MARCH 1968

PROCEEDINGS OF THE GEOS PROGRAM REVIEW MEETING
12 - 14 DECEMBER 1967

VOLUME I

GEOS-I OPERATIONS AND PLANS FOR GEOS-B

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6565 Arlington Boulevard, Post Office Box 530, Falls Church, Virginia 22046

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PROCEEDINGS OF THE GEOS PROGRAM REVIEW MEETING

12-14 December 1967
NASA Headquarters
400 Maryland Avenue, SW
Washington, D. C.

Volume I

GEOS-I OPERATIONS AND PLANS FOR GEOS-B

Edited by Communications & Systems, Incorporated
6565 Arlington Boulevard, Falls Church, Virginia

March 1968

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FOREWORD

On 12-14 December 1967 a GEOS Program Review Meeting was held at NASA Headquarters in Washington, D. C. The purpose of the meeting was to review the results obtained from the GEOS-I spacecraft which was launched into orbit on 6 November 1965 and to present the investigation plans for GEOS-B to be launched into orbit in January 1968.

The proceedings of this meeting are published in three volumes due to the extensive amount of material presented. The volumes are entitled:

Volume I - GEOS-I Operations and Plans for GEOS-B

Volume II - Geometric and Gravimetric Investigations with GEOS-I

Volume III - Tracking Intercomparison Tests with GEOS-I

This volume (Volume I) contains the presentations on the GEOS-I spacecraft description, operations conducted with GEOS-I, the participating networks, the GEOS-B spacecraft description and the investigation plans for GEOS-B. The volume is divided into two parts, the first part pertains to GEOS-I and the second part to GEOS-B.

Editor's Note:

GEOS-B was launched on 11 January 1968 at 11:16:00:006 EST from Satellite Launch Complex 2, at the Western Test Range (WTR). The spacecraft is now designated GEOS-II.

Based on tracking data obtained during the first few orbits, the actual orbital characteristics were determined to be as follows:

	Expected	Actual
Apogee (km)	1572.8	1574.5
Perigee (km)	1100.0	1079.5
Period (min)	112.392	112.18
Inclination (deg)	105.997	105.8
Eccentricity	.0306	.0321

LIST OF ATTENDEES

Mr. Leendert Aardoom
Geodetic Institute of the Technological University Delft
Kanaalweg 4
Delft, Netherlands

Mr. James R. Allder
Aerospace Corporation
P. O. Box 95085
Los Angeles, California

Mr. Richard J. Anderle
Naval Weapons Laboratory
Dahlgren, Virginia

Mr. Ray Andrel
Geonautics, Incorporated
803 West Broad Street
Falls Church, Virginia

Mr. John Berbert
Code 514
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. J. A. Bernar
Army Map Service
6500 Brooks Lane
Washington, D. C. 20315

Mr. H. D. Black
The Johns Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Spring, Maryland 20910

Mr. Piero Brovarone
Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge, Massachusetts 02138

Mr. Duane C. Brown
D. Brown Associates
P. O. Drawer 550
Melbourne, Florida 32901

Dr. Fausto M. Calabria
Geonautics, Incorporated
803 West Broad Street
Falls Church, Virginia

Mr. Robert P. Capria
General Electric Company
Spacecraft Department
P. O. Box 8555
Philadelphia, Pennsylvania 19101

Mr. R. G. Chaplick
Code 552
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. Bernard Chovitz
Room R131
ESSA
Rockville, Maryland 20852

Mr. Bernard Claveloux
Geonautics, Incorporated
803 West Broad Street
Falls Church, Virginia

Mr. R. E. Clayton
General Electric Company
P. O. Box 8555
Philadelphia, Pennsylvania 19101

Mr. L. R. Dailey
Aerospace Corporation
2350 East El Segundo Boulevard
El Segundo, California

Mr. Maurice D. D'Ana
Wolf Research and Development Corporation
4321 Hartwick Road
College Park, Maryland 20740

Mr. C. E. Doll
Code 552
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. David D. Dudley
Communications & Systems, Incorporated
6565 Arlington Boulevard
Falls Church, Virginia 22042

Mr. Robert E. Dwyer
Communications & Systems, Incorporated
6565 Arlington Boulevard
Falls Church, Virginia 22042

Mr. Wylie H. Ewing
Headquarters, 9th Aerospace Defense Division
9EDC-A
Ent Air Force Base, Colorado 80912

Dr. Heinrich K. Eichhorn von Wurmb
Department of Astronomy
University of South Florida
Tampa, Florida 33620

Mr. J. Robert Fischel
Communications & Systems, Incorporated
6565 Arlington Boulevard
Falls Church, Virginia 22042

Mr. Richard J. Farrar
Aerospace Corporation
2350 East El Segundo Boulevard
El Segundo, California

Mr. Doyle Fredrick
Room BF 866
The Pentagon
Washington, D. C.

