hopkins, Arizona	7921	2 (4)	2 (4)	2 (3)	6 (11)
Natal, Brazil	7929	7 (20)	2 (6)	13 (46)	22 (72)
Dionysos, Greece	7930		1 (3)	10 (37)	11 (40)
Total		15 (39)	17 (45)	50 (267)	82 (351)

Geos 1 (6508901)

Station										
Location	COSPAR number	January	February	March	April	May	June	July	August	Total
				Optical Returns						
San Fernando, Spain	9004	6	45	48	5	12	33	49	3	201
Naini Tal, India	9006	13	23	16	13	4		5		74
Maui, Hawaii	9012			9	12	17	21	27	22	108
Mt. Hopkins, Arizona	9021	19	26	28	11	6	32	15	1	138
Olifantsfontein, South Africa	9022	1	6	17	40	3	9	3	8	87
Island Lagoon, Australia	9023	8	10	15	22	6	11	14	45	131
Dodaira, Japan	9025	27	21	18	3	1	39	1		110
Arequipa, Peru	9027	4		25	36	1	9	13	75	163
Debre Zeit, Ethiopia	9028	8	15	11	12		15	9	2	72
Dionysos, Greece	9030	10	19	24	7	24	14	36	3	137
Natal, Brazil	9039	4	7	8	13		18	3	24	77
Rosamund, California	9113	12	17	15		9				53
Cold Lake, Canada	9114	3	27	14			17	5		66
Johnston Island	9117	3	5				41	10	4	63
Mt. John, New Zealand	9119	39	23		30	108	28	167	162	557
San Vito, Italy	9120	—	33	12	1	38	—	63	—	147
Total		158	276	260	205	229	287	420	349	2184
				Laser Returns						
Olifantsfontein, South Africa	7902		7 (33)	13 (220)	26 (349)	32 (390)	36 (658)	49 (1362)	46 (1152)	209 (4164)
Arequipa, Peru	7907	5 (10)	2 (12)	13 (113)	23 (187)	41 (461)	58 (1442)	12 (404)	38 (742)	192 (3371)
Mt. Hopkins, Arizona	7921	2 (3)	4 (9)	7 (63)	13 (74)	16 (53)	2 (11)			44 (213)
Natal, Brazil	7929	5 (13)	16 (68)	1 (7)	19 (79)	22 (110)	22 (108)	12 (74)	19 (231)	116 (690)
Dionysos, Greece	7930	—	4 (8)	3 (8)	4 (8)	6 (26)	14 (66)	4 (17)	—	35 (133)
Total		12 (26)	33 (130)	37 (411)	85 (697)	117 (1040)	132 (2285)	77 (1857)	103 (2125)	596 (8571)

D1C (6701101)

Station: Location	COSPAR number	March	April	June	Total
Optical Returns					
San Fernando, Spain	9004	6	17	51	74
Naini Tal, India	9006	6	14		20
Maui, Hawaii	9012	15	18	47	80
Mt. Hopkins, Arizona	9021	8	27	35	70
Olifantsfontein, South Africa	9022	11	7	5	23
Island Lagoon, Australia	9023	20	10	5	35
Dodaira, Japan	9025		16	1	17
Arequipa, Peru	9027		3	6	9
Debre Zeit, Ethiopia	9028	3	4	2	9
Dionysos, Greece	9030	2	19	33	54
Natal, Brazil	9039	1	2	4	7
Rosamund, California	9113		10	14	24
Cold Lake, Canada	9114				
Johnston Island	9117			12	12
Mt. John, New Zealand	9119	1	7		8
San Vito, Italy	9120		32	11	43
Total		73	189	226	488
Laser Returns					
Arequipa, Peru	7907			11 (134)	11 (134)
Mt. Hopkins, Arizona	7921	1 (6)		6 (19)	7 (25)
Natal, Brazil	7929			2 (11)	2 (11)
Dionysos, Greece	7930			36 (187)	36 (187)
Total		1 (6)		55 (351)	56 (357)

D1D (6701401)

Station								
Location	COSPAR number	January	February	March	April	May	July	Total
				Optical Returns				
San Fernando, Spain	9004	7	5	9	3	28	76	128
Naini Tal, India	9006	15	8	19	3	7		52
Maui, Hawaii	9012		8	25	4	50	55	142
Mt. Hopkins, Arizona	9021	12	8	13	5	12	18	68
Olifantsfontein, South Africa	9022	8	11		14	2	5	40
Island Lagoon, Australia	9023	24	18	9	14	7	5	77
Dodaira, Japan	9025	4	1	6	4	2	5	22
Arequipa, Peru	9027	1			4	4	5	14
Debre Zeit, Ethiopia	9028	2	5		2	3	6	18
Dionysos, Greece	9030	1	2	7	5	21	46	82
Natal, Brazil	9039		12	1			4	17
Rosamund, California	9113	10	1	4	2	13		30
Cold Lake, Canada	9114	2					5	7
Johnston Island	9117						5	5
Mt. John, New Zealand	9119	27	22		29	12	10	100
San Vito, Italy	9120	—	10	6	15	6	94	131
Total		113	111	99	104	167	339	933
				Laser Returns				
Arequipa, Peru	7907	4 (5)			2 (15)	23 (272)		29 (292)
Mt. Hopkins, Arizona	7921	1 (2)	2 (3)	4 (17)		56 (439)		63 (461)
Natal, Brazil	7929				2 (8)	5 (26)	3 (19)	10 (53)
Dionysos, Greece	7930	—	—	—	1 (2)	21 (57)	14 (75)	36 (134)
Total		5 (7)	2 (3)	4 (17)	5 (25)	105 (794)	17 (94)	138 (940)

Geos 2 (6800201)

Station								
Location	COSPAR number	March	April	May	June	July	August	Total
				Optical Returns				
San Fernando, Spain	9004	3	10	2		11	32	58
Naini Tal, India	9006	1	18	1			2	22
Maui, Hawaii	9012		19	18	12	19	25	93
Mt. Hopkins, Arizona	9021	5	30	5	1	3	1	45
Olifantsfontein, South Africa	9022	25	15	5	1	3	8	57
Island Lagoon, Australia	9023	23	23	9	7	12	17	91
Dodaira, Japan	9025	3	16	1			3	23
Arequipa, Peru	9027	24	21	14	3	18	60	140
Debre Zeit, Ethiopia	9028	3	16	5	1	10	23	58
Dionysos, Greece	9030	4	22	6		4	37	73
Natal, Brazil	9039	4	8	1	3	6	35	57
Rosamund, California	9113	3	10	4	4			21
Cold Lake, Canada	9114	10	10			3	26	49
Johnston Island	9117		2		1	8	8	19
Mt. John, New Zealand	9119	19	40	43	40	58	74	274
San Vito, Italy	9120	1	15	—	—	1	22	39
Total		128	275	114	73	156	373	1119
				Laser Returns				
Olifantsfontein, South Africa	7902	7 (51)	18 (108)	20 (181)	29 (328)	20 (257)	23 (239)	117 (1164)
Arequipa, Peru	7907	2 (8)	16 (106)	23 (243)	31 (594)	13 (233)	15 (173)	100 (1357)
Mt. Hopkins, Arizona	7921	3 (17)	10 (44)	15 (95)	1 (6)		1 (1)	30 (163)
Natal, Brazil	7929		9 (49)	10 (66)	12 (51)	9 (77)	14 (102)	54 (345)
Dionysos, Greece	7930	2 (3)	2 (2)	2 (2)	—	3 (7)	9 (40)	18 (54)
Total		14 (79)	55 (309)	70 (587)	73 (979)	45 (574)	62 (555)	319 (3083)

Peole (7010901)

Station: Location	COSPAR number	January	February	March	April	May	June	July	August	Total
					Optical Returns					
Maui, Hawaii	9012		8	8	3	7	2	9	9	46
Olifantsfontein, South Africa	9022			1	2		2			5
Arequipa, Peru	9027			4	10	10	11	8	18	61
Debre Zeit, Ethiopia	9028	10	8	6	10	14	2	6	7	63
Natal, Brazil	9039	11		4	7	12	9	6	16	65
Johnston Island	9117	1	14	2	1	1	2	7	—	28
Total		22	30	25	33	44	28	36	50	268
					Laser Returns					
Arequipa, Peru	7907			6 (30)	5 (14)	2 (22)	27 (208)		2 (14)	42 (288)
Natal, Brazil	7929	1 (1)		—	—	8 (21)	37 (192)	2 (20)	15 (58)	63 (292)
Total		1 (1)		6 (30)	5 (14)	10 (43)	64 (400)	2 (20)	17 (72)	105 (580)

EVALUATION OF LASER OPERATIONS

J. Thorp

We selected a 3-month period during ISAGEX for collecting laser data in order to evaluate the potential of the SAO laser system. We chose June, July, and August for its good weather and the South Africa station since it was ranging to only the Geos 1 and Geos 2 satellites. The evaluation, therefore, did not have to consider the questionable orbits or the bad aspect angles of the magnetically stabilized satellites.

Statistics were generated by using laser passage information compiled at each station. We considered both individual points (Figure 1) and total arcs (Figure 2). Two to 65 points were predicted per arc during this period, with an average of 35 points per arc. Arcs started and ended at 20° above the horizon.

For simplicity in preparing the graphs, each attempted point was considered an attempted arc and each successful point was considered a successful arc. This, however, did create some apparent discrepancies between the two graphs. The category "not attempted (N.A.) other," which includes pass conflicts, observer errors, and attempts not made owing to safety, shows a decided decrease when points are compared to arcs. The main reason for this is that points at the beginning and end of many passes were not attempted because of the hazards of operating below 30°.

Another discrepancy is apparent when successful points are compared to successful arcs. However, as the following statistics show, 44 to 64% of the arcs have less than 16 successful points:

	Percentage of arcs				Total predictions (points/arcs)	Total successes (points/arcs)
	Number of points					
	1–3	4–6	7–15	16 or more		
June	16%	20%	28%	36%	4834/141	1013/67
July	8%	10%	16%	66%	4001/114	1588/69
August	5%	11%	34%	50%	5572/152	1391/69

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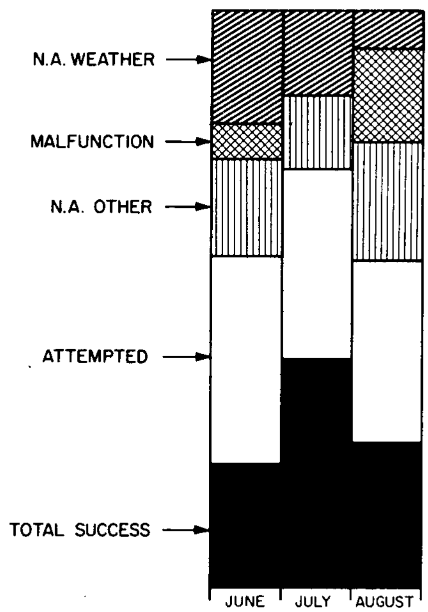

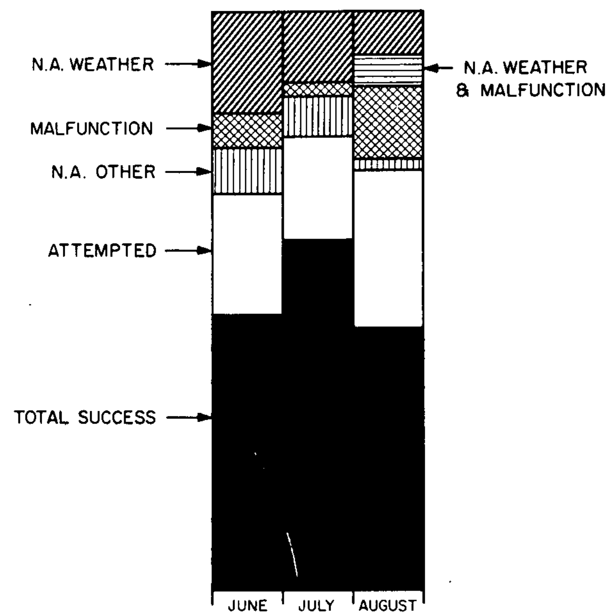

Figure 1. Percentage of total predicted points from South Africa.

Figure 2. Percentage of total predicted arcs from South Africa.

The percentage of successful points per pass seems to be related to weather (July had the best weather). During August, a period was reported as not attempted owing to a malfunction, but, in fact, the maintenance was scheduled for and performed during cloudy weather.

From the statistics, we can expect that, in general, with the laser system operating properly, about 30% of the predicted points will be successful. When dealing with arcs, we see a higher percentage of overall success, in that about half the predicted arcs are successful. If we discount weather completely, the success ratio is higher, around 70%. The cases studied are ideal, and we feel that this is the best the system can do under present circumstances. When bad weather occurs and when satellites with less stable orbits are added, the success ratio drops substantially.

PREDICTION PROBLEMS

J. Latimer

Generating accurate predictions is crucial to the successful use of static-pointing laser systems. The prediction—observation—orbit-determination cycle is a self-sustaining process when it works properly. In general, the process functioned reasonably well during ISAGEX, except for the Peole satellite, which, with a perigee of 500 km, is subject to a great deal of atmospheric drag.

Section 1 discusses the prediction accuracies obtained, and Section 2 presents a technique for improving poor predictions. Section 3 deals with the drag problem, especially as it relates to Peole.

1. PREDICTION ACCURACIES

In Table 1 we have estimated the accuracy of predictions for the ISAGEX satellites during the saturation observing periods. The best way to express accuracies seems to be in topocentric arcminutes, since this bears most directly on the static-pointing laser system. In general, because of the beamwidth, prediction accuracies to 10 arcmin are desirable; a smaller accuracy presents problems for acquisition (although the problem is not completely insurmountable, as discussed in Section 2).

Predictions degrade exponentially in time. We give accuracies for the first and last day of each week's predictions. Interpolation will provide estimates for the other days. The figure for the first day is actually the rms of the orbit determination. Since we never found any discontinuity between the rms orbit fit and the residuals of the first day's observations using the extrapolated orbit, this seems an appropriate measure of the starting value.

Table 1. Prediction accuracies (arcmin) from the first to the last day of each week.

ISAGEX period	Week	Peole	Geos 1	Geos 2	D1D	BE-B	BE-C	D1C
I	Jan. 6–13	No predictions	1–27			1.3–42		
	Jan. 13–20	Non-SAO orbit (25-min time difference)	1.8–54			2.3–20		
	Jan. 20–27	4–X	1.3–3.5			11.5–X		
II	Feb. 10–18	4.5–1155	1–2				1–3.5	
	Feb. 18–24	4–215	1.8–2.5				1–3.8	
	Feb. 24–Mar. 3	4–90	0.8–2				1–7	
	Mar. 3–10	4.8–350	0.8–4.8				1–X	
III	Mar. 24–31	4–63	0.8–13	1–10		10.8–37		
	Mar. 31–Apr. 7	5–167	0.8–2.5	0.8–6.8		0.8–2.8		
	Apr. 7–14	7.3–253	0.5–2.8	0.5–7.5		0.8–X		
IV	Apr. 28–May 5	0.8–850, 115	0.7–1.3	0.8–1.5	0.8–10			
	May 5–12	5–232, 29	0.7–9	0.8–1.5	0.5–9			
	May 12–19	4–54, 87	0.7–6	0.5–0.8	0.4–21			
V	June 5–9	1.5–220, 54	0.4–12	0.4–12				1–31
	June 9–16	2.4–53, 38	0.4–5	0.5–2				1–22
	June 16–23	3.5–38, 22	0.4–7	0.3–11				0.7–78
	June 23–30	0.3–69, 55	0.3–6	0.3–2				0.5–X
VI	July 14–21	2–490, 81	0.5–1.3	0.5–2.5	0.8–2			
	July 21-28	4.8–X, 59	0.5–4	0.5–13	0.7–14			
VII	Aug. 11–18	4.8–X, 116	0.5–5	0.5–4.5			1–2.5	
	Aug. 18–25	1.3–53, 87	0.5–3.4	0.5–1.4			1–9	
	Aug. 25–Sept. 1	1.5–132, 86	0.5–2	0.5–2			0.8–1.3	

The final day's accuracy is determined by a direct comparison of pointing angles from the expiring and the fresh predictions. This overlap day was generated to ensure operation even in the case of communications delays. Occasionally, there was no overlap day, and a comparison could not be made. This is indicated by an "X" in Table 1. Clearly, in any week, the final day's figure is uncertain by the amount of error in the next first day's prediction, which is almost always relatively small. The error is predominantly in the along-track direction; the across-track component is relatively insignificant.

Notice in the table the large errors in the Peole predictions. In an attempt to improve the accuracy, we generated Peole predictions twice a week beginning with period IV. From period IV on, we give two overlap-day comparisons in addition to the first orbit fit. Although there was noticeable improvement, Peole predictions remained troublesome (owing to atmospheric drag, see Section 3).

Finally, since we intended for these values to represent worst case situations, we chose to compare pointing angles at the culmination of each pass. Culmination, or the point of closest approach, is more sensitive to orbital errors than are lower elevation points.

2. FIELD UPDATING OF PREDICTIONS

One of the useful properties of laser ranging systems is their ability to operate at low elevation angles. This permits errors in the predicted satellite mean anomaly to be quickly detected and corrected. Generally, the error in satellite mean anomaly is the only significant one in satellite ephemerides, so that when this error has been determined by field personnel, they can update predictions from the Computations Center in Cambridge by applying a simple correction to the firing time of their look angles.

Figure 1 demonstrates how the error in mean anomaly is determined. The satellite is predicted to be at position 1, azimuth, altitude, and range from the station, at epoch 1, and at position 2 at epoch 2. Suppose that at epoch 1 the observed and the predicted range differ by Δr. (It is feasible to obtain returns in this case, provided the major component of the satellite's motion is toward the observer; this is true very early in the pass for passes with high culmination.) We can assume that the predicted time interval between epochs 1 and 2 is correct, although the epochs themselves are in error by Δt; and similarly s, the range interval between positions 1 and 2, is correct, although the range to position 1 is wrong. Then, $\Delta t = (d/s)\ \Delta r$, approximately.

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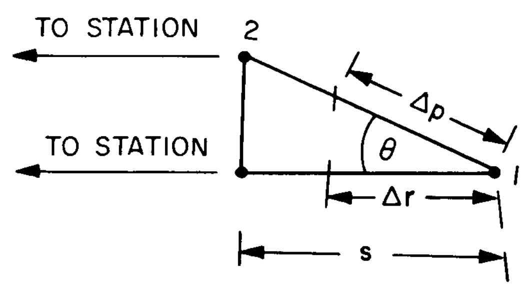

Figure 1. Satellite—station geometry at a low elevation angle.

Actually, for convenience, Δr and s are expressed in terms of propagation times rather than of distances. The time interval between successive predicted points, d, is almost always 15 sec; s varies, but it is typically around 0.5 msec for low elevation angles. In order to determine Δt quickly, station personnel use graphs of the linear relationships between Δt and Δr for the various values of s frequently encountered. The value Δr can be resolved to 1 nsec, so that, for example, when s = 0.5 msec and d = 15 sec,

$$\Delta t = \frac{30 \text{ msec mean-anomaly correction}}{1 \text{ nsec observed range error}} \quad .$$

Figure 2 is the station graph for determining the error in mean anomaly. Given Δr and s, Δt can be quickly found.

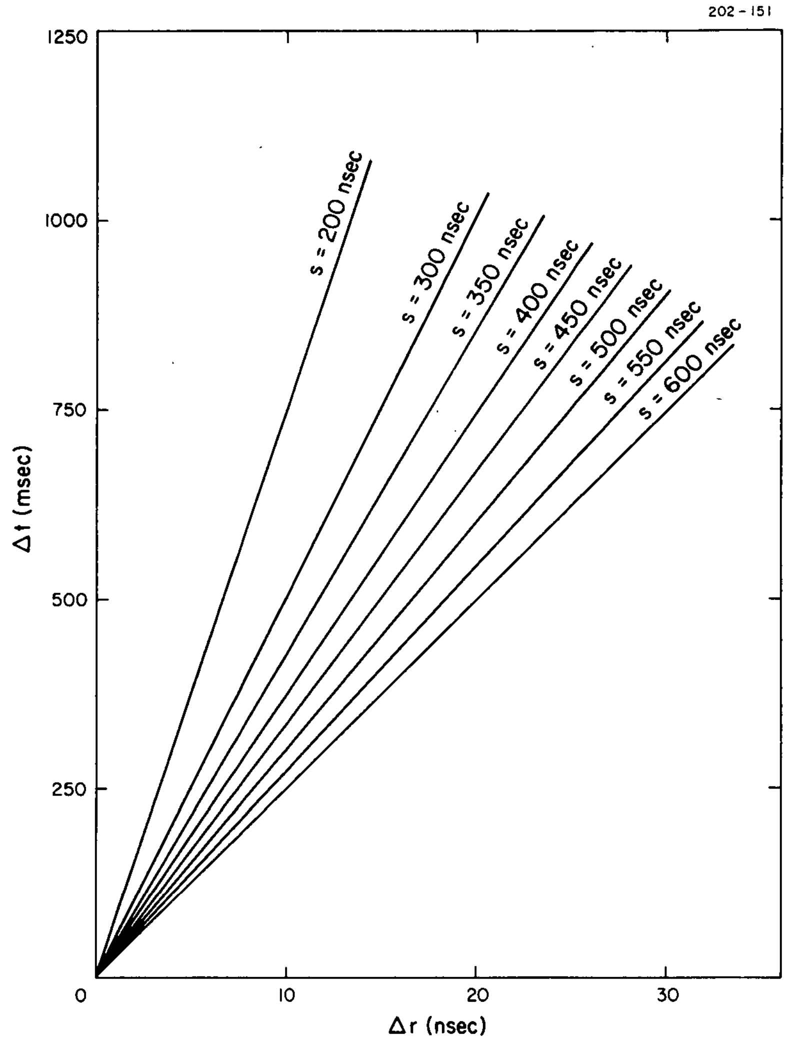

Figure 2. Typical station graph for determination of mean-anomaly error: s = propagation-time differences between successive predicted points; Δr = (observed - predicted) range propagation time; Δt = mean-anomaly correction; d = 15 sec.

3. ATMOSPHERIC-DRAG EFFECTS

The Peole satellite (7010901) has an apogee of 730 km and a perigee of 500 km. Predictions of it are difficult because not only is it subject to considerable atmospheric drag but also the drag is highly variable. Figure 3 shows the effects of drag varying by about an order of magnitude.

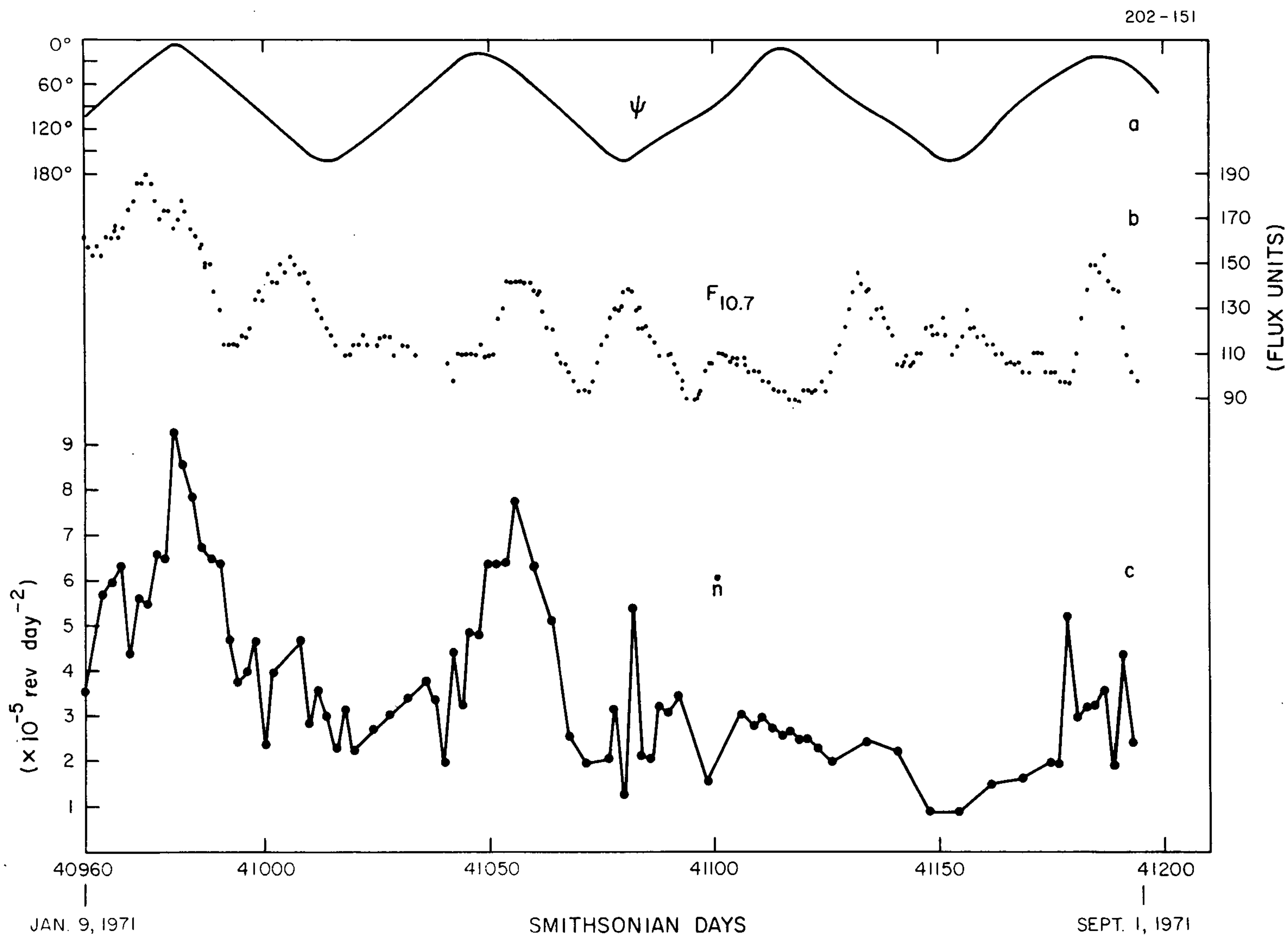

Figure 3. The effects of geocentric angle and the 10.7-cm solar flux on the orbital acceleration of Peole. (a) ψ, the geocentric angle between the perigee of Peole and the atmospheric hot spot; (b) $F_{10.7}$, the 10.7-cm solar flux; and (c), $\dot{n}$, the orbital acceleration of Peole.