Mr. Charles H. Frey
Department of Defense
Washington, D. C.

Mr. Lawrence Gambino
Survey and Geodesy Division
ETL
Fort Belvoir, Virginia 22060

Mr. E. M. Gaposchkin
Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge, Massachusetts 02138

Mr. Raul Garza-Robles
D. Brown Associates
5600 Annapolis Road
Lanham, Maryland 20801

Mr. Fred H. Gerring
Goodyear Aerospace Corporation
Department 913
1210 Massillon Road
Akron, Ohio 44315

Mr. William D. Googe
Army Map Service
6500 Brooks Lane
Washington, D. C. 20315

Mr. Roger C. Gore
Aerospace Corporation
2350 El Segundo Boulevard
El Segundo, California

Mr. Robert Greene
Code 67
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. George Hadgigeorge
AFCRL/CRJG
L. G. Hanscom Field
Bedford, Massachusetts

Mr. Nelson T. Hallmark
U. S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060

Mr. David W. Harris
Code 514
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. John G. Hartwell
D. Brown Associates
P. O. Drawer 550
Melbourne, Florida 32901

Mr. E. V. Hobbs
Code 513
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. Joseph R. Johns
Code 601
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. R. J. Katucki
General Electric Company
Spacecraft Department
P. O. Box 8555
Philadelphia, Pennsylvania 19101

Prof. William M. Kaula
Institute of Geophysics
University of California
Los Angeles, California 90024

Mr. Joseph Kay
Naval Air Systems Command
Code 53822
Washington, D. C.

Mr. Straton C. Laios
Code 573
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. James H. Latimer
Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge, Massachusetts 02138

Mr. Francis J. Lerch
Code 552
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. J. J. Levallois
Institut Geographique National
136 vis rue de Grenelle
Paris 7, France

Mr. E. Levin
Aerospace Corporation
P. O. Box 95085
Los Angeles, California

Mr. Fred M. Loveless
D. Brown Associates
P. O. Box 1305
Alexandria, Virginia

Dr. Charles A. Lundquist
Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge, Massachusetts 02138

Mr. Joe J. Lynn
D. Brown Associates
P. O. Drawer 550
Melbourne, Florida 32901

Dr. Stephen J. Madden, Jr.
MIT Experimental Astronomy Laboratory
265 Massachusetts Avenue
Cambridge, Massachusetts 02138

Mr. Richard T. Malone
U.S. Army Field Launch Director
ETL-SSC
U.S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060

Mr. Paul A. Maresca
Radio Corporation of America
9430 Lanham-Severn Road
Seabrook, Maryland

Mr. James G. Marsh
Code 552
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. Charles F. Martin
ACIC (ACDEG-2)
Second and Arsenal Streets
St. Louis, Missouri 63118

Mr. Chreston F. Martin
Wolf Research and Development Corporation
4321 Hartwick Road
College Park, Maryland 20740

Mr. John S. McCall
Officer Chief of Engineers
Headquarters, Department of the Army
Washington, D. C.

Mr. Foster Morrison
Geodetic Laboratory (ESSA)
6001 Executive Boulevard
Rockville, Maryland 20852

Dr. Samuel J. Moss
Wolf Research and Development Corporation
4321 Hartwick Road
College Park, Maryland 20740

Mr. George Mourad
Battelle Memorial Institute
505 King Avenue
Columbus, Ohio 43201

Prof. Ivan I. Mueller
Department of Geodetic Science
Ohio State University
164 West 19th Avenue
Columbus, Ohio 43210

Mr. Patrick Norris
Radio Corporation of America Service Company
4321 Hartwick Road
College Park, Maryland 20740

Col. John T. O'Donnell
Department of Defense
Washington, D. C.

Mr. Brian O'Neill
Wolf Research and Development Corporation
4321 Hartwick Road
College Park, Maryland 20740

Mr. John D. Oosterhout
Code 514
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. Horace C. Parker
Radio Corporation of America
9430 Lanham-Severn Road
Seabrook, Maryland 20801

Dr. Henry H. Plotkin
Code 524
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. Gerald L. Pucillo
Space Programs Office
NASA Electronics Research Center
575 Technology Square
Cambridge, Massachusetts 02139

Mr. James S. Reece
Geonautics, Incorporated
803 West Broad Street
Falls Church, Virginia

Mr. James A. Richardson
Geonautics, Incorporated
803 West Broad Street
Falls Church, Virginia

Mrs. Mary V. Russel
Flight Operations Engineer
General Electric Company
4321 Hartwick Road
College Park, Maryland 20740

Mr. Erich H. Rutscheidt
Code 14200
Army Map Service
6500 Brooks Lane
Washington, D. C. 20315

Mr. Jan Rolff
Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge, Massachusetts 02138

Mr. D. C. Romick
Department 455G
Goodyear Aerospace Corporation
1210 Massillon Road
Akron, Ohio 44315

Mr. Marcus A. Rosenbaum
Headquarters, U.S. Air Force (AFNINCB)
Washington, D. C.

Mr. J. D. Rosenberg
Code SAG
National Aeronautics and Space Administration
Washington, D. C. 20546

Mr. N. A. Roy
Wolf Research and Development Corporation
4321 Hartwick Road
College Park, Maryland 20740

Mr. Richard Sandifer
Wolf Research and Development Corporation
4321 Hartwick Road
College Park, Maryland

Mr. Stephen H. Sandler
Communications & Systems, Incorporated
6565 Arlington Boulevard
Falls Church, Virginia 22042

Dr. William A. Schmieman
Headquarters, 9ADD
9EDC-A
Ent Air Force Base, Colorado 80912

Mr. Philip M. Schwimmer
Department of Defense
Washington, D. C

Dr. Lad. Sehnal
Smithsonian Astrophysical Observatory
3 Exeter Park
Cambridge, Massachusetts 02140

Mr. Thomas O. Seppelin
Headquarters, Aeronautical Chart and Information Center
Second and Arsenal Streets
St. Louis, Missouri 63118

Dr. Dmitri Shchegolev
P. O. Box M-140
Pulkovo Observatory
Leningrad, USSR

Mr. Leonard H. Solomon
Smithsonian Astrophysical Observatory
60 Garden Street
Cambridge, Massachusetts 02138

Mr. H. Ray Stanley
National Aeronautics and Space Administration
Wallops Station
Wallops Island, Virginia 23337

Mr. Forrest H. Stieg
Communications & Systems, Incorporated
6565 Arlington Boulevard
Falls Church, Virginia 22042

Mr. William Strange
Geonautics, Incorporated
803 West Broad Street
Falls Church, Virginia

Mr. Dalton C. Tidwell, Jr.
Code 601
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. C. C. Tonies
Aerospace Corporation
P. O. Box 95085
Los Angeles, California 90045

Dr. James T. Vette
National Space Science Data Center
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. Richard L. Vitek
Code 14320
Army Map Service
6500 Brooks Lane
Washington, D. C. 20315

Mr. Carl A. Wagner
Code 643
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mrs. Marvel A. Warden
Code 14200
Army Map Service
6500 Brooks Lane
Washington, D. C. 20315

Dr. George Weiffenbach
The Johns Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Spring, Maryland 20910

Mr. William T. Wells
Wolf Research and Development Corporation
5801 Annapolis Road
Bladensburg, Maryland

Mr. Owen W. Williams
ARCRL/CRJ
L. G. Hanscom Field
Bedford, Massachusetts 01730

Mr. William E. Williams
Code TN
National Aeronautics and Space Administration
Washington, D. C. 20546

Mr. C. Byron Winn
Colorado State University
Mechanical Engineering Department
Fort Collins, Colorado 80521

Mr. Henry Woodward
General Electric Company
4321 Hartwick Road
College Park, Maryland 20740

Mr. Lem Wong
Aerospace Corporation
P. O. Box 95085
Los Angeles, California 90045

Lt. Cdr. J. Austin Yeager
Chief, Satellite Triangulation Division
Coast and Geodetic Survey
Rockville, Maryland

Mr. Steve M. Yionoulis
The Johns Hopkins University
Applied Physics Laboratory
8621 Georgia Avenue
Silver Spring, Maryland 20910

Mr. Paul J. Zalubas
Communications & Systems, Incorporated
6565 Arlington Boulevard
Falls Church, Virginia 22042

Mr. John B. Zegalia
Code 513
Goddard Space Flight Center
Greenbelt, Maryland 20771

Mr. Jack Zeigler
NASA/GOCC
Code 14N283
Goddard Space Flight Center
Greenbelt, Maryland 20771

OBJECTIVES OF THE NGSP

Jerome D. Rosenberg
GEOS Program Manager
NASA Headquarters

1. Geometric Objective

To provide the basis for establishing points on the physical surface of the Earth in a three-dimensional Cartesian coordinate system with its origin at the center of the mass and one axis coincident with a mean rotational axis of the Earth. This involves the establishment of control points in sufficient number to an accuracy of ± 10 meters to permit the connection and integration of major datums, significant datum blocks and isolated areas and stations in the worldwide reference system.

2. Gravimetric Objective

To establish the coefficients required for describing the gravitational field of the Earth in a spherical development through the 15th degree and order. These coefficients should be determined to a level of accuracy such that they contribute no more than ± 3 mgal rms error to the determination of $12^{\circ} \times 12^{\circ}$ mean anomalies at the Earth's surface.

3. System Evaluation and Data Integration Objective

To carry our system combination analyses as required to assist in achieving the accuracy goals of the geometric and gravimetric objectives of the program. These analyses will permit a definition of the accuracies of the observation systems used in the program, will allow determination of appropriate data integration procedures and data weights for the various systems, and should ultimately define the best geodetic system(s) for future use in satellite geodesy.