For predictions to be useful for laser ranging, we estimate that the acceleration in mean anomaly (the empirically determined term that represents the effect of drag) ought to be correct within 5 or 10 parts per million. As can be readily seen from Figure 3, the term frequently changes by several times this amount in just a few days. The problem amounts to predicting the future state of the atmosphere, for which there is no satisfactory procedure.

An additional problem is that of obtaining an adequate orbital determination in the first place. Orbit determination was frequently weak because of insufficient observations.

We attempted to correlate the orbital acceleration of Peole with two parameters that are readily obtainable. The first is ψ, the geocentric angle between the satellite perigee and the center of the atmospheric "hot spot," i.e., the subsolar "bulge" in the atmosphere. We set the hot-spot center at the subsolar point delayed by 30° in longitude. The angle ψ is plotted in Figure 3, along with preliminary values of our second parameter, the 10.7-cm solar flux, which gives a rough indication of the solar influence on atmospheric activity.

It seems apparent that the shapes of both the ψ and the flux curves are reflected in the acceleration of Peole, although not in any quantitatively consistent manner.

We conclude that the only feasible way to solve the prediction problem caused by Peole's high drag is to increase the frequency of the prediction–observation–orbit-determination cycle. Yet, a cycle faster than the present twice-weekly one is impractical. Possibly, an orbit-computation capability on location at the laser sites would permit a rapid and accurate enough iteration of the cycle for the drag problem to be overcome.

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SIGNAL STRENGTH AND OBSERVABILITY

J. Latimer

One problem that the laser-ranging technique continually presents is that of observability; that is, how can the observer know if a particular satellite and laser geometrical configuration is such that he is likely to receive a sufficiently strong return signal?

Although this question applies to all satellites, an especially striking situation is that of the four magnetically stabilized satellites (BE-B, BE-C, D1C, and D1D) when they are observed from stations in the southern hemisphere. It can be very difficult to observe them successfully because the retroreflector arrays, on the north-seeking ends of these satellites, tend to face away from southern stations.

To see the effect of this problem, we selected at random 26 passes (342 observations) of BE-C observed from station 7907 (Arequipa, Peru), at latitude -17°. The observations were made between August 31 and November 5, 1971, and all give acceptably small orbit-fit residuals. Figure 1 is a plot of the passes, in the station's altitude-azimuth coordinate system. Indeed, when the satellite is in the northern half of the sky, it cannot be observed from this station. (Attempts were made to observe all passes.)

If we assume that the satellite is always oriented along the lines of the earth's magnetic field, we can calculate the aspect angle at the satellite between the symmetry axis (North) and the line of sight to the station. We used the spherical-harmonic representation (up to degree and order 4*) of Cain, Hendricks, Langel, and Hudson (1967) as the geomagnetic model and derived aspect angles (see Appendix A) for each

*Although Cain's field is represented to degree and order 10, we found that the truncated field yielded aspect angles differing only by about 1°. This is sufficient, considering that the satellite is likely to oscillate about the field direction with an amplitude of a degree or more.

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of the 342 observations. Figure 2 is a plot of the reflective area versus the angle of incidence for the BE-C satellite. Cases 1 and 2 are measured from different radial angles. We used mean values, since there is no way to determine the radial angle, and the difference is slight. The histogram in Figure 3 shows the observed frequency of occurrence of each aspect angle. The significance of the aspect angle is its relation to the effective area of the satellite retroreflector array.

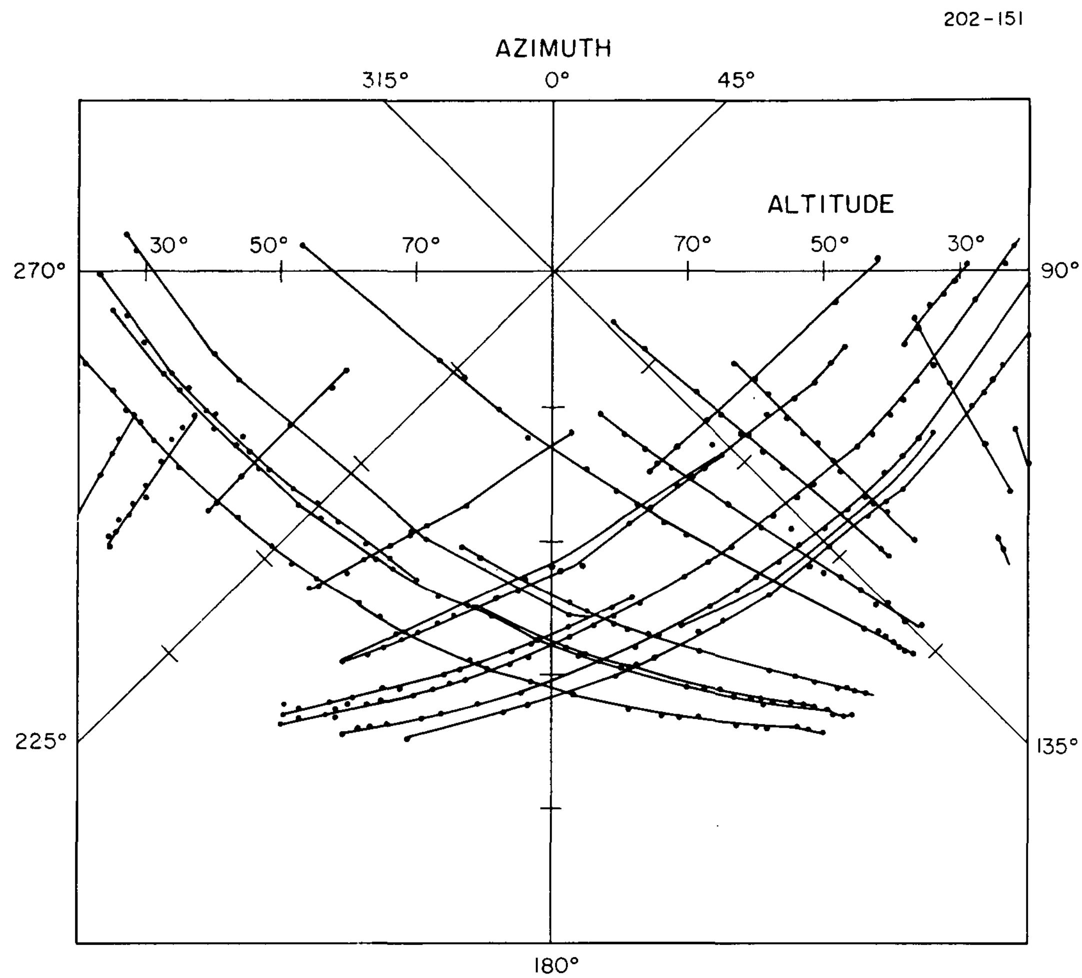

Figure 1. 26 passes of BE-C in the altitude-azimuth coordinate system of the Peru station.

We could avoid generating laser predictions for magnetically stabilized satellites that are impossible to observe by calculating the aspect angle, choosing a suitable limit for the angle, and suppressing all predicted points exceeding that limit. Although the histogram of Figure 3 serves to confirm Figure 2 (there were no returns from aspect angles greater than 110°, the Figure 3 cutoff), the slow fall-off of returns for large aspect angles suggests that we ought to consider the range equation if we wish to determine whether particular satellite—station geometries are likely to be observable.

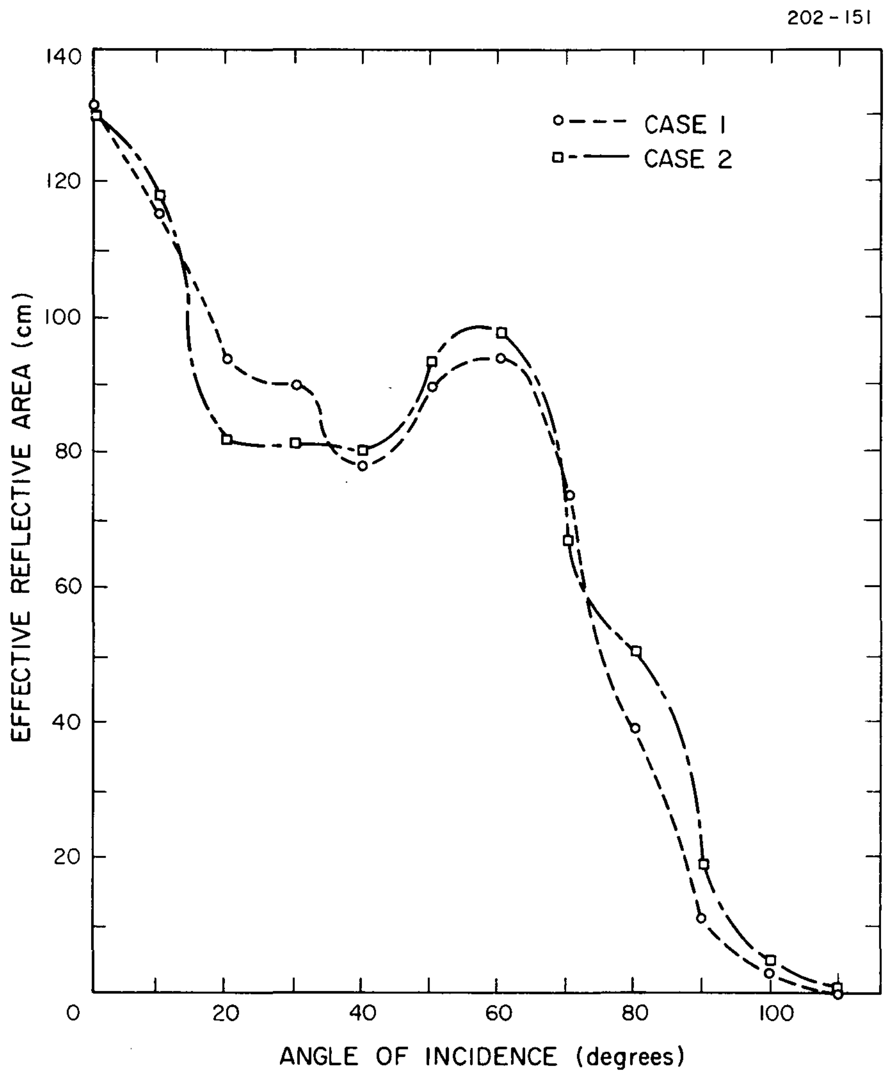

Figure 2. Reflective area vs. angle of incidence of BE-C (from Minott, 1963).

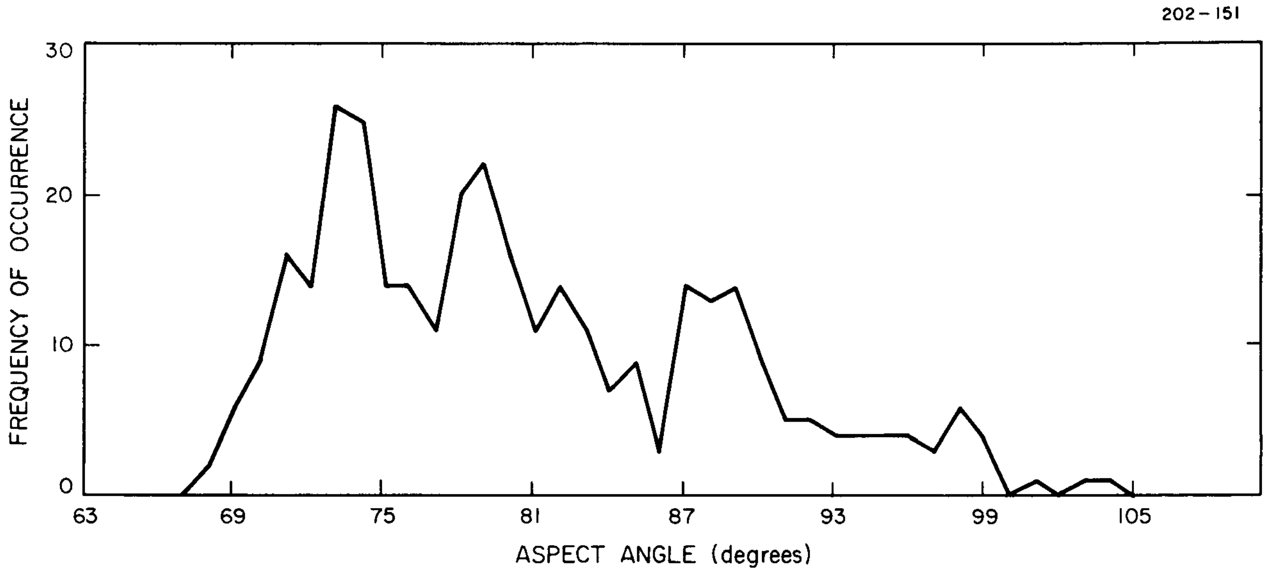

Figure 3. Histogram of the aspect angles of satellite BE-C.

We estimated average signal strengths for all the data by using the range equation of Appendix B and the retroreflector area function of Figure 2. The results are displayed in Figure 4. The large population at low signal strengths is disturbing, but we must consider the following factors:

A. Error in the assumed beam divergence. Owing to the method of recording the transmitted beam divergence, some estimates are surely too high; therefore, some signals are greater than indicated.

B. Scintillation. We estimated only the average signal — the actual signal may vary by more than an order of magnitude (Jaffe, 1971), and some of the low average signals probably yielded high actual signals.

C. Weak-signal conditions. There are many more opportunities to attempt observation under weak-signal conditions than under strong-signal conditions. Thus, although the probability of success diminishes, the number of opportunities greatly increases, yielding a significant number of weak-signal returns.

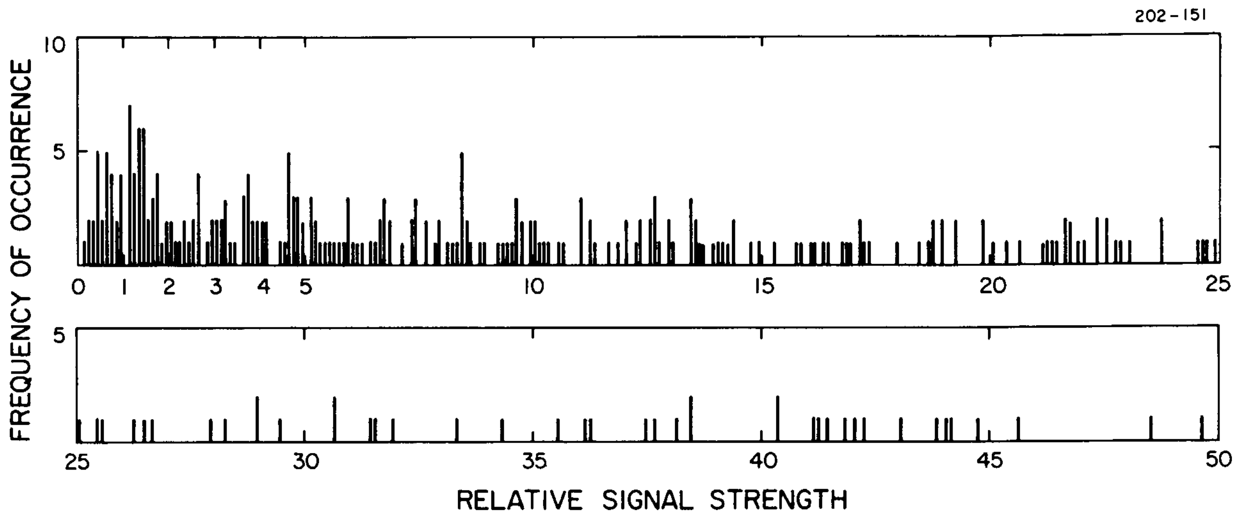

Figure 4. Histogram of relative signal strengths for Peru BE-C data.

Point C is easily verified. We constructed a uniform distribution of 706 satellite positions at a height of 1150 km (typical for BE-C) over Peru such that all points were above the elevation angle limit of 10°. By using a typical beam divergence (3.5 mrad) and the same values for the magnetic field that we used in Figure 3, we computed the expected average signal strengths. From the histogram in Figure 5, it is clear that the population of weak-signal situations is large.

In conclusion, we can see that satellite configurations yielding aspect angles greater than 110° can be suppressed without loss of possible observations. We will attempt to measure signal strengths directly in order to have a better idea of both the minimum useful signal and the statistical behavior of scintillation. In addition, we intend to extend this analysis to the gravitationally stabilized satellites Geos 1, Geos 2, and Peole. For these, the principal problem is that of obtaining returns at low station-elevation angles.

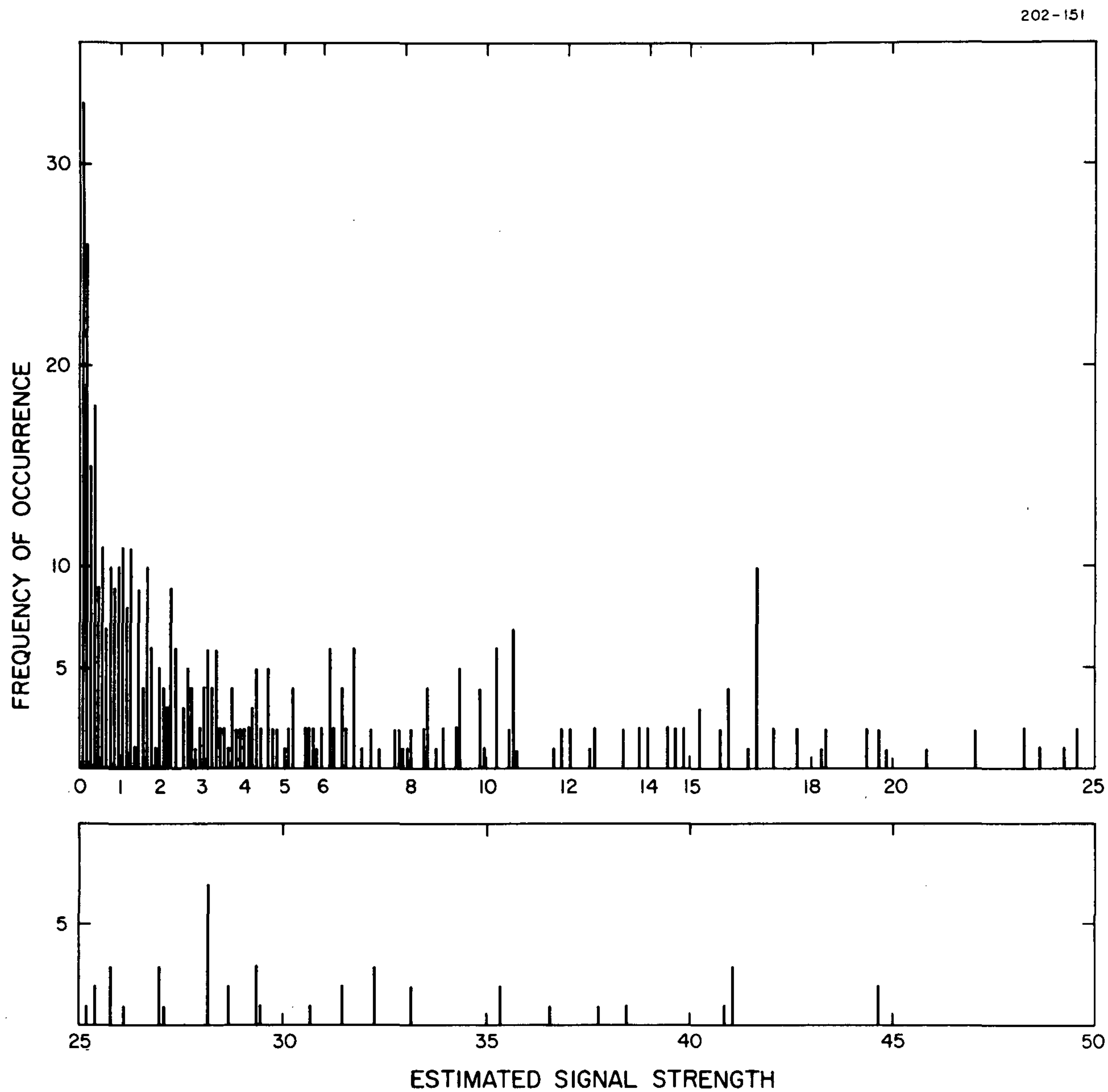

Figure 5. Histogram of estimated signal strengths for a uniform distribution of positions of BE-C from Peru.

REFERENCES

CAIN, J. C., HENDRICKS, S. J., LANGEL, R. A., and HUDSON, W. V.

1967. A proposed model for the International Geomagnetic Reference Field – 1965. NASA-TM-X-55845, 47 pp.

JAFFE, R. M.

1971. Signal strength fluctuations in a laser ranging system due to optical interference between the many reflectors on a satellite. JPL Technical Memorandum 391-218 to P. M. Muller, July 28.

MINOTT, P.O.

1963. Monthly research and advanced technology development activity report for April 1963. Optical Systems Branch, NASA/GSFC, Memorandum to H. J. Goett, April 23.

APPENDIX A

COMPUTATION OF ASPECT ANGLE α

Station position: $\vec{S}$

Observation vector (line-of-sight direction and range): $\vec{O}$

Satellite position: $\vec{P}$

Magnetic field at $\vec{P}$: $\vec{F}$

Clearly,

$$\vec{S} + \vec{O} = \vec{P}$$

and

$$\cos \alpha = - \frac{\vec{O} \cdot \vec{F}}{|\vec{O}||\vec{F}|} \quad ,$$

where $\vec{F} = \vec{F}\,(\vec{P})$; i.e.,

$$\vec{F} = -\nabla V \quad ,$$

where

$$V = a \sum_{n=1}^{n_{max}} \left(\frac{a}{r}\right)^{n+1} \sum_{m=0}^{n} \left(g_n^m \cos m\phi + h_n^m \sin m\phi\right) P_n^m\,(\theta) \quad ;$$

r, θ, and ϕ are polar coordinates for $\vec{P}$, a is the earth's mean radius, P_n^m are Schmidt normalized spherical functions, and g_n^m and h_n^m are the coefficients of the magnetic-field representation.

APPENDIX B

RANGE EQUATION

We use the range equation from Lehr (1966):

$$S = \frac{E}{2.86 \times 10^{-19}} \left(\frac{1}{R^4}\right)\left(\frac{A_s}{\Omega_t}\right)\left(\frac{A_r}{\Omega_s}\right) T^2 \quad \text{photons} \quad ,$$

where E is the output laser energy (≈ 7.2 J), R is the range to the satellite in megameters, T is the atmospheric transmission for Peru ($\approx e^{-0.071/\sin \alpha}$, where α is the elevation angle), A_s is the effective area of the satellite reflective surface, Ω_s is the solid angle of the reflected laser beam ($= 2.83 \times 10^{-9}$ sr), A_r is the effective area of the receiver aperture ($= 0.21$ m^2), and Ω_t is the solid angle of the transmitted laser beam. The numerical factor converts joules to photons at a wavelength of 6943 Å.

In addition, we use $N = S/58$ to represent the photodetector conversion efficiency, where N is the number of photoelectrons generated.

REFERENCE

LEHR, C. G.