GEOS-I SPACECRAFT PERFORMANCE

Dr. George Weiffenbach

Johns Hopkins University/Applied Physics Laboratory

Prepared For

GEOS PROGRAM REVIEW MEETING
12-14 December 1967

NASA HEADQUARTERS
400 Maryland Avenue, SW
Washington, D. C.

GEOS-I SPACECRAFT PERFORMANCE

Dr. George Weiffenbach

Johns Hopkins University/Applied Physics Laboratory

Introduction

GEOS-I was launched into orbit on 6 November 1965. The orbit had an apogee of about 2270 kilometers, a perigee of 1120 kilometers and an inclination of 59.4 degrees. The spacecraft functioned satisfactorily until a failure of the command subsystem, believed to be a component, occurred on 1 December 1966. At the time of failure, the doppler systems were on and continued to transmit and provide doppler geodesy.

Figure 1 is an illustration of GEOS-I. The satellite weighed 365 pounds and measured 51.95 inches across the corners and was 31.9 inches high. The spacecraft is gravity gradient stabilized and electrical power is obtained from panels of solar cells mounted about the body as illustrated.

Instrumentation

GEOS-I was equipped with four active geodetic systems. There was a doppler system which transmitted on three frequencies; 162 MHz, 324 MHz and 972 MHz. There were two transponders; one was the Army supplied SECOR which operated nominally at 200 and 400 MHz and there was also the GSFC Range and Range Rate transponder operating at S-Band. The fourth active system was four optical beacons, more information on this system is presented later in the paper. In addition to these four active systems, there was also a passive array of laser corner reflectors. This array consisted of 322 quartz prisms, with a total reflective area of about 1800 square centimeters.

Attitude Control

To make optimum use of the radiated power, both radio and optical, the GEOS-I satellite was earth oriented. The bottom of the spacecraft contained the optical beacons, laser corner reflectors and the various transmitter and transponder antennas. Earth orientation is accomplished with a gravity gradient passive stabilization system. The damper, which was also the end mass, consisted of a hollow sphere of aluminum and copper which was rigidly attached to the spacecraft. A bar magnet was placed inside the sphere in such a way that it was free to rotate with respect to the sphere. The magnet then became magnetically "anchored" to the field. Libration oscillations of the spacecraft produced rotation of the conducting shell relative to the anchored magnet which in turn resulted in a transfer of energy from the libration motion into an eddy-current loss in the conducting sphere.

Power Supply

Electrical power was supplied from three independent banks of solar cells, each with its own nickel cadmium battery. The only common connection between them was to the command system which would operate from any of the supplies for reasons of reliability. The arrays contained a total of about five thousand 2 x 2 cm N/P solar cells, with 20 mils of fused silica shielding. The total available power was nominally about 40 watts, the actual power was a function of the percent sunlight and the effects of radiation.

The optical system and the transponders each received power from identical systems, i.e., an eight cell NiCd battery with its own solar array. The remainder of the spacecraft received power from an eleven cell main battery and its corresponding solar array. Minimum sun conditions would permit over 600 lamp flashes per day and 40 minutes of operation for each transponder per day. One hundred percent sun increased these values to 900 and 1½ hours respectively.

Several months after launch a problem appeared in the power system. It manifested itself as a very sharp decrease in the current out of the main and transponder solar array at a certain solar aspect angle. This problem resulted in an overall loss of

6% of the power in these two systems. The cause of the problem was never resolved. Radiation degradation resulted in a loss of 15% of the power for the one year of operation.

Optical System

The optical system consisted of four xenon flash tubes, each with an output of 1500 candle seconds. The lamps were aligned parallel to the spacecraft's vertical axis. The lamp patterns were configured to produce a uniform illumination over the ground for the various zenith angles. Figure 2 is an illustration of the luminous intensity produced at the camera as a function of zenith angle for three levels of atmospheric extinction for an altitude of 600 nautical miles. Figure 3 is a similar plot for an altitude of 800 nautical miles. A ΔM of 0.25 corresponds to a clear atmosphere, 0.75 is considered moderately clear and 1.25 is poor.

The optical beacons were controlled by a memory and clock in the satellite. The lamps could be operated in sequences of five or seven, with any specific combination of one to four lamps being flashed simultaneously in each flash sequence. The first flash of every sequence was synchronized to occur at an integer WWV minute. There was a four second ± forty microseconds interval between subsequent flashes. A total of 59 flash sequences and a cycle time of 68 hours could be stored in the satellite's memory. Memory injection was accomplished normally once a day throughout the life of GEOS-I.