1966. Satellite tracking with a laser. Smithsonian Astrophys. Obs. Spec. Rep. No. 215, 58 pp.

DATA FORMATS

B. R. Miller

1. INTRODUCTION

The observational data formats described are the ones used by SAO in various computer programs.

The optical observation format is the same as that used in the past. It has been reproduced here to facilitate use by ISAGEX members.

The laser format has been revised to provide room for time designation to the nearest nanosecond and range to 0.01 m. Temperature is now given in degrees Celsius, pressure in millibars, and humidity in percent.

2. SAO OPTICAL OBSERVATION CARD FORMAT AND EXPLANATION

Field	Column	Description
1	1–7	Satellite identification
	1–2	year of launch from 1900
	3–5	number of launch in that year
	6–7	particle number
		Satellite 1959 α1, for example, would be designated 5900101.
2	8–12	Observation number – Each observation of a satellite in a given year is designated by a different number. The source of an observation is also indicated by the observation number.

1-9999	miscellaneous
10000-19999	Baker-Nunn, field-reduced
30000-39999	Moonwatch
50000-59999	miscellaneous
70000-79999	photoreduced Baker-Nunn

Field	Column	Description
3	13	Blank
4	14–17	Station number – In the COSPAR numbering format, e.g., 9039 is Natal, Brazil.
5	18–23	Date of observation
	18–19	year, from 1900
	20–21	month
	22–23	day
6	24–33	Time designation – Different types of observations are made using different time systems. Different times used in reporting SAO observations are as follows: a. Field-reduced Baker-Nunn observations – generally WWV received before 1966, UTC(USNO) after. b. Photoreduced Baker-Nunn observations – A.S Note: A.S is a time scale with a fixed relation to NBS(A) before April 1968 and to A.1 after then. Values of (A.S-WWV emitted) are available in tabular form.
	24–25	hour
	26–27	minute
	28–29	second
	30–33	fraction of seconds, to 0.1 msec
7	34–52	The interpretation of the following field depends on the code in column 56. If column 56 is 0, then the observation is right ascension and declination (α, δ).
	34	blank
	35–36	hours of α
	37–38	minutes of α
	39–40	seconds of α
	41–43	fractions of seconds to 0.001 sec
	44	sign of δ
	45–46	degrees of δ
	47–48	minutes of δ
	49–50	seconds of δ

Field	Column	Description
	51–52	fractions of seconds to 0.01 sec
		If column 56 is 1, the observation is altitude and azimuth corrected for atmospheric refraction. Altitude and azimuth observations not corrected for atmospheric refraction have 3 in column 56.
	34–36	degrees of azimuth; 999 indicates azimuth is in mils
	37–38	minutes of azimuth
	39–40	seconds of azimuth
	41–43	fraction of seconds to 0.001 sec
	37–41	mils to nearest tenth if azimuth is in mils; decimal point assumed before column 41
	44	blank
	45–46	degrees of altitude; 999 indicates altitude is in mils
	47–48	minutes of altitude
	49–50	seconds of altitude
	51–52	fractions of seconds to 0.01 sec
	45–51	mils to nearest tenth if altitude is in mils; decimal assumed before column 51
		If column 56 is 4, the observation is direction cosines (ℓ, m), corrected for refraction; a 5 in column 56 indicates the observation is in direction cosines uncorrected for refraction.
	34	sign of ℓ (blank or minus)
	35–42	ℓ to 8 decimal places (decimal point implied before column 35)
	43	blank
	44	sign of m (blank or minus)
	45–52	m to 8 decimal places (decimal point implied before column 45) $n = \ell^2 + m^2$
8	<u>53–58</u>	<u>Index codes</u>
	53	time-precision index

Code	Standard error in timing σ_t
0	No estimate
1	$\sigma_t \leq 0.0003$ sec
2	$0.0003 < \sigma_t \leq 0.002$
3	$0.002 < \sigma_t \leq 0.005$

Field	Column	Description

Code	Standard error in timing σ_t
4	$0.005 < \sigma_t \leq 0.02$
5	$0.02 < \sigma_t \leq 0.05$
6	$0.05 < \sigma_t \leq 0.2$
7	$0.2 < \sigma_t \leq 0.5$
8	$0.5 < \sigma_t \leq 2.0$
9	$\sigma_t > 2.0$

54–55 position precision index

Code	Standard error in direction σ_D
00	No estimate
01	$\sigma_D \leq 1''.5$
02	$1''.5 < \sigma_D \leq 2''.5$
03	$2''.5 < \sigma_D \leq 3''.5$
04	$3''.5 < \sigma_D \leq 4''.5$
05	$4''.5 < \sigma_D \leq 5''.5$
06	$5''.5 < \sigma_D \leq 6''.5$
07	$6''.5 < \sigma_D \leq 7''.5$
08	$7''.5 < \sigma_D \leq 8''.5$
09	$8''.5 < \sigma_D \leq 9''.5$
10	$9''.5 < \sigma_D \leq 10''.5$
11	$10''.5 < \sigma_D \leq 11''.5$
12	$11''.5 < \sigma_D \leq 12''.5$
13	$12''.5 < \sigma_D \leq 13''.5$
14	$13''.5 < \sigma_D \leq 14''.5$
15	$14''.5 < \sigma_D \leq 15''.5$
16	$15''.5 < \sigma_D \leq 16''.5$
17	$16''.5 < \sigma_D \leq 17''.5$
18	$17''.5 < \sigma_D \leq 18''.5$
19	$18''.5 < \sigma_D \leq 19''.5$
20	$19''.5 < \sigma_D \leq 20''.5$
21	$20''.5 < \sigma_D \leq 22''$
22	$22'' < \sigma_D \leq 23''.5$
23	$23''.5 < \sigma_D \leq 26''$
24	$26'' < \sigma_D \leq 29''$
25	$29'' < \sigma_D \leq 33''$

Field	Column	Description

Code	Standard error in direction σ_D
26	$33'' < \sigma_D \leq 38''$
27	$38'' < \sigma_D \leq 45''$
28	$45'' < \sigma_D \leq 54''$
29	$54'' < \sigma_D \leq 1'.1$
30	$1'.1 < \sigma_D \leq 1'.3$
31	$1'.3 < \sigma_D \leq 1'.7$
32	$1'.7 < \sigma_D \leq 2'.1$
33	$2'.1 < \sigma_D \leq 2'.7$
34	$2'.7 < \sigma_D \leq 3'.5$
35	$3'.5 < \sigma_D \leq 4'.4$
36	$4'.4 < \sigma_D \leq 5'.8$
37	$5'.8 < \sigma_D \leq 7'.5$
38	$7'.5 < \sigma_D \leq 9'.7$
39	$9'.7 < \sigma_D \leq 13'$
40	$13' < \sigma_D \leq 17'$
41	$17' < \sigma_D \leq 22'$
42	$22' < \sigma_D \leq 28'$
43	$28' < \sigma_D \leq 37'$
44	$37' < \sigma_D \leq 49'$
45	$49' < \sigma_D \leq 1^\circ.1$
46	$1^\circ.1 < \sigma_D \leq 1^\circ.4$
47	$1^\circ.4 < \sigma_D \leq 1^\circ.8$
48	$1^\circ.8 < \sigma_D \leq 2^\circ.4$
49	$2^\circ.4 < \sigma_D$

56 observation type index

Code	Explanation
0	right ascension, declination
1	altitude, azimuth (corrected for refraction)
2	not used
3	altitude, azimuth (uncorrected for refraction)
4	ℓ, m (direction cosines, corrected for refraction)
5	ℓ, m (direction cosines, uncorrected for refraction)

Field	Column	Description
	57	This index refers to the date of equator and equinox to which the observation is referred. (Meaningful for right ascension and declination only.)

Index	Date
0	Date of observation
1	1855.0
2	1875.0
3	1900.0
4	1950.0

Field	Column	Description
	58	instrument description index

Code	Optical observations
0	naked eye and binoculars, visual
1	telescope, aperture less than 5 inches
2	apogee telescope, astronomical refractor or reflector, theodolite, visual
3	Baker-Nunn camera, photographic
4	small missile tele-camera, tracking cameras with focal length 20 inches or greater, photographic
5	cinetheodolite, tracking cameras with focal length less than 20 inches, photographic
6	Harvard meteor camera (Super-Schmidt), photographic
7	stationary telescope or camera with focal length equal to or less than 10 inches, photographic
8	direction observation associated with a laser instrument
9	other instruments

Field	Column	Description
9	59–64	Blank
10	65–70	Conversion from the UT1 to the A.1 time system, i.e., A.1 - UT1
	65	minus if A.1 - UT1 is negative, or tens digit if positive and necessary

Field	Column	Description
	66	units digit of A. 1 - UT1 in seconds
	67–70	decimal fraction A. 1 - UT1
11	<u>71–80</u>	<u>Identification information</u>
	71–75	film number
	76	contains an S if observation is simultaneous
12	<u>77–78</u>	<u>Passive or flash information</u> a. If the satellite is a flashing one, column 77 will contain an F and column 78 will contain the number of the flash as it actually occurred. (This does not apply to ANNA flashes.) b. If the satellite is passive, columns 77 and 78 will contain the frame number.
13	<u>79</u>	Contains the letter associated with the film number if any; otherwise it will be blank.
14	<u>80</u>	Used for balloon satellites to indicate a precision reduction correction for satellite size has been added; otherwise blank.
11	<u>71–80</u>	<u>Moonwatch</u> – used for apparent magnitude information.

Precisely reduced Baker-Nunn observations are given in the coordinate system of the <u>SAO Star Catalog</u> (equator and equinox of 1950.0). The positions have been corrected for annual aberration, and the star positions, for proper motion to the year of observation. No corrections have been applied for diurnal aberration or parallactic refraction.

The time of the observation is given in A.S (Smithsonian Atomic Time), defined by the expression

$$A.S - UTC(USNO) = 6\overset{s}{.}140768 + 0.002592000\ (T - 39856.0)$$

for the time period February 1, 1968, to the present; T is the Universal Time in Modified Julian Days (MJD), and 39856 is January 1, 1968:

$$MJD = \text{Julian Day} - 2400000.5 \quad .$$

3. SAO LASER OBSERVATION FORMATS AND EXPLANATION

Field	Column	Description
1	1–7	Satellite identification
	1–2	year of launch from 1900
	3–5	number of launch in that year
	6–7	particle number
		Satellite 1964 64A, for example, would be designated 6406401
2	8–12	Observation number
		20000-29999 uncorrected observation
		70000-79999 corrected observation
		90000-99999 GOCC laser and direction observation
3	13	Blank
4	14–17	Station number – In the COSPAR numbering format, e.g., 7921 is SAO laser site at Mt. Hopkins, Arizona. Station designations in the 7000 series include laser sites.
5	18–23	Date of observation
	18–19	year from 1900
	20–21	month
	22–23	day
6	24–35	Time designation – Different types of observations are made using different time systems. Time systems used are indicated by the code in column 57.
	24–25	hour
	26–27	minute
	28–29	second
	30–35	fraction of seconds to 1 μsec
7	36–52	Interpretation of the following field depends on the codes in columns 56 and 57.
	36	blank

Field	Column	Description
	37–46	range in meters (decimal implied before column 45 allows range observations to be specified to 0.01 m)
	47–48	blank
	49–52	value of refractivity correction to 0.01 m – code 1 in column 57
8	53–58	Index codes
	53	time precision index
		Code — Standard error in timing σ_t
		0 — $\sigma_t \leq 0.000005$ sec
		1 — $\sigma_t \leq 0.0003$ sec
	54–55	standard deviation of the range σ_r in meters and tenths of meters
	56	observation type index
		Code — Explanation
		1 — altitude, azimuth on laser instrument
		8 — laser range
	57	code to indicate time system and corrections applied
		Code — Explanation
		0 — UTC emitted at transmission of laser pulse – no corrections applied to range
		1 — A.S time at reception of laser pulse – refractivity correction given in columns 49–52 but not applied to range
		2 — A.S time at reception of laser pulse – refractivity correction applied to range
		3 — UTC time at the satellite (GOCC observations – refractivity correction applied to range)
	58	Instrument description index
		Code — Explanation
		8 — Laser observation
9	59–64	Range correction – pulse shape and size – codes 0 and 1 in column 57
	59	sign
	60	meters

Field	Column	Description
	61	10 centimeters
	62	centimeters
	63–64	blank
11	65–77	Pressure, humidity, temperature – uncorrected observations only, code 0 in column 57
	65–66	blank
	67–70	barometric pressure in millibars
	71–72	humidity in percent
	73	sign of temperature
	74–76	temperature to tenths of degrees Celsius
	77	blank
	65–77	Conversion from the UT1 to the A. 1 time system i.e., A. 1 - UT1 (actually A. S), code 2 in column 57
	65	minus if A. S - UT1 is negative, or tens digit if positive and necessary
	66	units digit of A. S - UT1 in seconds
	67–72	decimal fraction of A. S - UT1
	74–77	blank
12	78–80	Identification information
	78	blank
	79	type of laser pass
	80	blank

Type of laser pass (column 79):

Code	Explanation
0	night pass, satellite illuminated
1	night pass, satellite in shadow
2	daylight pass

DATA VALIDATION

E. M. Gaposchkin and G. M. Mendes

Each observing station performs the following calibration exercises:

A. Determination of the fundamental system delays to be applied to measured time intervals.

B. Precision check of the fundamental time-interval measurement.

C. Determination of the reliability of an individual measurement.

D. Calculation of the reproducibility of an individual measurement.

Even with this elaborate procedure, further checking and information are necessary; two approaches are employed:

A. Pass analysis, which depends on trends, noise, and consistency of the data.

B. Comparison of observations with precision orbit computation.

This latter approach, the primary tool used, is the subject of this section.

Laser data have a precision of 1 m and an accuracy that is probably somewhat better. On the other hand, our current set of geodetic parameters is based primarily on 20- to 40-m camera data. From the determination of these geodetic results, Gaposchkin and Lambeck (1970, 1971) estimated the station coordinates to an accuracy of 5 to 10 m. The accuracy of our orbit computation is no better than 5 to 10 m for optimum satellites (Geos 1) and significantly worse for others (Peole). It is clear that we cannot obtain an unambiguous validation of 1-m laser data with a 10-m tool.

Orbits were computed with 4 days of data every 2 days, i.e., with 2 days of overlap. Four days was usually sufficient to compute a reliable orbit, yet short enough to minimize the effects of errors in the gravity field and station coordinates.

Owing to the paucity of laser data, we have also incorporated other tracking data, including minitrack and field-reduced Baker-Nunn. As the main computation center, SAO received laser data from CNES and GSFC to be used for predictions. We included these data in our reference orbits, although we recognized that such data did not have the benefit of refinement and validation by the originating agency. The supplementary laser data used were from stations 7050 (GSFC), 7060 (Guam), 7815 (moved to 7809, Haute Provence), and 7804 (San Fernando). The data from station 7820 (Dakar) were not included because of uncertainties in the coordinates and timing. It was not our purpose to validate the data from other agencies, but our success in validation indeed hinged on having these supplementary laser data.

Very bad data were easy to detect. The detection of poor data proved to be very difficult. Ultimately, three rules were applied:

A. The successive orbits had to be consistent. Nonuniform evolution of the mean orbital elements indicated poor data had been included in the orbit determination.

B. Orbital residuals had to be consistent (i.e., reproducible) in the two computed orbits. Using a conservative estimate of the orbital accuracy, observations that had residuals greater than 50 m (500 m for Peole) were rejected.

C. The run of residuals in a pass had to be smooth. A large variation in residuals ($\geq$50 m) from point to point (1 sec apart) must be an observational error as there is no unmodeled orbital perturbation of that magnitude. The run (trend or signature) of the residuals is a very powerful device and hinges on having more than 10 observations per pass. Many passes early in ISAGEX did not have sufficient data for this test to be applied, and these were consequently very difficult to validate.

The applications of these rules had varying degrees of success. The confidence we can put in the validated data varies considerably from satellite to satellite and from period to period. Some of the data in periods II and III are questionable. Such data are distributed so that only when they are combined with laser and precision-reduced camera data can a final evaluation be made.

A few data were analyzed on a pass-by-pass (short arc) basis. This involved use of the orbit-computation program as an interpolation device, determining the parameters I, e, M_0, and n. The other orbital elements were held fixed at the values computed from long-arc computation. This interpolation will reject the groww outliers and will provide a measure of the noise (i.e., the precision) of the data. We have found this noise to be 50 to 100 cm. Figure 1 gives the typical residuals from a short-arc orbital fit.

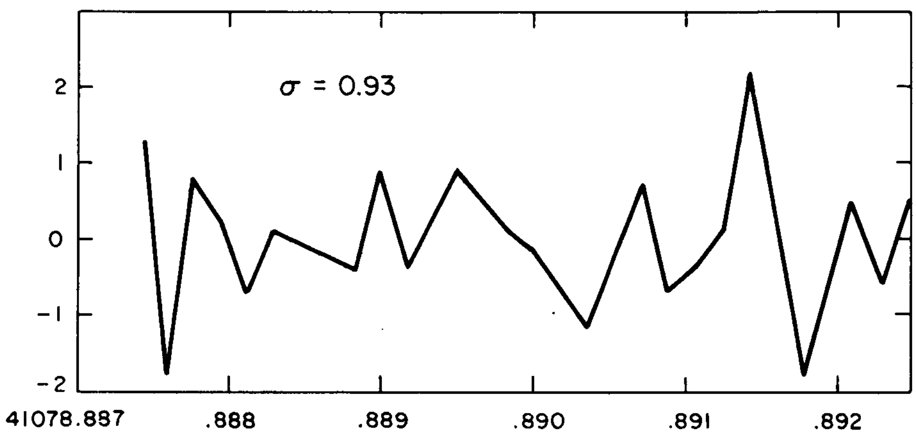

Figure 1. Residuals for short-arc fit of satellite 6508901 from station 7907.

It became apparent that the trend of residuals for 4-day arcs would provide the same information when plotted as the short-arc residuals do. Further, bad points not discarded by the short-arc procedure often resulted in poor short-arc fits. The longer arcs discarded these bad points. In addition, many passes had so few points (< 5) that short arcs were not possible. Finally, short-arc computation provided no estimate of the accuracy. We therefore abandoned this approach and proceeded to use 4-day arcs.

The SAO and the French laser data were input to our processing program in A.S time at reception of the laser pulse and without the refraction correction given. The refraction correction was computed following Tsiang and Lehr (this volume), and time was converted to A. S at the satellite for orbital computation. The GSFC laser data were input in UTC time at the satellite and with refraction applied to range; again, time was converted to A. S at the satellite. We also used as inputs the tesseral harmonics determined in Standard Earth (II) (Gaposchkin and Lambeck, 1970), the station coordinates listed in Table 1 below, and the polar-motion values published by BIH. In Table 1, the station coordinates are given in megameters and the weight in arcseconds for all but the laser stations, which are in meters. Photoreduced weights where applicable are in parentheses.

Figure 2 gives the residuals of the same pass as in Figure 1 as it appears in a 4-day arc. The interpolation curve has been drawn to illustrate the short-arc fit. This particular pass was chosen because it was representative of SAO's ISAGEX laser data. It has a noise level of 0.93-m rms and an accuracy of 2.2-m rms.

Figure 3 gives the history of the semimajor axis for Geos 1 (6508901). The scatter appears to be less than 1 m, which indicates that the data are good, well-distributed, and well-understood. Geos 1 is a well-behaved satellite with an inclination of 59°. It is visible to many stations, thus giving rise to a nicely distributed data set. Its eccentricity of 0.071 presents no problems in the determination of the argument of perigee, and if we look at M2 as an indication of the magnitude of the modeled drag, we see that it is about 5×10^{-7} rev day^{-2}, or 0.65 arcsec day^{-2}.

Figure 4 gives the semimajor axis for Peole (7010901), with a scatter of less than 10 m. With an inclination of 15°, an eccentricity of 0.016, and M2 of 3×10^{-5} rev day^{-2} (0.65 arcmin day^{-2}), orbit computation for Peole is very challenging. Its inclination made it visible to very few stations (7907, 7929, 7060, 4492, 4800), four of which are in South America, giving rise to a badly distributed view of the satellite's orbit. Satellites with small inclinations make computation of both the argument of node and the argument of perigee difficult. The modeling of the drag and the solving for $\dot{\omega}$ and $\dot{\Omega}$ became impossible. We assumed values for $\dot{\omega}$ and $\dot{\Omega}$, held them fixed, and solved for the drag modeling. This worked satisfactorily, but not so well as we had expected for laser data.

Table 1. Station coordinates used in the validation.

Station Location	COSPAR Number	X	Y	Z	Weight (arcsec)
		Baker-Nunn Stations			
San Fernando, Spain	9004	5.105588	-0.555228	3.769667	34 (4)
Naini Tal, India	9006	1.018203	5.471103	3.109623	34 (4)
Maui, Hawaii	9012	-5.466053	-2.404282	2.242171	34 (4)
Dakar, Senegal	9020	5.886264	-1.845649	1.615282	34 (4)
Mt. Hopkins, Arizona	9021	-1.936782	-5.077704	3.331916	34 (4)
Olifantsfontein, South Africa	9022	5.056125	2.716511	-2.775784	34 (4)
Island Lagoon, Australia	9023	-3.977765	3.725101	-3.303034	34 (4)
Dodaira, Japan	9025	-3.910438	3.376362	3.729219	34 (4)
Arequipa, Peru	9027	1.943040	-5.804207	-1.796491	34 (4)
Debre Zeit, Ethiopia	9028	4.903750	3.965201	0.963872	34 (4)
Dionysos, Greece	9030	4.595200	2.039446	3.912606	34 (4)
Natal, Brazil	9039	5.186461	-3.653856	-0.654325	34 (4)
Rosamund, California (AF)	9113	-2.450011	-4.624421	3.635035	34 (4)
Cold Lake, Canada (AF)	9114	-1.264838	-3.466884	5.185467	34 (4)
Johnston Island (AF)	9117	-6.007402	-1.111859	1.825730	34 (4)
Mt. John, New Zealand (AF)	9119	-4.533650	0.761590	-4.407772	34 (4)
San Vito, Italy (AF)	9120	4.613757	1.485659	4.132293	34 (4)
		Laser Stations			(m)
GSFC, Maryland	7050	1.130673	-4.831368	3.994112	2
Guam Island	7060	-5.068960	3.584106	1.458756	2
Salisbury, Australia	7803	-3.939150	3.467040	-3.613265	2
San Fernando, Spain	7804	5.105606	-0.555251	3.769633	2
Haute Provence, France	7809	4.578352	0.457957	4.403160	2
Haute Provence, France	7815	4.578371	0.457950	4.403134	2
Dakar, Senegal	7820	5.886271	-1.845666	1.615250	2
Olifantsfontein, South Africa	7902	5.056125	2.716511	-2.775784	2
Arequipa, Peru	7907	1.942775	-5.804081	-1.796933	2
Mt. Hopkins, Arizona	7921	-1.936781	-5.077701	3.331921	2
Natal, Brazil	7929	5.186461	-3.653856	-0.654325	2
Dionysos, Greece	7930	4.595207	2.039446	3.912595	2

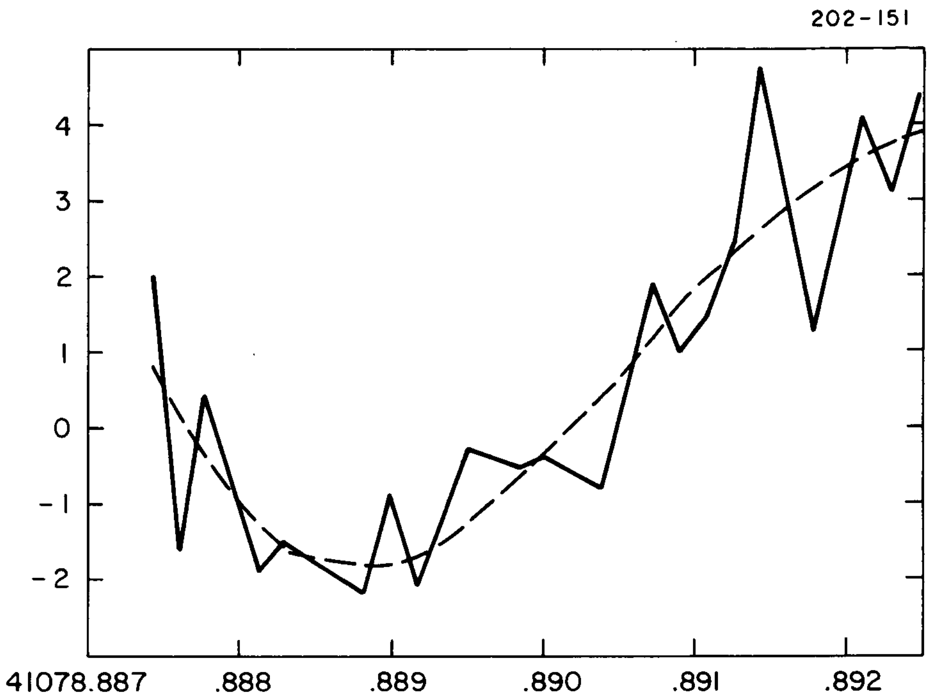

Figure 2. Residuals for 4-day fit for satellite 6508901 from station 7907.