The clock used to control the optical beacons was driven by the same oscillator which controls the doppler transmissions. The satellite clock was basically a frequency divider which divides the oscillator frequency by a ratio which can be adjusted over a total range of 38.6 ppm and whose epoch could be set by ground command. The 5 mc oscillator output was first amplified and shaped into a pulse train for a 49:1 shift-register flip-flop divider. The output of the 49:1 divider was a train of pulses at a nominal frequency of 102 kc, or a period of 9.80 microseconds.

This train of pulses was then fed through a pulse-delete circuit, and then to a 4485:1 shift-register divider whose output was a pulse train with a frequency of 1365 pulses per minute (22.750 cps). The memory provided the final division by 1365:1, resulting in a 1 pulse-per-minute clock.

The clock rate was adjusted by deleting individual pulses of the 102 kc signal from the 49:1 divider, each delete being specified by the contents of the clock normalizer bits in the memory which sends the appropriate delete commands to the pulse-delete circuit. Thus the period of each timing signal was increased by 9.8 microseconds per deletion command. The clock rate correction data was updated and stored in the memory at each memory injection.

Operational Problems

There was a problem with the optical system. A tentative hypothesis of the cause has been made, however, attempts to reproduce the same effect on the ground have been unsuccessful. After injection into orbit and prior to gravity gradient stabilization, GEOS-I had an inertial attitude such that the bottom of the satellite looked directly at the sun. It is believed that the tilecoat base on the lamp was carbonized by the focused sunlight from the reflectors and thus provided a conductive path. When the high voltage (~ 15,000 volts) trigger was applied to the lamp, noise spikes were generated which got into the memory circuits. This produced two different effects. One was a complete memory dump which was observed two or three times. The other was an interruption of the clock and a loss of some of the optical beacon program. This did create a problem in that each time a memory dump occurred, clock control was lost. Without clock control the clock drifted fairly rapidly. Because of this problem, the clock was only held within the required 400 microseconds of WWV for about 90% of the operating life of the satellite. At other times when light flashes were executed, it was possible to provide an after-the-fact calibration, usually to within about 100 microseconds. This even applied to some of the light flashes that were executed at a time when the clock was in error.

A malfunction of the thermostat in one oscillator oven was noted on 14 February 1966. The malfunction, which had caused the drift rate of the oscillator to become excessive, was corrected by switching to the alternate oven that day. Some timing errors resulted until the oscillator stabilized again. There was no difficulty as far as doppler data were concerned.

At that point there was an inadvertent oscillator switch which occurred at the time of a command system problem. The other oscillator was turned on and started aging. The system was reversed by throwing a lot of commands at the satellite and it recovered to its original aging curve.

The transponders operated essentially for the life of the spacecraft except for one difficulty, a thermal problem. For a short period of time while the spacecraft was in 100% sun, the motion about its vertical axis was very slow, essentially zero. The transponder on the sunlit side became too hot while the other became too cold. This resulted in some loss of operating time.

The two lower frequency doppler beacons have been on continuously and are still in operation. At the present time they appear to have developed an intermittent. This is presently being investigated.