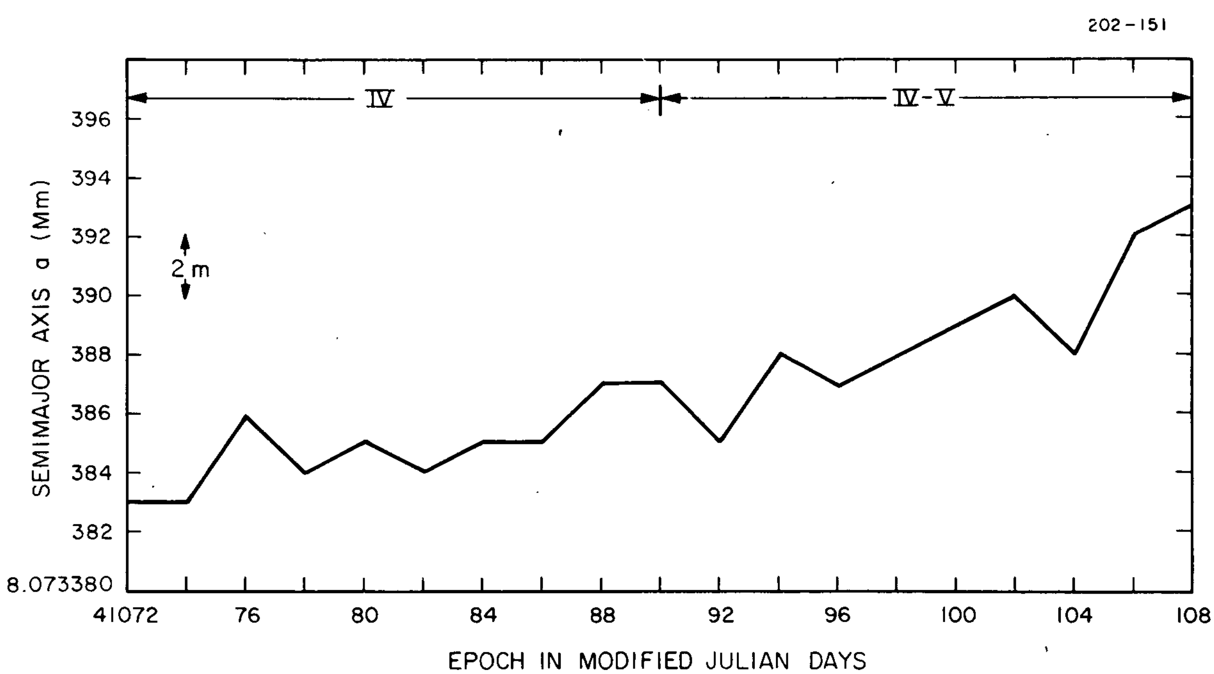

Figure 3. Evolution of semimajor axis for satellite 6508901 during ISAGEX periods IV and V.

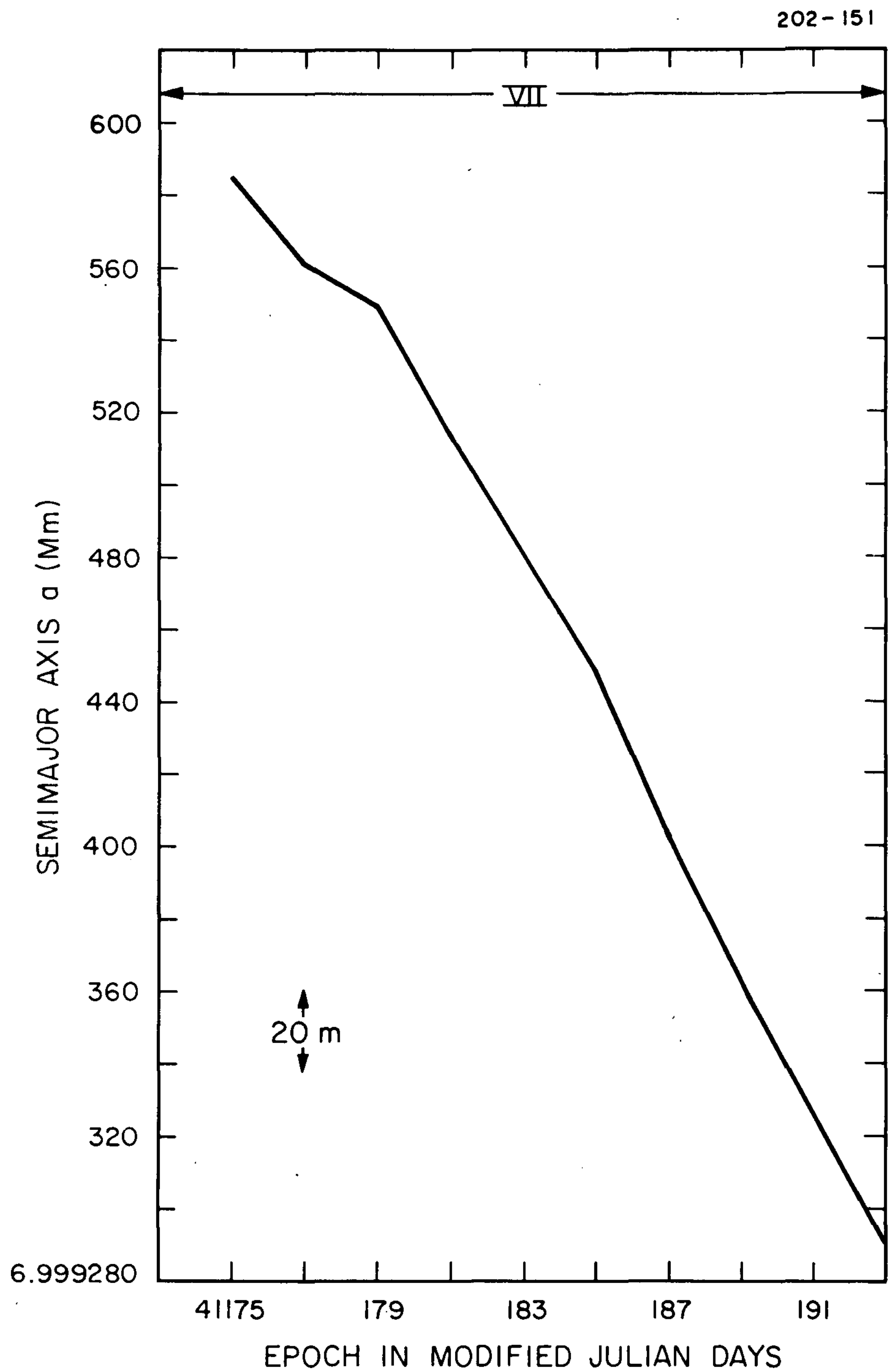

Figure 4. Evolution of semimajor axis for satellite 7010901 during ISAGEX period VII.

The scatter for the remaining satellites was about 3 m, except for BE-B (6406401), which had so few data that its scatter was about 7 m.

The number of validated SAO laser points broken down by station is given in Table 2. The ISAGEX periods covered by these data are listed in Table 3, where an X indicates a validated time period (Note: in-between time periods were also validated where possible).

Table 2. Number of validated SAO laser points.

	Station					
Satellite	7902	7907	7921	7929	7930	Total
6406401	-	12	13	5	-	30
6503201	3	162	3	41	33	242
6508901	3960	1408	164	528	106	6166
6701101	-	-	9	3	88	100
6701401	-	235	412	43	109	799
6800201	937	466	137	276	42	1858
7010901	-	35	-	230	-	265
Total	4900	2318	738	1126	378	9460

Table 3. Validated ISAGEX periods.

Satellite	II Feb. 15–Mar. 8 MJD 40997–41019		III Mar. 15–Apr. 15 41035–41057		IV Apr. 29–May 20 41070–41092		V June 5–26 41107–41129		VI July 14–31 41146–41164		VII Aug. 11–31 41174–41195
6406401			X								
6503201	X										X
6508901	X	X	X	X	X	X	X	X	X	X	X
6701101							X				
6701401					X				X		
6800201			X	X	X	X	X	X	X	X	X
7010901	X		X		X		X				X

As a result of our validation process, we can conclude the following:

A. The use of error signatures can be successfully employed to validate data. By error signatures, we mean:

1) Large scatter in the data.
2) Inconsistent mean orbital elements.
3) Lack of systematic trends in the residuals.

To observe these signatures, we require more than 10 observations per pass.

B. The overall accuracy of the data is at least 1 m, and the noise level, 60 cm.

C. The overall accuracy of our geodesy is 10 m for Geos-type satellites, as can be seen from the standard error of unit weight for orbital fits as reported by Gaposchkin and Mendes (this volume). This accuracy confirms the evaluation of Gaposchkin and Lambeck (1970, 1971). The weight for laser data was taken as 2 m.

D. With routine validation by use of Geos 1 data, a monitoring of a station's reliability to the 10- to 20-m level is possible.

REFERENCES

GAPOSCHKIN, E. M., and LAMBECK, K.

1970. 1969 Smithsonian Standard Earth (II). Smithsonian Astrophys. Obs. Spec. Rep. No. 315, 93 pp.

1971. Earth's gravity field to the sixteenth degree and station coordinates from satellite and terrestrial data. Journ. Geophys. Res., vol. 76, pp. 4855-4883.

G

ORBITAL ELEMENTS FROM ISAGEX DATA

E. M. Gaposchkin and G. M. Mendes

The process of data validation hinges on a consistent evolution of orbital elements derived from the data. These elements are also useful for other analyses – e.g., of zonal harmonics and earth tides – and are given here. Only those ISAGEX data available at SAO for validation were used; the orbital elements will be revised when the complete set of data has been processed. However, these orbits are an improvement over previous ones, especially for Peole (7010901), the first geodetic satellite with such a low inclination. This catalog of satellite data is similar to those previously published by SAO (see, e.g., Miller, 1968). The orbital elements are mean elements in the sense that the effects of the short-period perturbations due to the earth's gravity field have been eliminated.

The SAO mean elements have been computed from observations covering several days and are given in the form of a table. The successive sets of elements are essentially independent of each other. Only entries that are considered satisfactory are given. A missing epoch is due to insufficient data.

The times of epoch in the mean elements are reckoned in Julian Days. For convenience, the number 2400000.5 has been subtracted to provide an abbreviated rotation, which we call "Modified Julian Days" or MJD.

The units of the orbital elements are degrees for angular quantities, megameters for metric quantities, and revolutions for the mean anomaly.

The tabulated values of SAO mean elements are as follows:

line 1 Satellite designation, epoch, first and last dates, standard error of unit weight, number of observations, and date the orbit was computed.

line 2 Epoch.

line 3 ω, argument of perigee and secular rate.

line 4 Ω, right ascension of the ascending node and secular rate.

line 5 I, inclination.

line 6 e, eccentricity.

line 7 M, mean anomaly; n, mean motion; and higher polynomial term(s) as appropriate.

These elements include the long-period perturbations evaluated with the zonal harmonics as tabulated in Gaposchkin and Lambeck (1970, 1971); the short-period perturbations due to the geopotential computed with the numerical values given in Gaposchkin and Lambeck (1970, 1971); and the lunar perturbations with period $2\lambda_☾$ computed as given by Gaposchkin (1966). The fundamental constants GM, ae, and the velocity of light are as follows:

$$GM = 3.986013 \times 10^{20}\ \mathrm{cm}^3\ \mathrm{sec}^{-2} \quad ,$$

$$ae = 6.378155 \times 10^{8}\ \mathrm{cm} \quad ,$$

$$c = 2.997925 \times 10^{10}\ \mathrm{cm\ sec}^{-1} \quad .$$

The station coordinates used are given in Gaposchkin and Mendes (this volume).

The reference system adopted results in the inclination and the argument of perigee referred to the true equator of date. The right ascension of the ascending node is reckoned from the mean equinox of 1950.0 along the corresponding mean equator to the intersection with the moving true equator of date, and then along the true equator of date. To transform the right ascension of the node to the mean equinox of date, the following formula is used:

$$\Omega^\circ = \Omega^\circ(\mathrm{SAO}) + 3^\circ\!.508 \times 10^{-5}\ (\mathrm{MJD} - 33281) \quad .$$

The orbital theory used defines the mean elements. The orbit-computation program employed here is based on a set of formulas due to Aksnes (1970) for the short-period oblateness perturbations. The relationship between the mean elements from Von Zeipel's method as previously published and those by the Lie transform method is given by Aksnes (this volume).

REFERENCES

AKSNES, K.

1970. A second-order artificial satellite theory based on an intermediate orbit. NASA TR 32-1507, 34 pp.; also in Astron. Journ., vol. 76, pp. 1066-1076.

GAPOSCHKIN, E. M.

1966. Orbit determination. In Geodetic Parameters for a 1966 Smithsonian Institution Standard Earth, ed. by C. A. Lundquist and G. Veis, Smithsonian Astrophys. Obs. Spec. Rep. No. 200, vol. 1, pp. 77-183.

GAPOSCHKIN, E. M., and LAMBECK, K.

1970. 1969 Smithsonian Standard Earth (II). Smithsonian Astrophys. Obs. Spec. Rep. No. 315, 93 pp.

1971. Earth's gravity field to the sixteenth degree and station coordinates from satellite and terrestrial data. Journ. Geophys. Res., vol. 76, pp. 4855-4883.

MILLER, B., prepared

1968. Satellite orbital data, No. E-8. Smithsonian Astrophys. Obs. Spec. Rep. No. 290, 27 pp.

```
ORBIT
6406401                              41039    41035.0    41043.0      6.2780              60 01/17/72
P111       P111          P01           P111        P2111
  41039.000000       0.000000
  278.7807087280     -2.5180119844
  104.2687772770     -1.0787354273
   79.6679111814
     .0130767652       .0000098865
     .6780021561    13.7530048479        -1.9235E-07
         41039.00000           6.2780158724
  279.492806  104.268962   79.668055   .0120234    .6760245 13.7530048  7.3587451
ORBIT
6406401                              41043    41039.0    41047.0       .5269              45 01/17/72
P111       P111          P01           P111        P2111
  41043.000000       0.000000
  267.9946786661     -2.5744462705
   99.9635079570     -1.0797526566
   79.6863826585
     .0128931657      -.0000061161
     .6920803435    13.7531762692         1.5877E-06
         41043.00000            .5268857402
  267.829040    99.963466   79.686526   .0118275    .6925404 13.7531763  7.3586840
ORBIT
6406401                              41047    41043.0    41051.0      1.1939              61 01/17/72
P111       P111          P01           P111        P2111
  41047.000000       0.000000
  257.7302525130     -2.5582226726
   95.6434764827     -1.0799686443
   79.6867130913
     .0128562431      -.0000042422
     .7047209088    13.7531407589         1.0621E-06
         41047.00000           1.1938933219
  256.721349    95.643224   79.686853   .0118141    .7075229 13.7531409  7.3586966
ORBIT
6406401                              41051    41047.0    41055.0      2.1951              69 01/17/72
P111       P111          P01           P111        P2111
  41051.000000       0.000000
  247.5190572756     -2.5621451381
   91.3241079095     -1.0791272461
   79.684613864
     .0128611320       .0000030856
     .7172441151    13.7531626909         1.5213E-06
         41051.00000           2.1951327142
  245.704314    91.323653   79.684746   .0118756    .7222841 13.7531627  7.3586888
ORBIT
6406401                              41055    41051.0    41059.0      1.4235              58 01/17/72
P111       P111          P01           P111        P2111
  41055.000000       0.000000
  237.3005547540     -2.5803504425
   87.0010910753     -1.0803016506
   79.6883003128
     .0128640109       .0000054804
     .7298320939    13.7532274552         3.4794E-06
         41055.00000           1.4234942516
  234.736483    87.000448   79.688421   .0119661    .7369531 13.7532275  7.3586657
```

ORBIT
1965 32 A 41176 41174.0 41178.0 1.3921 445 12/29/71
P111 P111 P01 P111 P2111
41176.000000 0.000000
51.4878190650 5.1755335441
193.0539252842 -4.2543781674
41.1678686851
.0250807130 .0000006856
.4141977638 13.3558633786 1.2705E-06

ORBIT
1965 32 A 41178 41176.0 41180.0 1.6365 487 12/29/71
P111 P111 P01 P111 P2111
41178.000000 0.000000
61.8320762630 5.1714191338
184.5448354768 -4.2540835592
41.1681490609
.0250825680 .0000012936
.1259486040 13.3558792278 1.4522E-06

ORBIT
1965 32 A 41180 41178.0 41182.0 1.1616 450 12/29/71
P111 P111 P01 P111 P2111
41180.000000 0.000000
72.1718633352 5.1709332587
176.0364093575 -4.2543064897
41.1682824112
.0250856579 .0000011346
.8377211623 13.3558856531 1.0064E-06

ORBIT
1965 32 A 41182 41180.0 41184.0 1.0551 449 12/29/71
P111 P111 P01 P111 P2111
41182.000000 0.000000
82.5062382367 5.1808836927
167.5265263519 -4.2530506393
41.1685680823
.0250920320 .0000000646
.5495186723 13.3558598719 1.5352E-06

ORBIT
1965 32 A 41184 41182.0 41186.0 1.2162 455 12/29/71
P111 P111 P01 P111 P2111
41184.000000 0.000000
92.8625175697 5.1723704382
159.0197780565 -4.2536453522
41.1684976223
.0250926050 .0000017425
.2612673517 13.3558888821 1.0479E-06

ORBIT
1965 32 A 41186 41184.0 41188.0 1.1936 389 12/29/71
P111 P111 P01 P111 P2111
41186.000000 0.000000
103.2098141995 5.1747032716
150.5123965610 -4.2535632610
41.1684054067
.0250934159 -.0000007728
.9730367882 13.3558878169 1.1100E-06

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ORBIT
1965 32 A                    41188   41186.0   41190.0    1.0500          309 12/29/71
P111      P111      P01       P111      P2111
  41188.000000      0.000000
  113.5506630019    5.1724020085
  142.0036298030   -4.2542558616
   41.1690633412
     .0250963476     .0000034178
     .6848427686   13.3558980060       6.7377E-07
ORBIT
1965 32 A                    41190   41188.0   41192.0     .9554          237 12/29/71
P111      P111      P01       P111      P2111
  41190.000000      0.000000
  123.8887552076    5.1731138232
  133.4950433373   -4.2540263931
   41.1683266643
     .0251038676    -.0000049336
     .3966618788   13.3558993210      -9.7180E-07
ORBIT
1965 32 A                    41192   41190.0   41194.0     .8824          265 12/29/71
P111      P111      P01       P111      P2111
  41192.000000      0.000000
  134.2255677779    5.1671480773
  124.9869040354   -4.2550264099
   41.1682421744
     .0251009891     .0000042996
     .1084858018   13.3559187237       7.8128E-07
ORBIT
1965 32 A                    41194   41192.0   41196.0    1.0041          239 12/29/71
P111      P111      P01       P111      P2111
  41194.000000      0.000000
  144.5832025327    5.1876716646
  116.4768674715   -4.2544121473
   41.168234933
     .0250906913    -.0000121801
     .8202667524   13.3558666877      -4.5781E-07
```

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ORBIT
1965 89 A                     40999   40997.0   41001.0     2.8434             78 01/13/72
P111       P111        P01        P111       P31111
 40999.000000          0.000000
 330.4581490518         .5794357587
  87.0023513990       -2.2414144378
  59.3579641471
    .0712390167         .0002534964
   -.5833702426       11.9680930683        9.8182E-06       -6.2535E-06
        40999.00000            2.8434130479
 331.358479    87.035964    59.359423    .0706288    .4141335 11.9680931   8.0733197
ORBIT
1965 89 A                     41001   40999.0   41003.0     2.9988             87 01/13/72
P111       P111        P01        P111       P31111
 41001.000000          0.000000
 331.6675485335         .6272650946
  82.5172397793       -2.2451186191
  59.3627754590
    .0717276119         .0002221698
    .3526904904       11.9679759819        5.0628E-06        3.4275E-06
        41001.00000            2.9988010002
 332.572289    82.551534    59.364186    .0711511    .3501821 11.9679768   8.0733723
ORBIT
1965 89 A                     41003   41001.0   41005.0     2.1273             84 01/13/72
P111       P111        P01        P111       P31111
 41003.000000          0.000000
 333.0368893658         .6569786875
  78.0208966416       -2.2493428352
  59.3685275863
    .0716666243         .0000198968
    .2884402077       11.9679421789       -4.7176E-06       -3.7405E-06
        41003.00000            2.1273109105
 333.953390    78.055637    59.369870    .0711173    .2858991 11.9679422   8.0733875
ORBIT
1965 89 A                     41005   41003.0   41007.0     1.4791             95 01/13/72
P111       P111        P01        P111       P31111
 41005.000000          0.000000
 334.3348194527         .6481535275
  73.5249735744       -2.2476890873
  59.3687055772
    .0716668138        -.0000039927
    .2243516374       11.9679516145        7.8469E-07        2.2791E-06
        41005.00000            1.4791436913
 335.260746    73.560074    59.369984    .0711438    .2217843 11.9679516   8.0733833
ORBIT
1965 89 A                     41007   41005.0   41009.0     1.2410            102 01/13/72
P111       P111        P01        P111       P31111
 41007.000000          0.000000
 335.6350312447         .6579176477
  69.0313633199       -2.2477739640
  59.3697691886
    .0716634930         .0000039769
    .1602591652       11.9679368346       -3.8217E-06       -4.5077E-06
        41007.00000            1.2409517950
 336.570032    69.065817    59.370982    .0711670    .1576666 11.9679368   8.0733899
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ORBIT
1965 89 A                         41009   41007.0   41011.0     1.3495         158 01/13/72
P111      P111      P01       P111      P31111
  41009.000000      0.000000
  336.9408370566     .6487375812
   64.5370590501   -2.2467730231
   59.3678860228
     .0716697253     .0000043157
     .0961541428   11.9679600021      -2.3289E-06      -1.5266E-06
        41009.00000          1.3494774264
  337.884623   64.572812   59.369033   .0712003    .0935389 11.9679600   8.0733795
ORBIT
1965 89 A                         41011   41009.0   41013.0     1.3281         153 01/13/72
P111      P111      P01       P111      P31111
  41011.000000      0.000000
  338.2518319238     .6481649782
   60.0433297624   -2.2481952358
   59.3701754610
     .0716644470     .0000025338
     .0320346803   11.9679576604      -1.2589E-06       2.1223E-06
        41011.00000          1.3281092828
  339.203299   60.079416   59.371256   .0712221    .0293964 11.9679577   8.0733806
ORBIT
1965 89 A                         41013   41011.0   41015.0     1.2042         182 01/13/72
P111      P111      P01       P111      P31111
  41013.000000      0.000000
  339.5564392098     .6575505263
   55.5496559679   -2.2462530924
   59.3689291979
     .0716564594     .0000144582
     .9679287823   11.9679332943       2.8702E-06      -1.4573E-06
        41013.00000          1.2042341021
  340.515293   55.586003   59.369943   .0712415    .9652700 11.9679333   8.0733915
ORBIT
1965 89 A                         41015   41013.0   41017.0     1.4589         218 01/13/72
P111      P111      P01       P111      P31111
  41015.000000      0.000000
  340.8624099077     .6508604100
   51.0567300505   -2.2458525195
   59.3678832578
     .0716684274    -.0000028040
     .9038221746   11.9679496361       6.0768E-07       1.1765E-06
        41015.00000          1.4589444203
  341.828018   51.093327   59.368830   .0712731    .9011446 11.9679496   8.0733842
ORBIT
1965 89 A                         41017   41015.0   41019.0     1.4991         148 01/13/72
P111      P111      P01       P111      P31111
  41017.000000      0.000000
  342.1804524979     .6554004103
   46.5619938832   -2.2467178804
   59.3722493089
     .0716611287    -.0000005455
     .8396878317   11.9679521973      -1.6553E-06      -3.6465E-06
        41017.00000          1.4990930963
  343.152972   46.598901   59.373128   .0713015    .8369910 11.9679522   8.0733830
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ORBIT
1965 89 A                        41019   41017.0   41021.0     2.9056          262 01/17/72
P111     P111      P01      P111      P31111
  41019.000000        0.000000
  343.4803746514       .6536132967
   42.0680429194     -2.2458895651
   59.3717497483
     .0716647773       .0000041754
    .7756017992    11.9679473747      1.7289E-07      -8.2631E-07
        41019.00000          2.9056039362
  344.458638   42.105168    59.372561   .0713329    .7728890 11.9679474  8.0733852
ORBIT
1965 89 A                        41021   41019.0   41023.0     1.3105          154 01/17/72
P111     P111      P01      P111      P31111
  41021.000000        0.000000
  344.7862341872       .6524122869
   37.5756862263     -2.2461702443
   59.3713398791
     .0716672766     -.0000000716
    .7114876121    11.9679216499     -2.1862E-05      -5.4237E-06
        41021.00000          1.3104936087
  345.769769   37.613010    59.372083   .0713634    .7087602 11.9679216  8.0733968
ORBIT
1965 89 A                        41023   41021.0   41025.0     1.5943           25 01/17/72
P111     P111      P01      P111      P31111
  41023.000000        0.000000
  346.1688220688       .6592263928
   33.0816754173     -2.2471847134
   59.3705948920
     .0716437545       .0000253576
    .6472010251    11.9679484932     -4.2779E-05      -1.9215E-05
        41023.00000          1.5942996698
  347.157683   33.119173    59.371265   .0713696    .6444588 11.9679485  8.0733847
ORBIT
1965 89 A                        41037   41035.0   41039.0     2.1450          115 01/14/72
P111     P111      P111     P111      P31111
  41037.000000        0.000000
  355.2566432545       .6560932434
    1.6299975054     -2.2458241773
   59.3750640350     -.0011837717
     .0716632846     -.0000000135
    .1986417363    11.9679484649     -8.3247E-06       2.8636E-06
        41037.00000          2.1450054027
  356.264625    1.668290    59.375252   .0715865    .1958461 11.9679485  8.0733847
ORBIT
1965 89 A                        41039   41037.0   41041.0     1.6522          155 01/14/72
P111     P111      P111     P111      P31111
  41039.000000        0.000000
  356.5664358891       .6547197290
   -2.8627660305     -2.2466217077
   59.3738101390     -.0002773420
     .0716608207     -.0000012760
    .1345362136    11.9679471547     -1.3198E-07       9.3181E-09
        41039.00000          1.6521561680
  357.574945   -2.824471    59.373928   .0716126    .1317391 11.9679472  8.0733853
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ORBIT
1965 89 A                      41041   41039.0   41043.0    2.1911        201 01/14/72
P111      P111      P111      P111      P31111
  41041.000000          0.000000
  357.8753338018        .6527779836
   -7.3558717530       -2.2452746261
   59.3734168608        .0033496753
     .0716593744        .0000004394
     .0704315665     11.9679526916      2.0655E-07       1.4054E-07
          41041.00000            2.1911124425
  358.883936    -7.317578   59.373465   .0716396    .0676341 11.9679527   8.0733828
ORBIT
1965 89 A                      41043   41041.0   41045.0    1.1585        199 01/14/72
P111      P111      P111      P111      P31111
  41043.000000          0.000000
  359.1828890699        .6541413935
  -11.8487622378       -2.2465287861
   59.3736451170        .0000811117
     .0716586906       -.0000007886
     .0063320219     11.9679489722     -6.3371E-08       2.2632E-07
          41043.00000            1.1585083925
  360.191110   -11.810483   59.373624   .0716674    .0035356 11.9679490   8.0733845
ORBIT
1965 89 A                      41045   41043.0   41047.0    1.1224        129 01/14/72
P111      P111      P111      P111      P31111
  41045.000000          0.000000
     .4936537584        .6544824297
  -16.3415778733       -2.2464497795
   59.3733768817       -.0000989239
     .0716577322       -.0000011343
     .9422212617     11.9679466400      1.5443E-08       4.0074E-07
          41045.00000            1.1224202729
    1.500926   -16.303339   59.373286   .0716949    .9394274 11.9679466   8.0733855
ORBIT
1965 89 A                      41047   41045.0   41049.0    1.3105        116 01/14/72
P111      P111      P111      P111      P31111
  41047.000000          0.000000
    1.8022521974        .6544407289
  -20.8344327794       -2.2464421038
   59.3732588603       -.0001168305
     .0716553676       -.0000016078
     .8781184221     11.9679474396     -5.0045E-09       2.3893E-07
          41047.00000            1.3105403102
    2.808097   -20.796253   59.373099   .0717209    .8753285 11.9679474   8.0733852
ORBIT
1965 89 A                      41049   41047.0   41051.0    1.3758        137 01/14/72
P111      P111      P111      P111      P31111
  41049.000000          0.000000
    3.1102858564        .6537292700
  -25.3274808035       -2.2465865986
   59.3729093006       -.0002029073
     .0716530377       -.0000009515
     .8140170231     11.9679506693      1.1555E-07      -5.5883E-08
          41049.00000            1.3758233697
    4.114163   -25.289383   59.372680   .0717469    .8112325 11.9679507   8.0733837
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ORBIT
1965 89 A                    41051   41049.0   41053.0     2.5164        181 01/14/72
P111       P111        P111        P111        P31111
 41051.000000        0.000000
    4.4185444988        .6545542931
  -29.8209310423     -2.2465537816
   59.3719990631      -.0003747880
     .0716512958      -.0000011978
     .7499160410    11.9679476819     -1.1135E-07        8.4336E-08
         41051.00000          2.5164165706
     5.419873  -29.782943   59.371701   .0717733    .7471385 11.9679477   8.0733851
ORBIT
1965 89 A                    41053   41051.0   41055.0     2.8445        184 01/14/72
P111       P111        P111        P111        P31111
 41053.000000        0.000000
    5.7248590068        .6541535045
  -34.3136488804     -2.2466386061
   59.3715222055       .0000381330
     .0716513511       .0000008556
     .6858271382    11.9679493798      1.1799E-07       -1.2221E-08
         41053.00000          2.8445114693
    6.723158  -34.275782   59.371156   .0718014    .6830510 11.9679494   8.0733843
ORBIT
1965 89 A                    41055   41053.0   41057.0     1.5462        128 02/03/72
P111       P111        P111        P111        P31111
 41055.000000        0.000000
    7.0323120538        .6513063594
  -38.8077941344     -2.2474430032
   59.3685889714      -.0028630838
     .0716531573       .0000017032
     .6217230540    11.9679580643     -2.7396E-06       -8.3978E-07
*         41055.00000          1.5461555473
     8.026787  -38.770104   59.368154   .0718311    .6189645 11.9679581   8.0733804
ORBIT
1965 89 A                    41057   41055.0   41059.0      .9513         67 02/03/72
P111       P111        P111        P111        P31111
 41057.000000        0.000000
    8.3283991521        .6515593066
  -43.3002054204     -2.2446026509
   59.3709814110       .0008316603
     .0716729482       .0000147795
     .5576521687    11.9679531328      5.1111E-06        1.8762E-06
*         41057.00000           .9512889911
     9.318916  -43.262620   59.370479   .0718786    .5549045 11.9679531   8.0733826
ORBIT
1965 89 A                    41059   41057.0   41061.0     1.4005        117 02/03/72
P111       P111        P111        P111        P31111
 41059.000000        0.000000
    9.6497622792        .6499537355
  -47.7944213974     -2.2466050068
   59.3712110456       .0000456979
     .0716455243       .0000004630
     .4935176639    11.9679643397     -1.3494E-06       -8.1152E-07
*         41059.00000          1.4004607545
    10.536142  -47.757021   59.370640   .0718791    .4907815 11.9679643   8.0733776
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ORBIT
1965 89 A                    41061   41059.0   41063.0     1.5804          229 02/03/72
P111      P111      P111      P111      P31111
  41061.000000        0.000000
   10.9516000198       .6532233062
  -52.2880000010     -2.2468834093
   59.3707874372      -.0003636167
     .0716474174       .0000013151
     .4294358839    11.9679519173       2.6347E-07        1.2176E-07
*          41061.00000          1.5803995452
   11.932946  -52.253795   59.370150  .0719084   .4267136 11.9679519  8.0733832
ORBIT
1965 89 A                    41063   41061.0   41065.0     2.4938          301 01/13/72
P111      P111      P111      P111      P31111
  41063.000000        0.000000
   12.2580141751       .6532163847
  -56.7817772531     -2.2468137335
   59.3703470704      -.0002194360
     .0716479078      -.0000001385
     .3653455553    11.9679526149       3.1806E-07        2.9954E-08
           41063.00000          2.4937655317
   13.233839  -56.744787   59.369643  .0719363   .3626335 11.9679526  8.0733828
ORBIT
1965 89 A                    41065   41063.0   41067.0     2.1592          215 01/13/72
P111      P111      P111      P111      P31111
  41065.000000        0.000000
   13.5647201021       .6535308477
  -61.2756336349     -2.2470417341
   59.3701072907      -.0001218400
     .0716472498      -.0000005621
     .3012461438    11.9679524492       1.9302E-07        1.3355E-07
           41065.00000          2.1592126239
   14.534573  -61.238875   59.369336  .0719628   .2985557 11.9679524  8.0733829
ORBIT
1965 89 A                    41067   41065.0   41069.0     1.6930          176 01/13/72
P111      P111      P111      P111      P31111
  41067.000000        0.000000
   14.8703756721       .6528661654
  -65.7696467107     -2.2470194382
   59.3699522960      -.0001967583
     .0716471307       .0000005021
     .2371544523    11.9679530346      -7.1119E-07       -6.1456E-08
           41067.00000          1.6930247634
   15.833782  -65.733137   59.369116  .0719896   .2344818 11.9679530  8.0733827
ORBIT
1965 89 A                    41069   41067.0   41071.0     1.5885          293 01/13/72
P111      P111      P111      P111      P31111
  41069.000000        0.000000
   16.1760049841       .6525611643
  -70.2634158769     -2.2467396576
   59.3699302415       .0002597156
     .0716480476       .0000005095
     .1730589439    11.9679535819       1.5105E-07       -4.1236E-07
           41069.00000          1.5884815349
   17.132485  -70.227170   59.369028  .0720172   .1704055 11.9679536  8.0733824
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ORBIT
1965 89 A                        41071   41069.0   41073.0    1.3460          257 01/13/72
P111       P111       P111       P111       P31111
  41071.000000       0.000000
  -17.4802449117      .6514510519
  -74.7568908140    -2.2467096125
   59.3704541214      .0005146499
     .0716476416    -.0000017717
     .1089666663    11.9679554372     1.2620E-06      7.4587E-07
        41071.00000         1.3460419742
  18.429408  -74.720919   59.369487  .0720433   .1063335 11.9679554  8.0733816
ORBIT
1965 89 A                        41072   41070.0   41074.0    1.7923          316 12/04/71
P111       P111       P01        P111       P31111
  41072.000000       0.000000
   18.1340131645      .6528033447
  282.9961156364    -2.2468871205
   59.3698485969
     .0716486714    -.0000001535
    -.9230828252    11.9679523686    -2.1282E-07     -1.2003E-07
ORBIT
1965 89 A                        41074   41072.0   41076.0    3.2673          139 12/04/71
P111       P111       P01        P111       P31111
  41074.000000       0.000000
   19.4389257003      .6522341453
  278.5024353593    -2.2467493296
   59.3699330823
     .0716489502      .0000005135
     .0128216132    11.9679517823    -1.1232E-07      1.7892E-07
ORBIT
1965 89 A                        41076   41074.0   41078.0    1.8603          112 12/04/71
P111       P111       P01        P111       P31111
  41076.000000       0.000000
   20.7438759902      .6544555919
  274.0089504126    -2.2466444494
   59.3687177855
     .0716501966      .0000028260
     .9487249920    11.9679454462    -6.0260E-07      3.4567E-07
ORBIT
1965 89 A                        41078   41076.0   41080.0    1.8894          232 12/04/71
P111       P111       P01        P111       P31111
  41078.000000       0.000000
   22.0492804199      .6529662419
  269.5153612269    -2.2467910904
   59.3700270576
     .0716529050      .0000011703
     .8846244713    11.9679493851    -1.0785E-07     -1.2480E-07
ORBIT
1965 89 A                        41080   41078.0   41082.0    1.5273          241 12/04/71
P111       P111       P01        P111       P31111
  41080.000000       0.000000
   23.3551298339      .6528969802
  265.0214562996    -2.2469722895
   59.3698420366
     .0716545634      .0000004951
     .8205223404    11.9679480598    -3.2003E-07      8.2048E-08
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ORBIT
1965 89 A                    41082   41080.0   41084.0      .6775        168 12/04/71
P111      P111       P01       P111      P31111
  41082.000000       0.000000
   24.6595?16954      .6514449903
  260.5281393457    -2.2464301936
   59.3696739148
     .0716561002      .0000009250
     .7564205973    11.9679503075     -4.1341E-07      9.5439E-09
ORBIT
1965 89 A                    41084   41082.0   41086.0     1.6238        161 12/04/71
P111      P111       P01       P111      P31111
  41084.000000       0.000000
   25.9627467092      .6518248171
  256.0351456372    -2.2465632918
   59.3697614764
     .0716577085      .0000005157
     .6923138405    11.9679480421     -2.2778E-07      2.6027E-08
ORBIT
1965 89 A                    41086   41084.0   41088.0     2.7325        126 12/04/71
P111      P111       P01       P111      P31111
  41086.000000       0.000000
   27.2698496966      .6514883088
  251.5416652779    -2.2467241126
   59.3704780175
     .0716623352      .0000013975
     .6282068086    11.9679484826     -4.5207E-07      1.1681E-07
ORBIT
1965 89 A                    41088   41086.0   41090.0     1.8988        212 12/04/71
P111      P111       P01       P111      P31111
  41088.000000       0.000000
   28.5736916422      .6525234849
  247.0483161918    -2.2467327303
   59.3701739774
     .0716643320      .0000020351
     .5640998034    11.9679444686     -1.3559E-07      1.5556E-07
ORBIT
1965 89 A                    41090   41088.0   41092.0     3.3913        372 12/04/71
P111      P111       P01       P111      P31111
  41090.000000       0.000000
   29.8788634541      .6525824210
  242.5551298760    -2.2467058694
   59.3697853942
     .0716671300      .0000013158
     .4999880537    11.9679443466     -4.6324E-08     -3.8353E-08
ORBIT
1965 89 A                    41092   41090.0   41094.0     2.9677        279 12/11/71
P111      P111       P01       P111      P31111
  41092.000000       0.000000
   31.1825429218      .6511335911
  238.0619261293    -2.2466669466
   59.3696229375
     .0716680296     -.0000005668
     .4358793353    11.9679469204     -3.6853E-07     -6.9064E-08
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ORBIT
1965 89 A                41094   41092.0   41096.0     1.5351        117 12/11/71
P111      P111      P31       P111      P31111
  41094.000000     0.000000
    32.4882574705    .6532968541
   233.5686809714  -2.2466708331
    59.3694547130
      .0716726653    .0000031099
      .3717639319  11.9679400753      -5.4928E-07     1.5125E-07
ORBIT
1965 89 A                41096   41094.0   41098.0     1.4032        186 12/11/71
P111      P111      P31       P111      P31111
  41096.000000     0.000000
    33.7939155159    .6510990114
   229.0757864449  -2.2465207879
    59.3689237371
      .0716784382    .0000010631
      .3076442180  11.9679441562       3.4595E-07    -5.8870E-08
ORBIT
1965 89 A                41098   41096.0   41100.0     2.0047        218 12/11/71
P111      P111      P31       P111      P31111
  41098.000000     0.000000
    35.0978313954    .6522600093
   224.5824696711  -2.2466852857
    59.3688360063
      .0716790845    .0000002841
      .2435286961  11.9679415872       2.3227E-08     1.9063E-09
ORBIT
1965 89 A                41100   41098.0   41102.0     1.5152        173 12/11/71
P111      P111      P31       P111      P31111
  41100.000000     0.000000
    36.4032852544    .6536146337
   220.0890595557  -2.2467686225
    59.3686979838
      .0716807809    .0000019611
      .1794098015  11.9679383698      -3.7661E-07    -1.2845E-07
ORBIT
1965 89 A                41102   41100.0   41104.0     1.4889        200 12/11/71
P111      P111      P31       P111      P31111
  41102.000000     0.000000
    37.7088618846    .6534962328
   215.5956562132  -2.2467840063
    59.3682542945
      .0716831044    .0000026975
      .1152877896  11.9679366801      -3.4426E-07     6.4888E-08
ORBIT
1965 89 A                41104   41102.0   41106.0     1.6654        243 12/11/71
P111      P111      P31       P111      P31111
  41104.000000     0.000000
    39.0141344410    .6510600197
   211.1024844213  -2.2465778436
    59.3680476368
      .0716861824   -.0000003859
      .0511633641  11.9679409199       7.3626E-09     1.1548E-07
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ORBIT
1965 89 A                  41106   41104.0   41108.0     3.6015         217 12/11/71
P111       P111       P01       P111       P31111
  41106.000000       0.000000
  40.3198970510      .6548664610
 206.6090408276    -2.2467684207
  59.3675953821
    .0716884667      .0000014473
    .9870377467    11.9679327079      -1.2908E-07      -3.7051E-08
ORBIT
1965 89 A                  41108   41106.0   41110.0     2.1188         101 12/11/71
P111       P111       P01       P111       P31111
  41108.000000       0.000000
  41.6288031957      .6552610940
 202.1159029239    -2.2464361853
  59.3677591374
    .0716913881      .0000015234
    .9229037916    11.9679305985       3.7834E-07       3.1247E-07
ORBIT
1965 89 A                  41109   41107.0   41111.0      .8999         154 12/11/71
P111       P111       P111       P111       P31111
  41109.000000       0.000000
  42.2798147313      .6516002760
 199.8688715845    -2.2467638426
  59.3673896797     -.0004961533
    .0716902517      .0000006251
    .8908459222    11.9679392837      -5.9330E-07       7.1863E-08
ORBIT
1965 89 A                  41111   41109.0   41113.0     2.9877         202 12/11/71
P111       P111       P111       P111       P31111
  41111.000000       0.000000
  43.5842765512      .6507330261
 195.3768863853    -2.2458666066
  59.3680075786      .0009415216
    .0716956542      .0000031057
    .8267181762    11.9679399440       6.4951E-07       4.9738E-07
ORBIT
1965 89 A                  41113   41111.0   41115.0     4.0083         150 12/11/71
P111       P111       P111       P111       P31111
  41113.000000       0.000000
  44.8859114197      .6512970124
 190.8848588342    -2.2459227906
  59.3691965267     -.0005920801
    .0717021850      .0000032261
    .7626037203    11.9679447677      -5.0988E-07      -9.4970E-07
ORBIT
1965 89 A                  41115   41113.0   41117.0     1.5773         109 12/11/71
P111       P111       P111       P111       P31111
  41115.000000       0.000000
  46.1986949799      .6534143624
 186.3877988692    -2.2467646364
  59.3667548131      .0000302444
    .0716984645      .0000013563
    .6984623734    11.9679360157       4.7661E-08       7.0393E-08
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ORBIT
1965 89 A                       41117   41115.0   41119.0     3.6876         167 12/11/71
P111      P111      P111      P111      P31111
  41117.000000     0.000000
   47.5048353469    .6525417738
  181.8943745239  -2.2467327786
   59.3665121071   -.0004502082
    .0717000042     .0000006053
    .6343356553   11.9679364493     -6.2644E-07     3.9011E-07
ORBIT
1965 89 A                       41119   41117.0   41121.0     3.6235         279 12/16/71
P111      P111      P111      P111      P31111
  41119.000000     0.000000
   48.8098507214    .5526562048
  177.4009105583  -2.2467790053
   59.3661471949   -.0000132545
    .0717012477     .0000010703
    .5702090532   11.9679365698      1.3765E-08     1.7954E-07
ORBIT
1965 89 A                       41121   41119.0   41123.0     2.9878         266 12/16/71
P111      P111      P111      P111      P31111
  41121.000000     0.000000
   50.1158620319    .6535159213
  172.9071902892  -2.2469387595
   59.3659725324   -.0002100756
    .0717036078     .0000012324
    .5060820029   11.9679362915      2.9944E-07    -1.3911E-07
ORBIT
1965 89 A                       41123   41121.0   41125.0     2.0173         247 12/16/71
P111      P111      P111      P111      P31111
  41123.000000     0.000000
   51.4238054578    .6544772316
  168.4133743931  -2.2468239918
   59.3661355540    .0007967926
    .0717065840     .0000029015
    .4419519762   11.9679320772     -6.5165E-07     2.2641E-07
ORBIT
1965 89 A                       41125   41123.0   41127.0      .6945         266 12/17/71
P111      P111      P111      P111      P31111
  41125.000000     0.000000
   52.7306498980    .6529132386
  163.9198475398  -2.2469780646
   59.3667319858   -.0000213629
    .0717097224     .0000013247
    .3778215474   11.9679362355      9.0392E-08     1.3741E-07
ORBIT
1965 89 A                       41127   41125.0   41129.0     1.3255         281 12/17/71
P111      P111      P111      P111      P31111
  41127.000000     0.000000
   54.0365759785    .6526401891
  159.4259757686  -2.2467550427
   59.3666913108    .0000521010
    .0717121391     .0000010249
    .3136948081   11.9679377468     -2.7955E-08    -8.9658E-08
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ORBIT
1965 89 A                    41129    41127.0    41131.0     1.0456          230 12/17/71
P111       P111       P111       P111       P31111
  41129.000000     0.000000
   55.3442644787     .6537675374
  154.9328557852   -2.2467255330
   59.3668851608    -.0000397414
     .0717138423     .0000004855
     .2495629177   11.9679352404       3.6513E-07      3.3235E-08
ORBIT
1965 89 A                    41131    41129.0    41133.0     1.0251          282 12/17/71
P111       P111       P111       P111       P31111
  41131.000000     0.000000
   56.6515121893     .6528568132
  150.4396282656   -2.2467345643
   59.3672522123     .0002088604
     .0717155549     .0000026897
     .1854332033   11.9679364401      -2.4447E-07     -5.7245E-08
ORBIT
1965 89 A                    41133    41131.0    41135.0      .6963          276 12/17/71
P111       P111       P111       P111       P31111
  41133.000000     0.000000
   57.9554907035     .6512891775