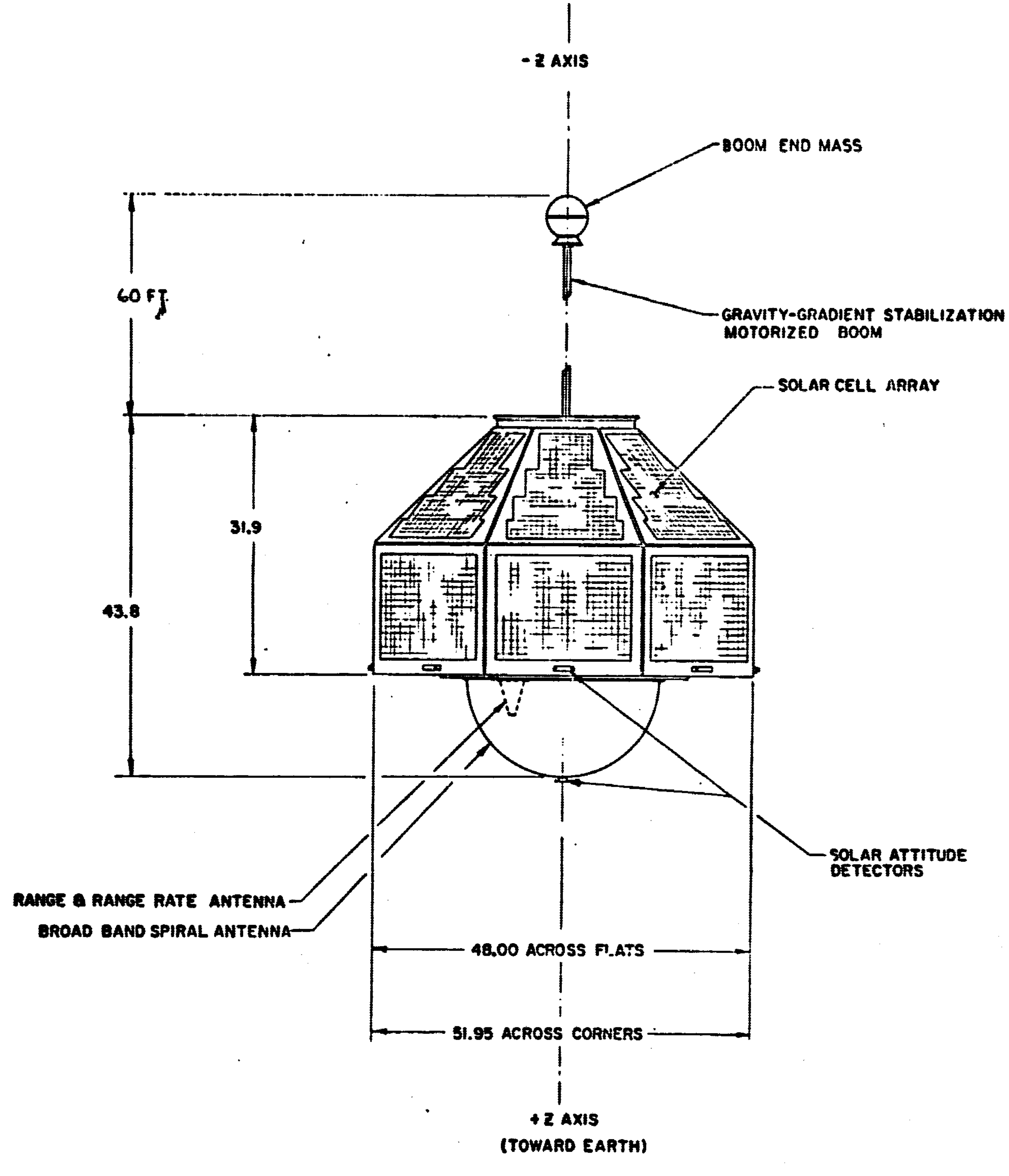


Figure 1. GEOS-I Structural Configuration