  145.9461495527   -2.2468798074
   59.3683123624    -.0000967632
     .0717200085    -.0000000529
     .1213113955   11.9679422901       4.0673E-07      7.9023E-08
ORBIT
1965 89 A                    41135    41133.0    41137.0      .5596          309 12/17/71
P111       P111       P111       P111       P31111
  41135.000000     0.000000
   59.2643670231     .6543798420
  141.4523630073   -2.2468232884
   59.3679207826     .0000359774
     .0717242371     .0000023437
     .0571770801   11.9679338630       3.9573E-07     -5.4746E-08
ORBIT
1965 89 A                    41137    41135.0    41139.0      .7398          280 12/17/71
P111       P111       P111       P111       P31111
  41137.000000     0.000000
   60.5729333689     .6541329076
  136.9587181135   -2.2468234369
   59.3680432144     .0000785516
     .0717287383     .0000020823
     .9930464621   11.9679353259      -5.5362E-08     -6.0557E-08
ORBIT
1965 89 A                    41139    41137.0    41141.0     1.0888          175 12/17/71
P111       P111       P111       P111       P31111
  41139.000000     0.000000
   61.8789242812     .6524536304
  132.4659932253   -2.2466035295
   59.3685064215     .0000935001
     .0717317157     .0000022328
     .9289211778   11.9679396736       8.6926E-07      3.0424E-07
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ORBIT
1965 89 A                      41141   41139.0   41143.0      .8429          186 12/17/71
P111      P111      P111      P111      P31111
  41141.000000       0.000000
     63.1835766155     .6526019629
    127.9726817055   -2.2467579345
     59.3693403156    -.0000393011
       .0717329997     .0000001910
       .8648030555   11.9679398813      7.9964E-07      5.2324E-07
ORBIT
1965 89 A                      41143   41141.0   41145.0     1.7455          320 12/17/71
P111      P111      P111      P111      P31111
  41143.000000       0.000000
     64.4923300448     .6545133949
    123.4789138610   -2.2466703441
     59.3691297683     .0000518560
       .0717401617     .0000026463
       .8006771492   11.9679366524     -3.9050E-07      1.7784E-07
ORBIT
1965 89 A                      41145   41143.0   41147.0     2.5000          404 12/17/71
P111      P111      P111      P111      P31111
  41145.000000       0.000000
     65.8003951835     .6535609976
    118.9856468452   -2.2466456253
     59.3694009128     .0001471941
       .0717449166     .0000022003
       .7365533567   11.9679394325     -1.5930E-07      1.3793E-07
ORBIT
1965 89 A                      41147   41145.0   41149.0     1.9375          263 12/17/71
P111      P111      P111      P111      P31111
  41147.000000       0.000000
     67.1082721201     .6543551189
    114.4925316912   -2.2463930455
     59.3697121733     .0002039850
       .0717508738     .0000046416
       .6724296545   11.9679367713      5.2797E-07      2.0303E-07
ORBIT
1965 89 A                      41148   41146.0   41150.0     1.6072          326 12/10/71
P111      P111      P111      P111      P31111
  41148.000000       0.000000
     67.7598510484     .6534045377
    112.2456087296   -2.2466140615
     59.3697315564     .0001489188
       .0717510644     .0000025345
       .6403779587   11.9679419386      4.1135E-07      3.0145E-08
ORBIT
1965 89 A                      41150   41148.0   41152.0     1.0417          337 12/10/71
P111      P111      P111      P111      P31111
  41150.000000       0.000000
     69.0683209024     .6547442438
    107.7521544933   -2.2467307141
     59.3697290596     .0000094462
       .0717573047     .0000036445
       .5762588331   11.9679392226      2.0719E-08      2.6181E-08
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ORBIT
1965 89 A                         41152   41150.0   41154.0     1.1569        323 12/10/71
P111        P111       P111       P111      P31111
  41152.000000       0.000000
   70.3777546489      .6533060138
  103.2589076680    -2.2465899879
   59.3699466534      .0001869836
    .0717642944       .0000014419
    .5121375171    11.9679441828     -8.6169E-08      2.2560E-08
ORBIT
1965 89 A                         41154   41152.0   41156.0     1.4729        306 12/10/71
P111        P111       P111       P111      P31111
  41154.000000       0.000000
   71.6840368334      .6528871412
   98.7659103009    -2.2464245343
   59.3703393843      .0002333871
    .0717671133       .0000017002
    .4480265161    11.9679456973      5.6032E-07      6.6601E-09
ORBIT
1965 89 A                         41156   41154.0   41158.0     2.1665        299 12/11/71
P111        P111       P111       P111      P31111
  41156.000000       0.000000
   72.9923446285      .6542728183
   94.2721419226    -2.2469353902
   59.3698508275     -.0001872203
    .0717717667       .0000022464
    .3839137922    11.9679446459      5.3899E-07     -4.5837E-08
ORBIT
1965 89 A                         41158   41156.0   41160.0     2.9329        214 12/11/71
P111        P111       P111       P111      P31111
  41158.000000       0.000000
   74.3001224450      .6543001763
   89.7783148753    -2.2469897871
   59.3696244490     -.0001441708
    .0717747144       .0000022825
    .3198075602    11.9679458281     -4.1306E-08     -5.7599E-08
ORBIT
1965 89 A                         41160   41158.0   41162.0     1.8840        118 12/11/71
P111        P111       P111       P111      P31111
  41160.000000       0.000000
   75.6072029973      .6519773781
   85.2850894517    -2.2464553540
   59.3702768002      .0005723497
    .0717758987      -.0000017291
    .2557022928    11.9679541040      1.0629E-06     -6.0841E-07
ORBIT
1965 89 A                         41162   41160.0   41164.0      .5269        152 01/12/72
P111        P111       P111       P111      P31111
  41162.000000       0.000000
   76.9123987425      .6574393102
   80.7885007980    -2.2456337223
   59.3669265137      .0013908160
    .0717631575       .0000079177
    .1916129659    11.9679338781      3.3441E-07     -5.6575E-08
         41162.00000                .5263948739
   77.132124   80.796815   59.363999   .0729594   .1910031 11.9679339   8.0733913
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ORBIT
1965 89 A                    41164   41162.0   41166.0    1.0622        262 01/12/72
P111    P111    P111    P111    P31111
  41164.000000       0.000000
   78.2269279977      .6555709826
   76.2972194290    -2.2469894626
   59.3695117318    -.0002021650
     .0717856310     .0000036465
     .1274835931    11.9679447545     2.3658E-07     -2.3194E-07
       41164.00000          1.0621823137
   78.424876   76.304720   59.366568   .0729880   .1269342 11.9679448  8.0733864
ORBIT
1965 89 A                    41166   41164.0   41168.0    1.1114        263 12/16/71
P111    P111    P111    P111    P31111
  41166.000000       0.000000
   79.5330930917      .6568957114
   71.8030798001    -2.2468083134
   59.3692884982     .0009842296
     .0717840601     .0000060571
     .0633922563    11.9679385875    -8.5354E-07      6.0239E-07
ORBIT
1965 89 A                    41168   41166.0   41170.0    2.6150        346 12/16/71
P111    P111    P111    P111    P31111
  41168.000000       0.000000
   80.8446910161      .6530626218
   67.3097219338    -2.2469030135
   59.3694501227    -.0001651678
     .0717936569     .0000002311
     .9992775282    11.9679532054     2.4843E-07      9.2726E-08
ORBIT
1965 89 A                    41170   41168.0   41172.0    1.5592        344 12/16/71
P111    P111    P111    P111    P31111
  41170.000000       0.000000
   82.1526860781      .6546334782
   62.8155273819    -2.2472906051
   59.3692094287     .0000213397
     .0717947501     .0000009672
     .9351802972    11.9679504751     3.5427E-07     -4.6053E-08
ORBIT
1965 89 A                    41172   41170.0   41174.0     .8129        209 12/16/71
P111    P111    P111    P111    P31111
  41172.000000       0.000000
   83.4623218781      .6548546454
   58.3208698359    -2.2473523940
   59.3692017530    -.0000117250
     .0717966458     .0000007382
     .8710811610    11.9679494997    -1.6663E-06     -6.7173E-07
ORBIT
1965 89 A                    41174   41172.0   41176.0    1.1912        156 12/16/71
P111    P111    P111    P111    P31111
  41174.000000       0.000000
   84.7751162512      .6511062586
   53.8275268353    -2.2478848892
   59.3680063925     .0017589276
     .0717975699     .0000013217
     .8069714200    11.9679623898    -1.6665E-06      2.6992E-07
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ORBIT
1965 89 A                        41176   41174.0   41178.0      4.2435           351 12/10/71
P111       P111       P111       P111       P31111
  41176.000000        0.000000
    86.0783682969      .6534585898
    49.3332502007    -2.2469122406
    59.3702872307     -.0001147772
      .0717987292      .0000005386
      .7428873585    11.9679525143      4.3335E-07     -1.9621E-08
ORBIT
1965 89 A                        41178   41176.0   41180.0      3.4796           564 12/10/71
P111       P111       P111       P111       P31111
  41178.000000        0.000000
    87.3860339024      .6546237936
    44.8393743863    -2.2470368755
    59.3701305327      .0001238538
      .0718000771      .0000004955
      .6787916623    11.9679504923      1.0305E-07     -1.7853E-08
ORBIT
1965 89 A                        41180   41178.0   41182.0      2.2467           621 12/10/71
P111       P111       P111       P111       P31111
  41180.000000        0.000000
    88.6952361979      .6548831572
    40.3452219188    -2.2471406814
    59.3703852350      .0002313166
      .0718001763     -.0000006122
      .6146931557    11.9679499664     -1.0443E-07     -7.1395E-08
ORBIT
1965 89 A                        41182   41180.0   41184.0      2.0390           446 12/10/71
P111       P111       P111       P111       P31111
  41182.000000        0.000000
    90.0030894671      .6537994533
    35.8511463792    -2.2470105685
    59.3708672561      .0002200939
      .0717987706     -.0000006470
      .5505969917    11.9679517504     -1.5334E-07      5.1091E-08
ORBIT
1965 89 A                        41184   41182.0   41186.0      3.2032           433 12/10/71
P111       P111       P111       P111       P31111
  41184.000000        0.000000
    91.3110874994      .6537109940
    31.3574488766    -2.2467744257
    59.3711394147      .0000579032
      .0717970395      .0000003707
      .4864989502    11.9679524682     -6.4152E-08     -1.2695E-07
ORBIT
1965 89 A                        41186   41184.0   41188.0      1.5891           371 12/10/71
P111       P111       P111       P111       P31111
  41186.000000        0.000000
    92.6183244882      .6532713473
    26.8638742976    -2.2469288542
    59.3713256834      .0002844896
      .0717971082     -.0000003438
      .4224035908    11.9679532342     -2.6162E-07     -2.8709E-07
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ORBIT
1965 89 A                    41188   41186.0   41190.0     1.6454          294 12/16/71
P111      P111      P111      P111      P31111
  41188.000000       0.000000
   93.9255450243      .6538565998
   22.3700253458    -2.2469536302
   59.3720213968      .0004088878
     .0717954205    -.0000011700
     .3583056597    11.9679496470      -1.9109E-07      6.1989E-08
ORBIT
1965 89 A                    41190   41188.0   41192.0     2.7197          255 12/16/71
P111      P111      P111      P111      P31111
  41190.000000       0.000000
   95.2327930926      .6532854269
   17.8763672720    -2.2464857385
   59.3726182285    -.0000893820
     .0717928747    -.0000010151
     .2942052946    11.9679499137      -2.4174E-07      1.9352E-08
ORBIT
1965 89 A                    41192   41190.0   41194.0     1.7918          256 12/16/71
P111      P111      P111      P111      P31111
  41192.000000       0.000000
   96.5389365013      .6529594193
   13.3835433564    -2.2467624809
   59.3722183844      .0002053864
     .0717910332    -.0000008978
     .2301054638    11.9679510670      -6.0498E-08     -1.4803E-07
ORBIT
1965 89 A                    41194   41192.0   41196.0     1.3598          200 12/16/71
P111      P111      P111      P111      P31111
  41194.000000       0.000000
   97.8452294152      .6532221871
    8.8896669160    -2.2472261476
   59.3729312424      .0008847676
     .0717887777    -.0000019952
     .1660054211    11.9679493345      -4.9995E-07     -2.6585E-07
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ORBIT
1967 11 A                      41111   41109.0   41113.0     3.3796          51 12/30/71
P111       P111        P01        P111       P31111
  41111.000000         0.000000
  219.1412813552       5.9834012500
  231.3521619755      -4.7384303320
   39.9620868732
     .0512050626      -.0000025413
   -.9179076443      13.8602244502      5.4541E-06      -3.9829E-07
ORBIT
1967 11 A                      41113   41111.0   41115.0     5.2336          90 12/30/71
P111       P111        P01        P111       P31111
  41113.000000         0.000000
  231.0998791644       5.9875854473
  221.8648803545      -4.7415544215
   39.9593428911
     .0512063728      -.0000031031
     .8026103373     13.8602401276      6.4019E-06       1.4176E-07
ORBIT
1967 11 A                      41115   41113.0   41117.0     2.6217         106 12/30/71
P111       P111        P01        P111       P31111
  41115.000000         0.000000
  243.0869880137       5.9824316804
  212.3797858400      -4.7440671888
   39.9582628823
     .0512002971        .0000023592
     .5230798244     13.8602809476      4.6073E-06       4.9439E-07
ORBIT
1967 11 A                      41117   41115.0   41119.0     2.3661         125 12/30/71
P111       P111        P01        P111       P31111
  41117.000000         0.000000
  255.0535338676       5.9840096233
  202.8927200475      -4.7429100453
   39.9583904001
     .0512029935        .0000003330
     .2436557935     13.8602953203      4.2929E-06      -9.6002E-07
ORBIT
1967 11 A                      41119   41117.0   41121.0     2.4694         262 02/07/72
P111       P111        P01        P111       P31111
  41119.000000         0.000000
  267.0185666717       5.9828510563
  193.4075623389      -4.7433000459
   39.9582685020
     .0512033952        .0000000220
     .9642636773     13.8603175790      4.8333E-06      -8.3451E-07
*          41119.00000             2.4693908979
  266.988775  193.407417   39.960144   .0506690    .9643469 13.8603176   7.3207118
ORBIT
1967 11 A                      41121   41119.0   41123.0     2.6791         288 02/07/72
P111       P111        P01        P111       P31111
  41121.000000         0.000000
  278.9842804357       5.9838915964
  183.9209141956      -4.7432149815
   39.9582167241
     .0512030195      -.0000000742
     .6849119189     13.8603263311      4.0381E-06       6.7345E-07
*          41121.00000             2.6790791398
  279.073796  183.921352   39.960074   .0506740    .6846618 13.8603263   7.3207087
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ORBIT
1967 11 A                    41123    41121.0    41125.0      2.2058          198 02/07/72
P111       P111       P31        P111       P31111
  41123.000000       0.000000
  290.9557243466     5.9864022425
  174.4347652172    -4.7427801671
   39.9582377538
     .0512031898     -.0000002239
     .4055737068   13.8603383858        3.6940E-06      -7.3818E-07
*          41123.00000        2.2057914277
  291.161503  174.435770   39.960003   .0507003   .4049987 13.8603384  7.3207045
ORBIT
1967 11 A                    41125    41123.0    41127.0      2.1089          189 02/07/72
P111       P111       P31        P111       P31111
  41125.000000       0.000000
  302.9307628383     5.9919821858
  164.9491135219    -4.7428761273
   39.9581591280
     .0512022339     -.0000097460
     .1262545565   13.8603369708        6.5994E-06       7.1384E-07
*          41125.00000        2.1089314531
  303.245598  164.950646   39.959752   .0507459   .1253749 13.8603370  7.3207050
ORBIT
1967 11 A                    41127    41125.0    41129.0      2.5896          179 02/07/72
P111       P111       P 1        P111       P31111
  41127.000000       0.000000
  314.9010183468     5.9852055295
  155.4589862729    -4.7437775564
   39.9593869082
     .0511998217     -.0000016276
     .8469983191   13.8603787505        8.0150E-06       1.5864E-06
*          41127.00000        2.5896001786
  315.313500  155.460988   39.960759   .0508089   .8458460 13.8603788  7.3206903
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ORBIT
6701401                          41072    41070.0    41074.0      3.0511            221 01/04/72
P111       P111       P01        P111       P31111
  41072.000000     0.000000
  151.5922726442   5.4102751498
  168.2220309887  -4.2226936477
   39.4323738523
     .0840063953   -.0000017948
   -.6557712736   13.0935086672        1.7557E-06        3.2077E-07
ORBIT
6701401                          41074    41072.0    41076.0      2.9861            256 01/04/72
P111       P111       P01        P111       P31111
  41074.000000     0.000000
  162.4127744247   5.4103556512
  159.7766831038  -4.2226137172
   39.4323254836
     .0840030351   -.0000016851
     .5312559170  13.0935194587        3.5281E-06        1.4367E-07
ORBIT
6701401                          41076    41074.0    41078.0      4.5980            218 01/04/72
P111       P111       P01        P111       P31111
  41076.000000     0.000000
  173.2356992522   5.4115259269
  151.3312189519  -4.2227118985
   39.4321122188
     .0839981327   -.0000022750
     .7183040149  13.0935321334        4.1558E-06       -2.9122E-08
ORBIT
6701401                          41078    41076.0    41080.0      2.7782            263 01/04/72
P111       P111       P01        P111       P31111
  41078.000000     0.000000
  184.0597274343   5.4125156843
  142.8859204657  -4.2226366699
   39.4322276296
     .0839958610   -.0000020238
     .9053834529  13.0935484783        5.0901E-06       -1.8311E-07
ORBIT
6701401                          41080    41078.0    41082.0      1.9301            262 01/04/72
P111       P111       P01        P111       P31111
  41080.000000     0.000000
  194.8851157284   5.4129663622
  134.4405633183  -4.2227517022
   39.4322913959
     .0839925474   -.0000013064
     .0924979783  13.0935637248        2.2402E-06       -6.0045E-07
ORBIT
6701401                          41082    41080.0    41084.0      3.7237            265 01/04/72
P111       P111       P01        P111       P31111
  41082.000000     0.000000
  205.7108830798   5.4123688883
  125.9948451096  -4.2228431891
   39.4321397588
     .0839893669   -.0000013424
     .2796317090  13.0935693383        1.4881E-06        4.8919E-07
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ORBIT
6701401                  41084   41082.0   41086.0     3.9848          242 01/04/72
P111      P111      P31      P111      P31111
 41084.000000      0.000000
 216.5325465923    5.4105059598
 117.5495556994   -4.2226265066
  39.4320777365
    .0839856797   -.0000014595
    .4667774204   13.0935745152      1.0572E-06      5.4817E-07
ORBIT
6701401                  41086   41084.0   41088.0     2.6045          118 01/04/72
P111      P111      P31      P111      P31111
 41086.000000      0.000000
 227.3529050653    5.4104304581
 109.1042450757   -4.2224448856
  39.4324515688
    .0839817229   -.0000011586
    .6539352525   13.0935821170      2.9104E-06      4.7381E-07
ORBIT
6701401                  41088   41086.0   41090.0     2.9464           81 01/04/72
P111      P111      P31      P111      P31111
 41088.000000      0.000000
 238.1727439342    5.4093113816
 100.6605732508   -4.2219375412
  39.4322378316
    .0839798125   -.0000015482
    .8411145165   13.0935968753      3.9027E-06      8.3131E-07
ORBIT
6701401                  41090   41088.0   41092.0     2.9730          105 01/04/72
P111      P111      P31      P111      P31111
 41090.000000      0.000000
 248.9958839267    5.4107968115
  92.2139670625   -4.2219769856
  39.4336273987
    .0839791284    .0000015346
    .0283224346   13.0936139487      4.2632E-06     -3.9050E-07
ORBIT
6701401                  41148   41146.0   41150.0     1.73            223 12/28/71
P111      P111      P31      P111      P2111
 41148.000000      0.000000
 202.8333448540    5.4103091846
 207.3126284934   -4.2231986041
  39.4314439178
    .0838908996    .0000018741
    .4627741899   13.0937960155      9.3962E-07
ORBIT
6701401                  41150   41148.0   41152.0     1.12            200 12/28/71
P111      P111      P31      P111      P2111
 41150.000000      0.000000
 213.6549020564    5.4111086027
 198.8677183541   -4.2220575246
  39.4315115389
    .0838837164   -.0000050702
    .6503600265   13.0937978914      4.0251E-06
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ORBIT
6701401                        41152   41150.0   41154.0    1.93           140 12/28/71
P111      P111       P01        P111       P2111
  41152.000000     0.000000
  224.4740501289   5.4084984113
  190.4221617227   -4.2258281968
   39.4311231517
     .0838878469     .0000084194
     .8379885632   13.0938240538      9.7049E-06
ORBIT
6701401                        41154   41152.0   41156.0    1.75           101 12/28/71
P111      P111       P 1        P111       P2111
  41154.000000     0.000000
  235.2943647136   5.4093728256
  181.9801108984   -4.2211591133
   39.4311001482
     .0838892281     .0000017979
     .0256235282   13.0938257147      2.8133E-06
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ORBIT
68 002 01                          41037   41035.0   41039.0     2.6290          121 01/13/72
P111       P111       P111       P111       P31111
  41037.000000        0.000000
   70.5557863676    -1.6029134021
  241.6939204418     1.4021953764
  105.8049278790      .0034030320
     .0319771143    -.0000066691
     .7005154170   12.8306052717     1.9850E-06     -1.7780E-06
       41037.00000          2.6289534070
   71.076043  241.692711  105.805355  .0327989   .6990705 12.8306053  7.7073317
ORBIT
68 002 01                          41039   41037.0   41041.0     1.5576          165 01/13/72
P111       P111       P111       P111       P31111
  41039.000000        0.000000
   67.3342694598    -1.6251825597
  244.4998491656     1.3999496948
  105.8102362650    -.0021716896
     .0319770677    -.0000036586
     .3617722561   12.8306554249    -6.8598E-08     -9.8375E-09
       41039.00000          1.5576300815
   67.936364  244.498448  105.810654  .0327810   .3601000 12.8306654  7.7073076
ORBIT
68 002 01                          41041   41039.0   41043.0     1.2975          183 01/13/72
P111       P111       P111       P111       P31111
  41041.000000        0.000000
   64.0824108109    -1.6261944378
  247.2993328206     1.4000384736
  105.8084640684    -.0000848689
     .0319698798    -.0000001878
     .0231064983   12.8306697521     5.0624E-07      1.6325E-07
       41041.00000          1.2975326434
   64.765472  247.297745  105.808871  .0327534   .0212094 12.8306698  7.7073059
ORBIT
68 002 01                          41043   41041.0   41045.0     2.2158          147 01/13/72
P111       P111       P111       P111       P31111
  41043.000000        0.000000
   60.8214587189    -1.6321711422
  250.1019213372     1.4014846411
  105.8128717012      .0019313604
     .0319558971    -.0000076201
     .6844686197   12.8306892842     3.9275E-06      9.8511E-07
       41043.00000          2.2157920317
   61.583513  250.100150  105.813266  .0327163   .6823521 12.8306893  7.7072980
ORBIT
68 002 01                          41045   41043.0   41047.0     1.1427          128 01/13/72
P111       P111       P111       P111       P31111
  41045.000000        0.000000
   57.5929597668    -1.6265393527
  252.9026826268     1.4004494207
  105.8100226195      .0006168129
     .0319702633    -.0000008005
     .3457484619   12.8306710563    -3.3434E-07      3.8313E-08
       41045.00000          1.1427438684
   58.430303  252.900735  105.810404  .0327055   .3434228 12.8306711  7.7073053
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ORBIT
68 002 01                      41047   41045.0   41049.0     1.3492          127 01/13/72
P111      P111      P111      P111      P31111
  41047.000000      0.000000
   54.3542753383   -1.6254184041
  255.7047381554    1.4014459745
  105.8105538974     .0010168118
     .0319759837    -.0000057659
     .0070543353   12.8306674757       4.8006E-08     -4.8076E-08
         41047.00000         1.349237359
   55.264531  255.702620  105.810921  .0326835   .0045262 12.8306675  7.7073068
ORBIT
68 002 01                      41049   41047.0   41051.0     1.6834          116 01/13/72
P111      P111      P111      P111      P31111
  41049.000000      0.000000
   51.1002002860   -1.6254177645
  258.5049636214    1.3996523432
  105.8122440256     .0017080433
     .0319634077    -.0000076945
     .6683959705   12.8306669518       7.7014E-07     -7.0759E-08
         41049.00000         1.6834144756
   52.081254  258.502682  105.812596  .0326408   .6656712 12.8306670  7.7073070
ORBIT
68 002 01                      41051   41049.0   41053.0     1.8307          157 02/03/72
P111      P111      P111      P111      P31111
  41051.000000      0.000000
   47.8596429412   -1.6209658863
  261.3078714605    1.4003926778
  105.8122220130     .0000485445
     .0319729815     .0000002990
     .3297065582   12.8306570886      -2.3192E-06      1.2150E-06
*         41051.00000         1.8306591010
   48.907421  261.305433  105.812557  .0326183   .3267965 12.8306571  7.7073109
ORBIT
68 002 01                      41053   41051.0   41055.0     1.9435          173 02/03/72
P111      P111      P111      P111      P31111
  41053.000000      0.000000
   44.6163335446   -1.6239608942
  264.1092246264    1.4010530075
  105.8121731013     .0000805399
     .0319724281    -.0000007478
     .9919233660   12.8306655854       1.7113E-07     -1.0947E-07
*         41053.00000         1.9434511755
   45.727827  264.106638  105.812490  .0325835   .9879363 12.8306656  7.7073075
ORBIT
68 002 01                      41055   41053.0   41057.0     2.4572          152 02/03/72
P111      P111      P111      P111      P31111
  41055.000000      0.000000
   41.3771432433   -1.6208216285
  266.9113293315    1.4014862465
  105.8125728922    -.0004969453
     .0319744125    -.0000030790
     .6523323936   12.8306592303       4.5741E-06      2.4715E-06
*         41055.00000         2.4571745047
   42.548581  266.908602  105.812871  .0325493   .6490789 12.8306592  7.7073101
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ORBIT
68 002 01                     41057   41055.0   41059.0     .6505          134 02/03/72
P111     P111      P111     P111     P31111
 41057.000000      0.000000
   38.1474005583  -1.6155744064
  269.7128585582   1.4006216268
  105.8138992502    .0008839022
     .0319885193    .0000091129
     .3136095429  12.8306421620    4.0412E-06     1.4962E-06
*        41057.00000         .6504556058
  39.374337  269.709999  105.814178  .0325255   .3102019 12.8306422  7.7073169
ORBIT
68 002 01                     41059   41057.0   41061.0    1.0207          149 02/03/72
P111     P111      P111     P111     P31111
 41059.000000      0.000000
   34.9017428559  -1.6169453595
  272.5153065552   1.4012963478
  105.8163465390    .0018325088
     .0319775765  -.0000002204
     .9749517794  12.8306484786   -7.2234E-07     8.4616E-07
*        41059.00000        1.0207228832
  36.181398  272.512325  105.816605  .0324747   .9713967 12.8306485  7.7073144
ORBIT
68 002 01                     41061   41059.0   41063.0    1.2253          154 02/03/72
P111     P111      P111     P111     P31111
 41061.000000      0.000000
   31.6481289457  -1.6340491429
  275.3167780389   1.4011181056
  105.8153711250  -.0014266876
     .0319776654  -.0000037784
     .6362973356  12.8306927849   -1.3680E-06    -2.2206E-07
*        41061.00000        1.2253306441
  32.976227  275.313684  105.815607  .0324334   .6326088 12.8306928  7.7072966
ORBIT
68 002 01                     41063   41061.0   41065.0     .9891          170 02/03/72
P111     P111      P111     P111     P31111
 41063.000000      0.000000
   28.4082786849  -1.6215690035
  278.1189864792   1.4007731138
  105.8142535984    .0000534125
     .0319807617    .0000009862
     .2976062257  12.8306589950    4.4788E-07     4.7841E-07
*        41063.00000         .9891206337
  29.780215  278.115789  105.814468  .0323938   .2937959 12.8306590  7.7073102
ORBIT
68 002 01                     41065   41063.0   41067.0    1.7648          139 01/13/72
P111     P111      P111     P111     P31111
 41065.000000      0.000000
   25.1646917003  -1.6237191722
  280.9206347047   1.4012211628
  105.8145898679  -.0002147132
     .0319832280    .0000022930
     .9589281975  12.8306667317   -8.9646E-08    -6.0274E-08
         41065.00000        1.7648419574
  26.576046  280.917345  105.814782  .0323521   .9550084 12.8306667  7.7073071
```