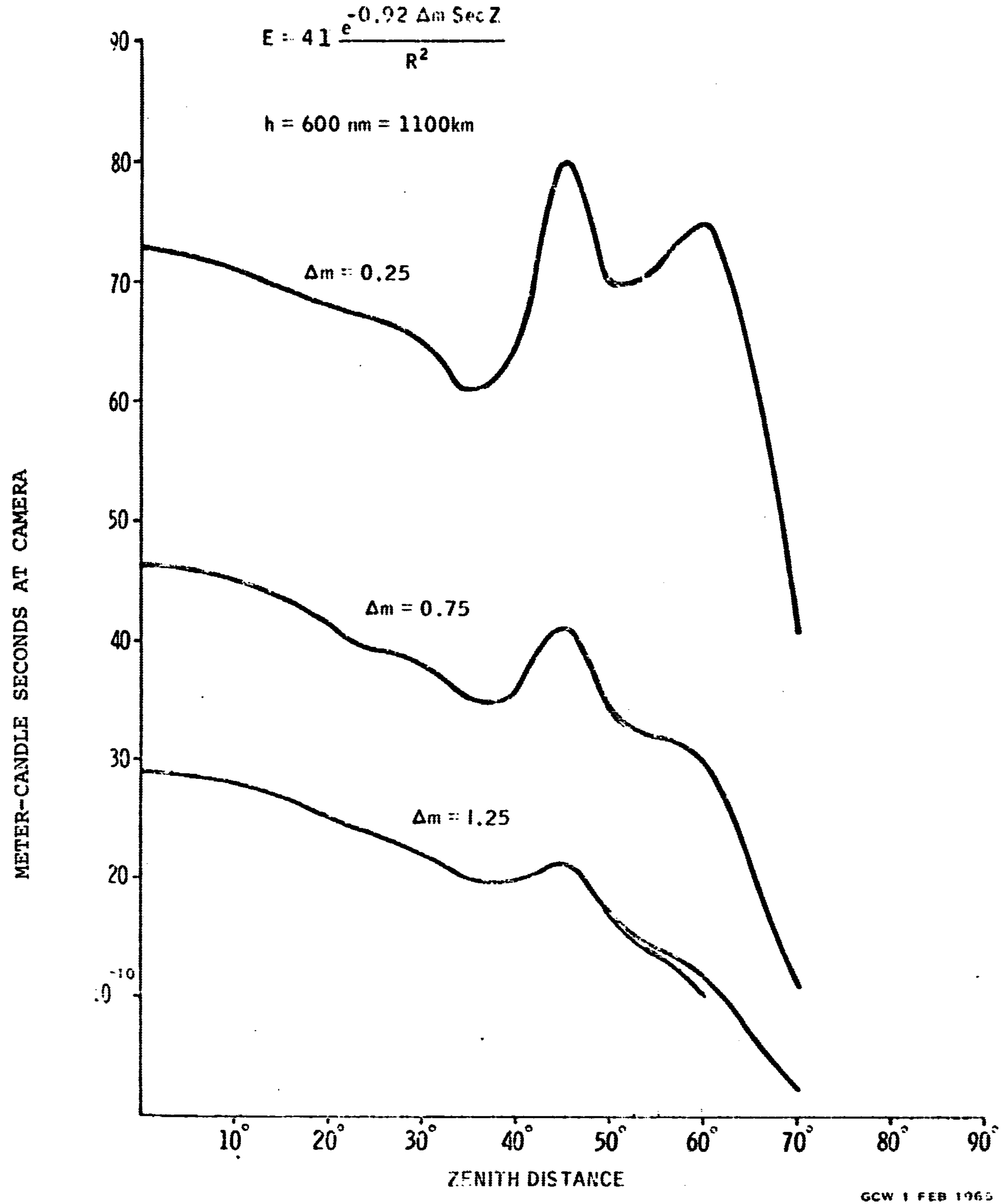
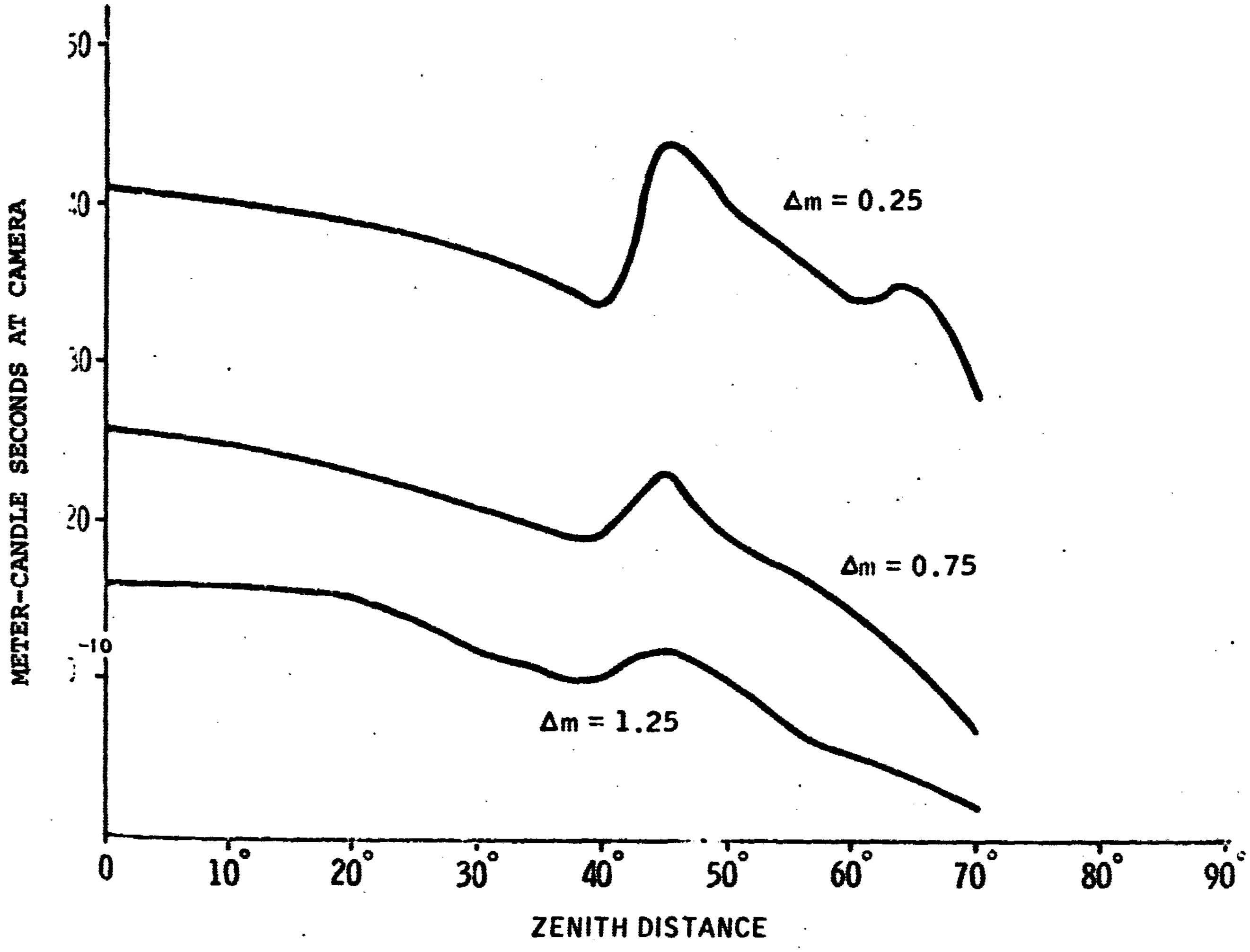