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ORBIT
68 002 01                          41067   41065.0   41069.0      1.6022            135 01/13/72
P111     P111       P111       P111       P31111
  41067.000000      0.000000
   21.9257853881   -1.6203324234
  283.7229298619    1.4006510339
  105.8152472226     .0014228102
     .0319854319   -.0000006278
     .6202412598   12.8306568717      -7.3033E-07       -6.3234E-08
         41067.00000          1.6022217210
   23.371953  283.719558  105.815415  .0323091    .6162248 12.8306569  7.7073110
ORBIT
68 002 01                          41069   41067.0   41071.0      1.8625            202 01/13/72
P111     P111       P111       P111       P31111
  41069.000000      0.000000
   18.6830225826   -1.6216703010
  286.5252438704    1.4012133064
  105.8149402520     .0007443049
     .0319858591     .0000009452
     .2815606009   12.8306607977      -1.7666E-07        9.1321E-07
         41069.00000          1.8625005083
   20.159526  286.521801  105.815084  .0322632    .2774599 12.8306608  7.7073094
ORBIT
68 002 01                          41071   41069.0   41073.0      1.7092            166 01/13/72
P111     P111       P111       P111       P31111
  41071.000000      0.000000
   15.4467424799   -1.6153859884
  289.3272771028    1.4005944462
  105.8169384582     .0007359632
     .0319871226   -.0000029150
     .9428651303   12.8306431389      -2.1664E-07        3.5256E-07
         41071.00000          1.7992080272
   16.948616  289.323773  105.817058  .0322174    .9386940 12.8306431  7.7073165
ORBIT
1968 02 A                          41072   41070.0   41074.0      2.6648            221 12/11/71
P111     P111       P01        P111       P31111
  41072.000000      0.000000
   13.8250736875   -1.6192847532
  290.7280908769    1.4010563797
  105.8155077341
     .0319901514     .0000016175
    -.2264723868   12.8306564742       2.3306E-07       -1.7306E-07
ORBIT
1968 02 A                          41074   41072.0   41076.0      1.4781            148 12/11/71
P111     P111       P01        P111       P31111
  41074.000000      0.000000
   10.5856345732   -1.6201101740
  293.5310797656    1.4016532246
  105.8157544648
     .0319870481   -.0000027973
     .4348428748   12.8306579040       1.2768E-07        3.3782E-07
ORBIT
1968 02 A                          41076   41074.0   41078.0      1.4371            124 12/11/71
P111     P111       P01        P111       P31111
  41076.000000      0.000000
    7.3449949349   -1.6184721909
  296.3326777784    1.4003660467
  105.8154842189
     .0319887192     .0000032233
     .0961606990   12.8306526680      -6.3784E-07        2.1943E-07
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ORBIT
1968 02 A                    41078   41076.0   41080.0     2.4515        146 12/11/71
P111       P111       P01        P111      P31111
  41078.000000       0.000000
    4.1086267211    -1.6194038076
  299.1344969840     1.4010847351
  105.8161955331
     .0319930790      .0000021890
     .7574652497    12.8306561187      -3.1131E-07      -2.1909E-07
ORBIT
1968 02 A                    41080   41078.0   41082.0     1.4737        138 12/11/71
P111       P111       P01        P111      P31111
  41080.000000       0.000000
     .8701511883    -1.6199676152
  301.9368725115     1.4011893770
  105.8160392826
     .0319928480     -.0000004794
     .4187755309    12.8306563250      -1.0855E-07       2.0402E-07
ORBIT
1968 02 A                    41082   41080.0   41084.0     2.4886        167 12/11/71
P111       P111       P01        P111      P31111
  41082.000000       0.000000
   -2.3690646429    -1.6162360360
  304.7389251584     1.4008134678
  105.8164132031
     .0319936786      .0000010182
     .0800865211    12.8306482554       1.6009E-06      -7.8328E-07
ORBIT
1968 02 A                    41084   41082.0   41086.0     1.6841        114 12/11/71
P111       P111       P01        P111      P31111
  41084.000000       0.000000
   -5.6424163549    -1.6215667266
  307.5399185082     1.4004521785
  105.8178061653
     .0319959802      .0000028155
     .7414900515    12.8306654727       5.6716E-06       2.2177E-06
ORBIT
1968 02 A                    41086   41084.0   41088.0     1.1253        106 12/11/71
P111       P111       P01        P111      P31111
  41086.000000       0.000000
   -8.8443677831    -1.6125128490
  310.3435514435     1.4010879459
  105.8170120497
     .0319979320     -.0000051096
     .4027687798    12.8306400196      -2.3215E-06       4.3363E-07
ORBIT
1968 02 A                    41088   41086.0   41090.0     3.7206        195 12/16/71
P111       P111       P01        P111      P31111
  41088.000000       0.000000
  -12.0789560919    -1.6187218794
  313.1455922367     1.4010142024
  105.8167060701
     .0319950943     -.0000004382
     .0640123782    12.8306556139       4.4012E-08       4.4559E-08
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ORBIT
1968 02 A                        41090   41088.0   41092.0      5.0266          261 12/16/71
P111       P111       P31        P111       P31111
 41090.000000      0.000000
 -15.3133066587    -1.6176695365
 315.9478289051     1.4011659766
 105.8167552944
     .0319958860      .0000014746
     .7253163776    12.8306534135       -1.4203E-07      -6.3356E-08
ORBIT
1968 02 A                        41094   41092.0   41096.0      2.4487           58 12/16/71
P111       P111       P31        P111       P31111
 41094.000000      0.000000
 -21.7682518174    -1.6383149289
 321.5530547954     1.4005906165
 105.8140830909
     .0319794504     -.0000094038
     .0478836770    12.8307164301        3.4046E-06      -3.1284E-06
ORBIT
1968 02 A                        41096   41094.0   41098.0       .3375           51 12/16/71
P111       P111       P31        P111       P31111
 41096.000000      0.000000
 -25.0154846453    -1.6299494751
 324.3539263247     1.4009452347
 105.8151945228
     .0319784505      .0000199500
     .7092224174    12.8306701180        8.7566E-06       8.2779E-06
ORBIT
1968 02 A                        41098   41096.0   41100.0      1.6406          125 12/17/71
P111       P111       P31        P111       P31111
 41098.000000      0.000000
 -28.2471500180    -1.6123090115
 327.1558033700     1.4006324515
 105.8167910325
     .0319915315     -.0000036248
     .3705151548    12.8306344298       -2.9639E-06      -1.6816E-07
ORBIT
68 02 A                          41109   41107.0   41111.0     30.4275           64 12/10/71
P111       P111       P31        P111       P31111
 41109.000000      0.000000
 314.0001977436    -2.1297616666
 342.5859900640     1.3998013846
 105.7416243322
     .0319925419      .0001950227
     .5076033627    12.8319921287        1.3543E-07      -5.6963E-06
ORBIT
68 02 A                          41111   41109.0   41113.0       .8857          101 12/10/71
P111       P111       P31        P111       P31111
 41111.000000      0.000000
 310.6845726708    -1.6244321566
 345.3704388467     1.4012725915
 105.8171196885
     .0319865685     -.0000003463
     .1691021764    12.8306694825       -1.2276E-07       1.1777E-07
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ORBIT
68 02 A                                      41113    41111.0    41115.0     2.1307            102 12/10/71
P111         P111         P01         P111         P31111
  41113.000000           0.000000
  307.4378391116        -1.6205810432
  348.1728690371         1.4010299522
  105.8169157875
     .0319845429          .0000003918
     .8304366527        12.8306601125       -4.1945E-07        6.5190E-07
ORBIT
68 02 A                                      41115    41113.0    41117.0     3.4264             67 12/10/71
P111         P111         P01         P111         P31111
  41115.000000           0.000000
  304.2021216795        -1.6180959863
  350.9753708467         1.4011612853
  105.8175931052
     .0319842514         -.0000011931
     .4917443110        12.8306545865       -7.2814E-07       -4.1947E-07
ORBIT
68 02 A                                      41117    41115.0    41119.0     1.8140            236 12/10/71
P111         P111         P01         P111         P31111
  41117.000000           0.000000
  300.9569957760        -1.6231487801
  353.7770909792         1.4011317206
  105.8171569622
     .0319793522          .0000005070
     .1530784388        12.8306688790       -5.4310E-07        5.0270E-08
ORBIT
68 02 A                                      41119    41117.0    41121.0     4.0519            276 12/10/71
P111         P111         P01         P111         P31111
  41119.000000           0.000000
  297.7114812318        -1.6216985693
  356.5792988548         1.4010533924
  105.8170909259
     .0319801030          .0000001552
     .8144122964        12.8306637208        1.0872E-07        5.1313E-08
ORBIT
68 02 A                                      41121    41119.0    41123.0     3.7784            141 12/10/71
P111         P111         P01         P111         P31111
  41121.000000           0.000000
  294.4676100251        -1.6203743430
  359.3813583671         1.4009648645
  105.8173346756
     .0319787613         -.0000023853
     .4757421622        12.8306608775       -1.5492E-07       -4.4726E-08
ORBIT
68 02 A                                      41123    41121.0    41125.0     1.5319            132 12/10/71
P111         P111         P01         P111         P31111
  41123.000000           0.000000
  291.2253927964        -1.6233076822
    2.1836573916         1.4011124853
  105.8171233723
     .0319732677         -.0000010729
     .1370677160        12.8306704905       -6.2835E-07       -1.0463E-06
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68 02 A                             41125   41123.0   41127.0     1.4492          145 12/16/71
P111      P111      P01       P111      P31111
  41125.000000      0.000000
  287.9816459129   -1.6175453743
    4.9857162522    1.4011307874
  105.8167060312
     .0319766192   -.0000039955
     .7983943770   12.8306487748      1.2838E-06     1.3224E-06
ORBIT
68 02 A                             41127   41125.0   41129.0     1.0555          138 12/16/71
P111      P111      P01       P111      P31111
  41127.000000      0.000000
  284.7331132213   -1.6200516034
    7.7875031766    1.4010879128
  105.8166941424
     .0319746024    .0000007468
     .4597333204   12.8306588805      3.4639E-07     2.3825E-08
ORBIT
68 02 A                             41129   41127.0   41131.0     1.0779          121 12/16/71
P111      P111      P01       P111      P31111
  41129.000000      0.000000
  281.4932634516   -1.6141846778
   10.5908368436    1.4009210004
  105.8171033462
     .0319823069   -.0000000082
     .1210529830   12.8306376129     -2.1138E-07     2.2080E-06
ORBIT
1968 02 A                           41148   41146.0   41150.0     1.2823          141 12/10/71
P111      P111      P111      P111      P31111
  41148.000000      0.000000
  250.6758137652   -1.6247783691
   37.2099031685    1.4014147067
  105.8156102960    .0008249557
     .0319784024    .0000005664
     .9036728028   12.8306726306     -3.3693E-07    -2.9624E-09
ORBIT
1968 02 A                           41150   41148.0   41152.0     1.1658          130 12/10/71
P111      P111      P111      P111      P31111
  41150.000000      0.000000
  247.4248009747   -1.6253107916
   40.0131277658    1.4016171520
  105.8176545937    .0010575693
     .0319757106   -.0000015949
     .5650196825   12.8306726326      3.8982E-07     2.4922E-07
ORBIT
1968 02 A                           41152   41150.0   41154.0      .9790           97 12/10/71
P111      P111      P111      P111      P31111
  41152.000000      0.000000
  244.1911591274   -1.6284051224
   42.8143108132    1.4013640157
  105.8157926019    .0008003766
     .0319849244    .0000002918
     .2263225180   12.8306829955     -4.8174E-07    -5.7769E-07
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ORBIT
1968 02 A                         41154    41152.0    41156.0      1.0207         132 12/10/71
P111       P111       P111       P111       P31111
  41154.000000      0.000000
  240.9527601814   -1.5799603353
   45.6179561377    1.3979560605
  105.8162621228    -.0039749646
     .0319961227     .0000063997
     .8876395808  12.8305537732      -2.9697E-06      -1.8773E-06
ORBIT
1968 02 A                         41156    41154.0    41158.0      1.3741         121 12/10/71
P111       P111       P111       P111       P31111
  41156.000000      0.000000
  237.7368920012   -1.6072366890
   48.4185635757    1.4009657010
  105.8152859670    -.0002896322
     .0319868819    -.0000025116
     .5488802710  12.8306167864       7.6309E-07       1.0995E-06
ORBIT
1968 02 A                         41158    41156.0    41160.0      1.2467          92 12/10/71
P111       P111       P111       P111       P31111
  41158.000000      0.000000
  234.4855706435   -1.6131910581
   51.2226658199    1.4027567286
  105.8138352824    -.0021005369
     .0319995906     .0000034515
     .2102263727  12.8306346172       7.4098E-06       5.6897E-06
ORBIT
1968 02 A                         41160    41158.0    41162.0      1.0978         123 12/10/71
P111       P111       P111       P111       P31111
  41160.000000      0.000000
  231.2250055446   -1.6086743807
   54.0217701441    1.4002331545
  105.8142698518    -.0009872071
     .0319909938     .0000015503
     .8715998492  12.8306278137       6.6465E-07      -3.0033E-07
ORBIT
1968 02 A                         41162    41160.0    41164.0       .8289         114 12/10/71
P111       P111       P111       P111       P31111
  41162.000000      0.000000
  227.9844958583   -1.6075865045
   56.8247287885    1.4007035780
  105.8156889538     .0002933462
     .0319910729     .0000046070
     .5329193610  12.8306240386      -1.2694E-06       8.9561E-07
ORBIT
1968 02 A                         41164    41162.0    41166.0      1.7609         131 12/10/71
P111       P111       P111       P111       P31111
  41164.000000      0.000000
  224.7670634809   -1.6118718502
   59.6271437481    1.4014248403
  105.8152527760    -.0003257848
     .0320017272     .0000053146
     .1941743423  12.8306181713      -4.3300E-06       1.0711E-05
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ORBIT
1968 02 A                      41166   41164.0   41168.0    1.3246         125 12/17/71
P111      P111      P111      P111      P31111
  41166.000000      0.000000
  221.5230027818   -1.6249846245
   62.4283648228    1.4009351312
  105.8154582164     .0015519410
     .0319877816     .0000047009
     .8554970137   12.8306738218      3.6309E-07     -8.4733E-07
ORBIT
1968 02 A                      41168   41166.0   41170.0    1.4568         129 12/17/71
P111      P111      P111      P111      P31111
  41168.000000      0.000000
  218.2647903200   -1.6277198141
   65.2312001450    1.3994246307
  105.8137704249     .0003445700
     .0319869890    -.0000052719
     .5168666218   12.8306801560     -2.6527E-06     -5.4344E-06
ORBIT
1968 02 A                      41170   41168.0   41172.0    1.0953          72 12/17/71
P111      P111      P111      P111      P31111
  41170.000000      0.000000
  215.0783671363   -1.5773316028
   68.0310333803    1.4000336342
  105.8127909273    -.0033324271
     .0319624978    -.0000285471
     .1779973238   12.8305250684      1.9849E-05      7.7586E-06
ORBIT
1968 02 A                      41172   41170.0   41174.0     .9700         113 12/17/71
P111      P111      P111      P111      P31111
  41172.000000      0.000000
  211.7971720899   -1.6132572855
   70.8341296928    1.4005183817
  105.8147676219    -.0005294646
     .0319933172     .0000035353
     .8394522694   12.8306364135     -6.2255E-07      1.5281E-06
ORBIT
1968 02 A                      41174   41172.0   41176.0    1.2141         140 12/17/71
P111      P111      P111      P111      P31111
  41174.000000      0.000000
  208.5416326537   -1.6169436330
   73.6357726523    1.4009895492
  105.8129573726     .0006596040
     .0319895985     .0000036173
     .5008034099   12.8306478848      7.4588E-09      5.1393E-08
ORBIT
1968 02 A                      41176   41174.0   41178.0     .8422         147 12/11/71
P111      P111      P111      P111      P31111
  41176.000000      0.000000
  205.3087329662   -1.6167144160
   76.4373466949    1.4005366787
  105.8129177273    -.0004578974
     .0319930418    -.0000011489
     .1620965901   12.8306464157     -3.7554E-07      2.1328E-07
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ORBIT
1968 02 A                       41178   41176.0   41180.0     2.4092          209 12/16/71
P111      P111       P111      P111      P31111
  41178.000000      0.000000
  202.0684506214    -1.6205925663
   79.2388824649     1.4009959099
  105.8126080563    -.0002517297
     .0319915956     .0000015594
     .8234078014    12.8306573919      -1.1583E-07      5.4302E-09
ORBIT
1968 02 A                       41180   41178.0   41182.0     2.6784          225 12/16/71
P111      P111       P111      P111      P31111
  41180.000000      0.000000
  198.8272338977    -1.6198143937
   82.0408040283     1.4009949188
  105.8122472003    -.0001081578
     .0319940089     .0000002110
     .4847223538    12.8306553348       4.2228E-08     -7.7658E-08
ORBIT
1968 02 A                       41182   41180.0   41184.0     3.6024          245 12/16/71
P111      P111       P111      P111      P31111
  41182.000000      0.000000
  195.5913041050    -1.6187206571
   84.8424009475     1.4007197774
  105.8112470942    -.0002406234
     .0319924100     .0000006178
     .1460226079    12.8306511153      -2.8686E-07      5.0067E-08
ORBIT
1968 02 A                       41184   41182.0   41186.0     2.6971          229 12/16/71
P111      P111       P111      P111      P31111
  41184.000000      0.000000
  192.3691063922    -1.6062366303
   87.6437401823     1.4008227242
  105.8108983558     .0000885715
     .0319962666     .0000019513
     .8072847933    12.8306169714       4.8816E-09      1.5317E-06
ORBIT
1968 02 A                       41188   41186.0   41190.0     3.1229          162 12/16/71
P111      P111       P111      P111      P31111
  41188.000000      0.000000
  185.8703918437    -1.6147352718
   93.2467705959     1.4003027959
  105.8107200093    -.0000662665
     .0319909740    -.0000016763
     .1299456235    12.8306419495       5.0357E-08     -1.8295E-06
ORBIT
1968 02 A                       41190   41188.0   41192.0     1.7981          163 12/16/71
P111      P111       P111      P111      P31111
  41190.000000      0.000000
  182.6330696346    -1.6198838032
   96.0479681931     1.4005618227
  105.8099964629    -.0004471673
     .0319909079     .0000006527
     .7912451380    12.8306528341      -3.8208E-08      2.0140E-08
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ORBIT
1968 02 A                    41192  41190.0  41194.0    1.8506          204 12/16/71
P111     P111      P111      P111      P31111
  41192.000000     0.000000
 179.3921345141   -1.6179499412
  98.8497994440    1.4010168538
 105.8103107128     .0003864645
    .0319913600     .0000000204
    .4525549167   12.8306478488     -5.9879E-07     2.7902E-07
ORBIT
1968 02 A                    41194  41192.0  41196.0    1.8419          119 12/16/71
P111     P111      P111      P111      P31111
  41194.000000     0.000000
 176.1557495179   -1.6144640776
 101.6515777746    1.4002010042
 105.8103976578    -.0004754438
    .0319913413     .0000022781
    .1138510514   12.8306356725      1.3538E-06     2.9663E-06
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ORBIT
1970 109 A                    41008   41006.0   41010.0     5.6095           89 01/27/72
P110       P110       P01       P111       P2111
  41009.000000      -1.000000
  113.9976101141    13.0699780000
   40.1426252113    -6.9858900000
   15.0044491333
     .0166053083     -.0001003948
   -.9252147843     14.8162110555     4.7799E-05
        41008.00000          5.6095030529
 113.685947  40.140942  15.003715  .0169121  .0756566 14.8162111  7.0023532
ORBIT
1970 109 A                    41010   41008.0   41012.0     4.8217           98 01/27/72
P110       P110       P01       P111       P2111
  41010.000000       .000000
  140.1243560864    13.0699780000
   26.1696682165    -6.9858900000
   15.0037254664
     .0163618383     -.0001211353
     .7074090058    14.8163574633     2.9465E-05
        41010.00000          4.8216520160
 139.524257  26.166577  15.003213  .0165082  .7090864 14.8163575  7.0023071
ORBIT
1970 109 A                    41012   41010.0   41014.0     2.2372           65 01/27/72
P110       P110       P01       P111       P2111
  41012.000000       .000000
  166.7887733590    13.0699780000
   12.2487107867    -6.9858900000
   15.0025986709
     .0165052933     -.0000521316
     .3387453979    14.8164992639     3.6126E-05
        41012.00000          2.2372442199
 166.029219  12.244823  15.002410  .0165589  .3408684 14.8164993  7.0022624
ORBIT
1970 109 A                    41014   41012.0   41016.0      .6192           41 01/27/72
P110       P110       P01       P111       P2111
  41014.000000       .000000
  192.9042297292    13.0699780000
   -1.6944169410    -6.9858900000
   15.0017593658
     .0164334004     -.0000355307
     .9718856193    14.8166391045     3.0637E-05
        41014.00000           .6191936778
 192.135180  -1.698220  15.001933  .0163840  .9740347 14.8166391  7.0022183
ORBIT
1970 109 A                    41016   41014.0   41018.0     1.3377           36 01/27/72
P110       P110       P01       P111       P2111
  41016.000000       .000000
  218.8455178157    13.0699780000
  -15.6549498233    -6.9858900000
   14.9908594146
     .0165127414      .0000673615
     .6057670955    14.8167001339    -4.0613E-06
        41016.00000          1.3377433259
 218.231240 -15.657947  14.991363  .0163704  .6074835 14.8167001  7.0021991
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ORBIT
1970 109 A                   41018   41016.0   41020.0    1.9996        30 01/27/72
P110      P110      P01      P111      P2111
  41018.000000       .000000
  245.9760854537   13.0699780000
  -29.6005265023   -6.9858900000
   15.0011581222
     .0164350280     .0000199342
     .2365245070   14.8168323508        3.2126E-05
        41018.00000         1.9995933979
  245.652074  -29.602071   15.001893  .0162261   .2374297 14.8168324  7.0021575
ORBIT
1970 109 A                   41020   41018.0   41022.0    2.0134        85 01/27/72
P110      P110      P01      P111      P2111
  41020.000000       .000000
  272.6066486971   13.0699780000
  -43.6072726300   -6.9858900000
   15.0078452473
     .0164221264    -.0000407134
     .8690211776   14.8168958092       -2.2514E-05
        41020.00000         2.0134058133
  272.642926  -43.607101   15.008649  .0161931   .8689197 14.8168958  7.0021375
ORBIT
1970 109 A                   41038   41036.0   41040.0     .8583        28 01/27/72
P110      P110      P01      P111      P2111
  41039.000000     -1.000000
  150.6945603435   13.2313000000
  190.8840785948   -6.9791030000
   14.9924524001
     .0165018339    -.0000773456
    -.4256554425   14.8176012168        3.3790E-05
        41038.00000          .8582907454
  150.017648  190.880564   14.992056  .0166141   .5762867 14.8176012  7.0019152
ORBIT
1970 109 A                   41040   41038.0   41042.0     .7805        14 01/27/72
P110      P110      P01      P111      P2111
  41040.000000       .000000
  176.9637711697   13.2313000000
  176.9004533522   -6.9791030000
   14.9965354818
     .0163717796    -.0000173769
     .2103553986   14.8177491220        1.9662E-05
        41040.00000          .7804545015
  176.176491  176.896531   14.996487  .0163855   .2125555 14.8177491  7.0018686
ORBIT
1970 109 A                   41042   41040.0   41044.0    2.8939        50 01/27/72
P110      P110      P01      P111      P2111
  41042.000000       .000000
  203.5956905295   13.2313000000
  162.9771833638   -6.9791030000
   14.9974537526
     .0163366134    -.0000854290
     .8454033090   14.8178828633        4.4414E-05
        41042.00000         2.8938663027
  202.866874  162.973657   14.997768  .0162466   .8474397 14.8178829  7.0018265
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ORBIT
1970 109 A                      41044   41042.0   41046.0      1.0042          31 01/27/72
P110       P110       P01       P111       P2111
   41044.000000        .000000
   229.9226581508    13.2313000000
   149.0432009805    -6.9791030000
    14.9958412161
      .0163243337     -.0000780984
      .4816972316    14.8180543923        3.2508E-05
         41044.00000          1.0041568058
   229.407910  149.040762   14.996450  .0161499   .4831353 14.8180544   7.0017725
ORBIT
1970 109 A                      41046   41044.0   41048.0      1.3560          77 01/27/72
P110       P110       P01       P111       P2111
   41046.000000        .000000
   256.7004040101    13.2313000000
   135.0745054124    -6.9791030000
    14.9947531524
      .0163056117      .0000165588
      .1171541725    14.8182676546        4.9134E-05
         41046.00000          1.3560215758
   256.515836  135.073642   14.995530  .0160829   .1176698 14.8182677   7.0017053
ORBIT
1970 109 A                      41048   41046.0   41050.0      1.3237          54 01/27/72
P110       P110       P01       P111       P2111
   41048.000000        .000000
   283.2032100914    13.2313000000
   121.1217506888    -6.9791030000
    14.9926911854
      .0162915214     -.0000119598
      .7537623859    14.8184709852        4.8760E-05
         41048.00000          1.3237049448
   283.386594  121.122607   14.993468  .0160687   .7532501 14.8184710   7.0016412
ORBIT
1970 109 A                      41050   41048.0   41052.0       .5989          32 01/27/72
P110       P110       P01       P111       P2111
   41050.000000        .000000
   309.7159209709    13.2313000000
   107.1522774642    -6.9791030000
    15.0112820179
      .0162767959      .0000195378
      .3907837941    14.8186856512        6.4437E-05
         41050.00000           .5988923620
   310.228916  107.154697   15.011893  .0161012   .3893507 14.8186857   7.0015736
ORBIT
1970 109 A                      41052   41050.0   41054.0       .6394          44 01/27/72
P110       P110       P01       P111       P2111
   41052.000000        .000000
   336.2479283687    13.2313000000
    93.1647466374    -6.9791030000
    15.0142015670
      .0162934078      .0000125002
      .0283002030    14.8189431450        6.4272E-05
         41052.00000           .6394289474
   336.978902   93.168269   15.014517  .0161997   .0262579 14.8189431   7.0014925
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ORBIT
1970 109 A                    41054   41052.0   41056.0     1.0063          84 01/27/72
P110       P110       P01       P111       P2111
  41054.000000        .000000
    2.7256270133    13.2313000000
   79.2596721468    -6.9791030000
   15.0075614685
     .0162825550     -.0000045669
     .6662522403    14.8191906766        6.3572E-05
        41054.00000            1.0063113092
   3.518222   79.263581   15.007518   .0162950   .6640374 14.8191907  7.0014146
ORBIT
1970 109 A                    41056   41054.0   41058.0     1.2202          86 01/27/72
P110       P110       P01       P111       P2111
  41056.000000        .000000
   29.2176691756    13.2313000000
   65.3046785464    -6.9791030000
   14.9995626573
     .0162772718      .0000019798
     .3048175320    14.8194815092        7.8292E-05
        41056.00000            1.2202134497
  29.905120   65.308151   14.999173   .0163893   .3028962 14.8194815  7.0013230
ORBIT
1970 109 A                    41078   41076.0   41080.0     1.2164          94 01/26/72
P110       P110       P01       P111       P2111
  41078.000000       0.000000
  320.5956965347    13.2313000000
  271.7696667966    -6.9779800000
   14.9976494841
     .0162098124      .0000593937
     .3576925923    14.8212304127        3.2133E-05
        41078.00000            1.2164003330
  321.216815  271.772598   14.998149   .0160657   .3559574 14.8212304  7.0007722
ORBIT
1970 109 A                    41080   41078.0   41082.0     1.7718          111 01/26/72
P110       P110       P01       P111       P2111
  41080.000000       0.000000
  347.0521275860    13.2313000000
  257.8154677388    -6.9779800000
   14.9971256649
     .0162941433      .0000219332
     .0002864568    14.8213324141        1.2854E-05
        41080.00000            1.7717995816
  347.827124  257.819235   14.997298   .0162446  -.0018790 14.8213324  7.0007401
ORBIT
1970 109 A                    41082   41080.0   41084.0     2.1962          80 01/26/72
110        P110       P01       P111       P2111
  41082.000000       0.000000
   13.5491920826    13.2313000000
  243.8539724895    -6.9779800000
   14.9967707723
     .0163092858      .0000356790
     .6429352798    14.8214496016        5.4071E-05
        41082.00000            2.1962220098
  14.316223  243.857806   14.996580   .0163641   .6407917 14.8214496  7.0007032
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ORBIT
1970 109 A                    41084   41082.0   41086.0      1.7420            65 01/26/72
P110        P110        P01        P111        P2111
  41084.000000        0.000000
    40.0403458242    13.2313000000
   229.8909187079    -6.9779800000
    14.9975169521
      .0163153847      .0000082698
      .2857767936    14.8214937713         2.1241E-05
         41084.00000           1.7420237143
   40.640090  229.893992   14.997005  .0164621   .2841004 14.8214938  7.0006892
ORBIT
1970 109 A                    41086   41084.0   41088.0       .8018            76 01/26/72
P110        P110        P01        P111        P2111
  41086.000000        0.000000
    66.5858714371    13.2313000000
   215.9119698331    -6.9779800000
    14.9969637973
      .0163106085     -.0000118568
      .9286924360    14.8215920266         2.1360E-05
         41086.00000            .8017866649
   66.895706  215.913583   14.996240  .0165182   .9278263 14.8215920  7.0006583
ORBIT
1970 109 A                    41088   41086.0   41090.0      1.0530            52 01/26/72
P110        P110        P01        P111        P2111
  41088.000000        0.000000
    93.0307837754    13.2313000000
   201.9794654965    -6.9779800000
    14.9941307780
      .0163473941      .0000550941
      .5719566099    14.8216961565         3.3062E-05
         41088.00000           1.0529855560
   92.989729  201.979250   14.993343  .0165727   .5720714 14.8216962  7.0006255
ORBIT
1970 109 A                    41090   41088.0   41092.0      1.5620            90 01/26/72
P110        P110        P01        P111        P2111
  41090.000000        0.000000
   119.2477380010    13.2313000000
   187.9916531073    -6.9779800000
    14.9982512702
      .0163426456     -.0000012096
      .2162916868    14.8218355316         3.1293E-05
         41090.00000           1.5619758801
  118.867211  187.989669   14.997561  .0165402   .2173554 14.8218355  7.0005816
ORBIT
1970 109 A                    41109   41107.0   41111.0       .7052            76 01/27/72
P110        P110        P01        P111        P2111
  41109.000000         .000000
    11.1522322900    13.2313000000
    55.3607003258    -6.9791610000
    14.9942681818
      .0161992127      .0000447854
      .8361724099    14.8226010489         2.8195E-05
         41109.00000            .7052227118
   11.931971   55.364535   14.994110  .0162449   .8339935 14.8226010  7.0003406
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1970 109 A                        41111   41109.0   41113.0       .7817              82 01/27/72
P110      P110       P01        P111        P2111
  41111.000000         .000000
   37.6184686554   13.2313000000
   41.4035740097   -6.9791610000
   14.9937852316
     .0162511899       .0000211312
     .4814669023   14.8227127571         2.9754E-05
        41111.00000              .7817104074
   38.241582    41.406734    14.993301   .0163905     .4797253 14.8227128   7.0003054
ORBIT
1970 109 A                        41113   41111.0   41115.0       .7937              78 01/27/72
P110      P110       P01        P111        P2111
  41113.000000         .000000
   64.0643578099   13.2313000000
   27.4356780249   -6.9791610000
   14.9979923323
     .0162697125       .0000092814
     .1270817136   14.8228244981         2.7563E-05
        41113.00000              .7937275765
   64.406364    27.437448    14.997284   .0164732     .1261257 14.8228245   7.0002702
ORBIT
1970 109 A                        41115   41113.0   41117.0      2.1062              93 01/27/72
P110      P110       P01        P111        P2111
  41115.000000         .000000
   90.4616968917   13.2313000000
   13.4749373388   -6.9791610000
   14.9996902416
     .0162625690      -.0000046600
     .7730285379   14.8229310793         2.6361E-05
        41115.00000             2.1062156613
   90.455404    13.474905    14.998905   .0164883     .7730461 14.8229311   7.0002367
ORBIT
1970 109 A                        41117   41115.0   41119.0     12.8867             140 01/27/72
P110      P110       P01        P111        P2111
  41117.000000         .000000
  116.8956227249   13.2313000000
    -.4853875190   -6.9791610000
   14.9998017867
     .0162490187      -.0000060182
     .4190745818   14.8230330602         2.6886E-05
        41117.00000            12.8867483437
  116.541315     -.487216    14.999100   .0164509     .4200650 14.8230331   7.0002046
ORBIT
1970 109 A                        41119   41117.0   41121.0      1.4955             118 01/27/72
P110      P110       P01        P111        P2111
  41119.000000         .000000
  143.3752916351   13.2313000000
  -14.4525639635   -6.9791610000
   14.9988456954
     .0162548082      -.0000064148
     .0652135344   14.8231332581         2.4920E-05
        41119.00000             1.4955271590
  142.743686   -14.455768    14.998372   .0163911     .0669788 14.8231333   7.0001730
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ORBIT
1970 109 A                    41121   41119.0   41123.0     1.4929            97 01/27/72
P110       P110       P01       P111       P2111
  41121.000000        .000000
  169.8495203685    13.2313000000
  -28.4173738492    -6.9791610000
   14.9989260649
     .0162353120     -.0000175922
     .7115650046    14.8232340778        2.5247E-05
         41121.00000            1.4929365808
  169.068531  -28.421230    14.998781  .0162770    .7137474 14.8232341  7.0001413
ORBIT
1970 109 A                    41123   41121.0   41125.0      .4896            54 01/27/72
P110       P110       P01       P111       P2111
  41123.000000        .000000
  196.3032519744    13.2313000000
  -42.3761315558    -6.9791610000
   14.9986873073
     .0161947374     -.0000209343
     .3581449965    14.8233139472        1.8403E-05
         41123.00000             .4896415741
  195.534675  -42.379812    14.998904  .0161322    .3602924 14.8233139  7.0001161
ORBIT
1970 109 A                    41175   41173.0   41177.0     1.7166            57 01/27/72
P110       P110       P01       P111       P2111
  41176.000000       -1.000000
  165.1661015790    13.2313000000
  314.5214490840    -6.9843190000
   14.9957520698
     .0161879298     -.0000269425
    -.7858694897    14.8249988867        1.9491E-05
         41175.00000            1.7165674713
  164.398138  314.517663    14.995545  .0162476    .2162765 14.8249989  6.9995857
ORBIT
1970 109 A                    41177   41175.0   41179.0     2.3691            69 01/27/72
P110       P110       P01       P111       P2111
  41177.000000        .000000
  191.6907361089    13.2313000000
  300.5495962155    -6.9843190000
   14.9973465989
     .0161470748     -.0000305658
     .8640365657    14.8250775960        1.9095E-05
         41177.00000            2.3690513880
  190.905303  300.545841    14.997201  .0161025    .8662310 14.8250775  6.9995610
ORBIT
1970 109 A                    41179   41177.0   41181.0     2.2346            62 01/27/72
P110       P110       P01       P111       P2111
  41179.000000        .000000
  218.2623337746    13.2313000000
  286.5775438954    -6.9843190000
   14.9955314669
     .0161679425      .0000007012
     .5139427785    14.8251155467        5.2514E-05
         41179.00000            2.2346122867
  217.629957  286.574580    14.996017  .0160275    .5157094 14.8251155  6.9995490
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ORBIT
1970 109 A                    41181   41179.0   41183.0    1.5320          42 01/27/72
P110      P110      P01       P111      P2111
  41181.000000        .000000
  244.6891722027   13.2313000000
  272.6105980294   -6.9843190000
   15.0030392811
     .0160325894    -.0001026940
     .1644126216   14.8252301318        2.9862E-05
        41181.00000          1.5320326982
  244.340515  272.609013   15.003748   .0158259    .1653865 14.8252301  6.9995130
ORBIT
1970 109 A                    41183   41181.0   41185.0    2.3427          36 01/27/72
P110      P110      P01       P111      P2111
  41183.000000        .000000
  271.0531340676   13.2313000000
  258.6292653753   -6.9843190000
   15.0129014350
     .0161951745    -.0000721248
     .8152712987   14.8253324034        3.1722E-05
        41183.00000          2.3426983513
  271.067998  258.629334   15.013695   .0159660    .8152298 14.8253324  6.9994808
ORBIT
1970 109 A                    41185   41183.0   41187.0    .7959           54 01/27/72
P110      P110      P01       P111      P2111
  41185.000000        .000000
  297.8733021328   13.2313000000
  244.6692965364   -6.9843190000
   15.0050750695
     .0160777369    -.0000369165
     .4650331142   14.8254363980        3.1718E-05
        41185.00000           .7959201566
  298.253454  244.671036   15.005770   .0158757    .4639713 14.8254364  6.9994480
ORBIT
1970 109 A                    41187   41185.0   41189.0    .4898           72 01/27/72
P110      P110      P01       P111      P2111
  41187.000000        .000000
  324.4608090375   13.2313000000
  230.6941616555   -6.9843190000
   15.0120282462
     .0160638066     .0000099147
     .1157142991   14.8255816758        3.6436E-05
        41187.00000           .4897865172
  325.120986  230.697227   15.012481   .0159319    .1138701 14.8255817  6.9994023
ORBIT
1970 109 A                    41189   41187.0   41191.0    1.1768          60 01/27/72
P110      P110      P01       P111      P2111
  41189.000000        .000000
  351.0431980811   13.2313000000
  216.7308527916   -6.9843190000
   14.9967729616
     .0160920548     .0000471117
     .7666769253   14.8257069377        1.9887E-05
        41189.00000          1.1768441673
  351.837659  216.734635   14.996890   .0160582    .7644573 14.8257069  6.9993629
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ORBIT
1970 109 A                  41191   41189.0   41193.0    1.1241          48 01/27/72
P110      P110      P01      P111      P2111
  41191.000000      .000000
   17.5029544798    13.2313000000
  202.8030085336    -6.9843190000
   15.0003444146
     .0161546547    -.0000172657
     .4180872685    14.8258272354      4.4253E-05
         41191.00000          1.1241308961
   18.261910  202.806746   15.000103  .0162245   .4159664 14.8258272  6.9993250
ORBIT
1970 109 A                  41193   41191.0   41195.0     .8775          66 01/27/72
P110      P110      P01      P111      P2111
  41193.000000      .000000
   44.0306781599    13.2313000000
  188.8190039296    -6.9843190000
   14.9981293727
     .0161879624     .0000223658
     .0697335006    14.8259420878      2.4511E-05
         41193.00000           .8775494227
   44.597739  188.821874   14.997573  .0163461   .0681486 14.8259427  6.9992889
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A NOTE ON THE RELATIONSHIP AND AGREEMENT BETWEEN TWO SATELLITE THEORIES

K. Aksnes

We shall refer to the two theories under consideration as theory A (Gaposchkin, Cherniack, Briggs, and Benima, 1971; Kozai, 1962) and theory B (Aksnes, 1970). The main purpose here is to introduce some simple theoretical relations by means of which, when the elements of one theory are given, we can predict those of the other.

Theory B differs from theory A in that the former makes use of 1) a reference orbit that is a rotating ellipse (intermediate orbit) instead of a fixed ellipse, 2) Hill variables instead of Delaunay variables, and 3) Hori's method in Lie series rather than Von Zeipel's method in Taylor series.

In both theories, the periodic perturbations are expressed as deviations from a mean orbit whose elements are semimajor axis a, eccentricity e, mean anomaly M, inclination i, argument of perigee ω, and right ascension of the ascending node Ω. To distinguish between the two sets of elements, we shall attach a subscript "0" to those of theory A. Although, strictly speaking, the formulas introduced below are valid only if the mean elements are constants or linear functions of time, they should also be sufficiently good approximations if the mean elements are allowed to contain long-period terms, as is the case with the SAO mean elements.

For convenience, M, ω, and Ω have been so defined that

$$M = M_0, \quad \omega = \omega_0, \quad \Omega = \Omega_0 \quad . \tag{1}$$

However, internally, theory B utilizes a set of elements g and h that differ from ω and Ω by the amount of rotation that the intermediate orbit is undergoing, viz.,

$$\omega = g + g_{21}(g + M) \quad , \quad \Omega = h + g_{32}(\omega + M) \quad , \tag{2}$$

where

$$g_{21} = -\frac{3}{4}\gamma(1-5c^2) - \frac{1}{64}\gamma^2(41+30c^2-135c^4) + 0(\gamma^3) \quad ,$$

$$g_{32} = -\frac{3}{16}c\,[8\gamma + \gamma^2(7-33c^2)] + 0(\gamma^3) \quad . \tag{3}$$

Here and in the following, we have used the notation

$$c = \cos i \quad , \quad n = \sqrt{\mu/a^3} \quad , \quad \eta = \sqrt{1-e^2} \quad , \quad G = \eta\sqrt{\mu a} \quad ,$$

$$\gamma = \frac{J_2}{a^2\eta^4} \quad , \quad \gamma_4 = \frac{J_4}{J_2^2} \quad ,$$

where a is measured in earth radii. The mean rates of change of M_0, ω_0, and Ω_0 are given by

$$\begin{aligned}\dot{M}_0 = n_0 - \frac{3}{4}n_0\gamma_0\eta_0\Big\{1 - 3c_0^2 - \frac{1}{32}\gamma_0\Big[10(1-6c_0^2+13c_0^4)\\ - 5(5-18c_0^2+5c_0^4)e_0^2 + 16\eta_0(1-6c_0^2+9c_0^4)\\ - 15\gamma_4(3-30c_0^2+35c_0^4)e_0^2\Big]\Big\} + 0(\gamma^3) \quad ,\end{aligned} \tag{4}$$

$$\begin{aligned}\dot{\omega}_0 = -\frac{3}{4}n_0\gamma_0\Big\{1 - 5c_0^2 + \frac{1}{32}\gamma_0\Big[2(5+43c_0^2)(1-5c_0^2)\\ + (25-126c_0^2+45c_0^4)e_0^2 - 24\eta_0(1-8c_0^2+15c_0^4)\\ + 20\gamma_4(3-36c_0^2+49c_0^4) + 45\gamma_4(1-14c_0^2+21c_0^4)e_0^2\Big]\Big\} + 0(\gamma^3) \quad ,\end{aligned} \tag{5}$$

and

$$\begin{aligned}\dot{\Omega}_0 = -\frac{3}{2}n_0\gamma_0 c_0\Big\{1 - \frac{1}{16}\gamma_0\Big[4 - 40c_0^2 - (9-5c_0^2)e_0^2\\ + 12\eta_0(1-3c_0^2) - 5\gamma_4(3-7c_0^2)(2+3e_0^2)\Big]\Big\} + 0(\gamma^3) \quad .\end{aligned} \tag{6}$$

These are invariant rates, and although expressed differently, they must be equal individually to $\dot{M}$, $\dot{\omega}$, and $\dot{\Omega}$, which are given by

$$\dot{M} = n + \frac{3}{128} n\gamma^2 \eta \Big[8(1 - 6c^2 + 5c^4) - 5(5 - 18c^2 + 5c^4) e^2 - 15\gamma_4(3 - 30c^2 + 35c^4) e^2\Big] + 0(\gamma^3) \quad , \tag{7}$$

$$\left.\begin{aligned} \dot{\omega} &= \dot{g} + g_{21} (\dot{g} + \dot{M}) \quad , \\ \dot{g} &= -\frac{1}{128} n\gamma^2 \Big[44 - 300c^4 + (75 - 378c^2 + 135c^4) e^2 + 60\gamma_4(3 - 36c^2 + 49c^4) \\ &\quad + 135\gamma_4(1 - 14c^2 + 21c^4) e^2\Big] + 0(\gamma^3) \quad , \end{aligned}\right\} \tag{8}$$

and

$$\left.\begin{aligned} \dot{\Omega} &= \dot{h} + g_{32}(\dot{\omega} + \dot{M}) \quad , \\ \dot{h} &= \frac{3}{32} nc\gamma^2 [2 - 10c^2 - (9 - 5c^2) e^2 - 5\gamma_4 (3 - 7c^2)(2 + 3e^2)] + 0(\gamma^3) \quad . \end{aligned}\right\} \tag{9}$$

Aksnes (1970) has shown that the elements a, e, and i relate to a_0, e_0, and i_0 through the following equations:

$$\frac{1}{a} = \frac{1}{a_0} \left\{1 - \frac{1}{2} \eta_0 \gamma_0 (1 - 3c_0^2) + \frac{1}{32} \eta_0 \gamma_0^2 \Big[1 + 6\eta_0 - (6 + 36\eta_0) c_0^2 + (45 + 54\eta_0) c_0^4\Big]\right\} + 0(\gamma^3) \quad , \tag{10}$$

$$G = G_0 \left[1 + \frac{1}{4} \gamma_0 (1 - 3c_0^2)\right] + 0(\gamma^2) \quad , \tag{11}$$

and

$$c = c_0\left[1 + \frac{3}{4} \gamma_0 (1 - c_0^2)\right] + 0(\gamma^2) \quad . \tag{12}$$

While the third-order parts of equations (3) to (9) are available in the cited literature, the terms beyond the second order in equation (10) and the first order in equations (11) and (12) are not known.

For conversion between the two sets of mean elements, equations (1) and (10) to (12) will suffice. In view of the importance of these equations, we have tested them on the orbits of three actual satellites (Table 1). The first two sets of elements have been derived by fitting theory A (line 1) and theory B (line 2) to a series of mostly very accurate laser observations in the manner described by Gaposchkin and Mendes ("Orbital Elements from ISAGEX Data," this volume). The third line shows the elements predicted for theory B by means of the above-mentioned equations and the elements on line 1. The agreement between the last two sets of elements is very good and well within standard errors. The two theories agree on the computed ranges to a few tenths of a meter.

Table 1. Comparison of mean elements for three satellites at epoch 41080.0.

Satellite	Theory	a	e	i	M	ω	Ω
6701401, 261 observations	A	1.1925238	0.0838280	39°.44949	33°.64344	194°.54493	134°.43624
	B	1.1921616	0.0838340	39.43323	33.64344	194.54491	134.43625
	B (Pred.)	1.1921616	0.0838329	39.43321	33.64344	194.54493	134.43624
6508901, 241 observations	A	1.2656913	0.0721680	59.38145	294.47892	24.26520	265.05593
	B	1.2657869	0.0721670	59.36859	294.47892	24.26519	265.05594
	B (Pred.)	1.2657869	0.0721664	59.36859	294.47892	24.26520	265.05593
6800201, 138 observations	A	1.2080431	0.0320070	105.80768	149.20308	2.42648	301.93324
	B	1.2083920	0.0320040	105.81605	149.20308	2.42648	301.93324
	B (Pred.)	1.2083920	0.0320045	105.81605	149.20308	2.42648	301.93324

REFERENCES

AKSNES, K.

1970. A second-order artificial satellite theory based on an intermediate orbit. NASA TR 32-1507, 34 pp.; also in Astron. Journ., vol. 75, pp. 1066-1076.

GAPOSCHKIN, E. M., CHERNIACK, J. R., BRIGGS, R., and BENIMA, B.

1971. Third-order oblateness perturbations for an artificial satellite. Presented at the 52nd American Geophysical Union Meeting, Washington, D.C., April; to be published as Smithsonian Astrophys. Obs. Spec. Rep.

KOZAI, Y.

1962. Second-order solution of artificial satellite theory without air drag. Astron. Journ., vol. 67, pp. 446-461.

ABBREVIATIONS USED IN THIS REPORT

BIH	Bureau International de l'Heure
CNES	Centre National d'Etudes Spatiales
EPSOC	Earth Physics Satellite Observation Campaign
GOCC	Geodetic Operations Control Center
GSFC	Goddard Space Flight Center
IGY	International Geophysical Year
ISAGEX	International Satellite Geodesy Experiment
NASA	National Aeronautics and Space Administration
NTU	National Technical University, Athens, Greece
PMT	Photomultiplier Tube
SAO	Smithsonian Astrophysical Observatory
USNO	United States Naval Observatory