Figure 2. Illumination at Camera vs Zenith Distance Using 4 GEOS-A Lamps at a Satellite Altitude of 600nm, and 3 Different Levels of Atmospheric Extinction

$$E = 4I\,\frac{e^{-0.92\,\Delta m\,\mathrm{Sec}\,Z}}{R^2}$$

$h = 800\mathrm{nm} = 1480\mathrm{km}$



GCW 1 FEB 1965

Figure 3. Illumination at Camera us Zenith Distance Using 4 GEOS-A Lamps at a Satellite Altitude of 600nm, and 3 Different Levels of Atmospheric Extinction

STATIONS SERVICED BY THE NGSP

Geonautics, Incoporated
Falls Church, Virginia

Prepared For

GEOS PROGRAM REVIEW MEETING
12-14 December 1967

NASA HEADQUARTERS
400 Maryland Avenue, SW
Washington, D. C.

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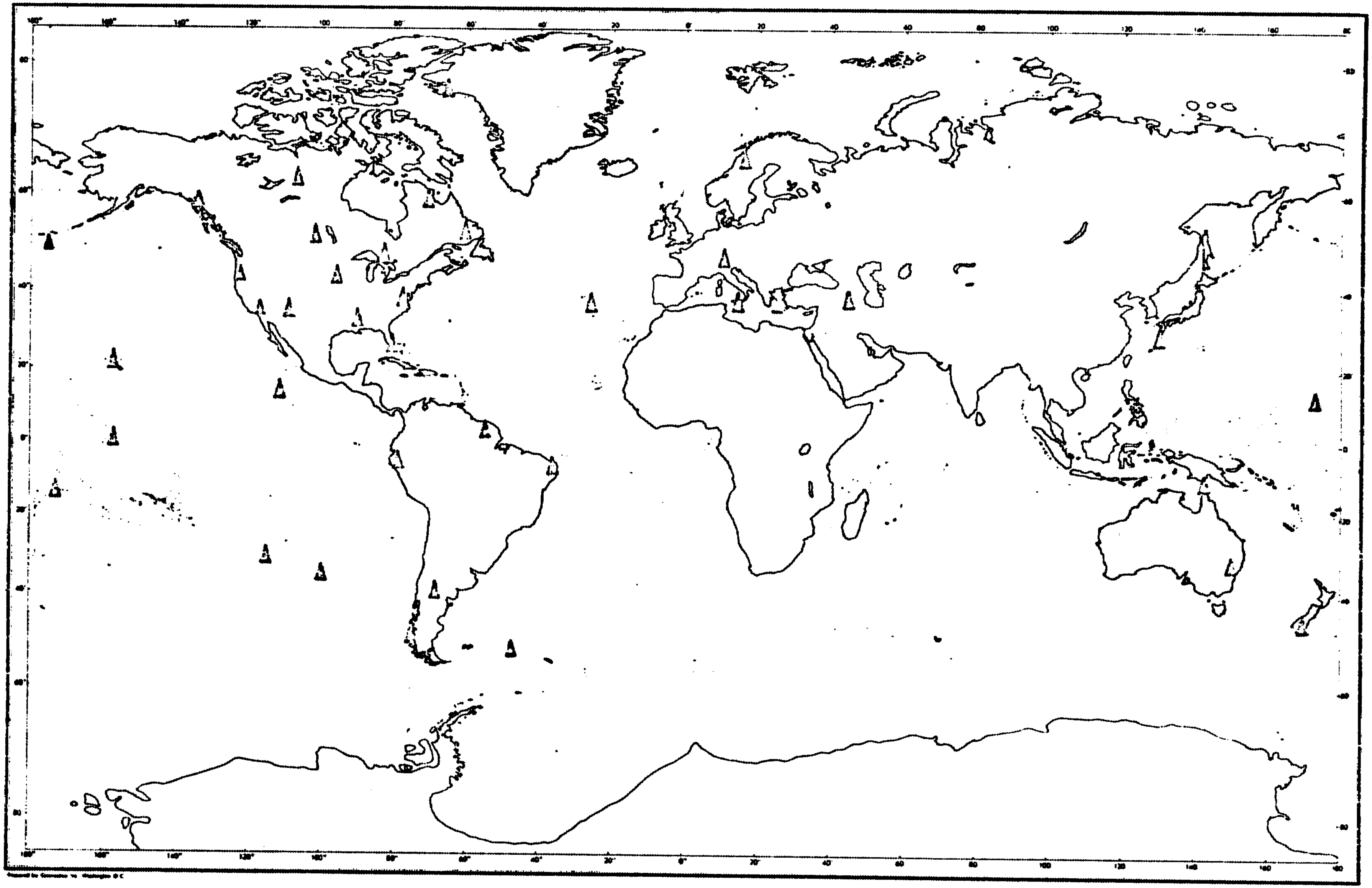
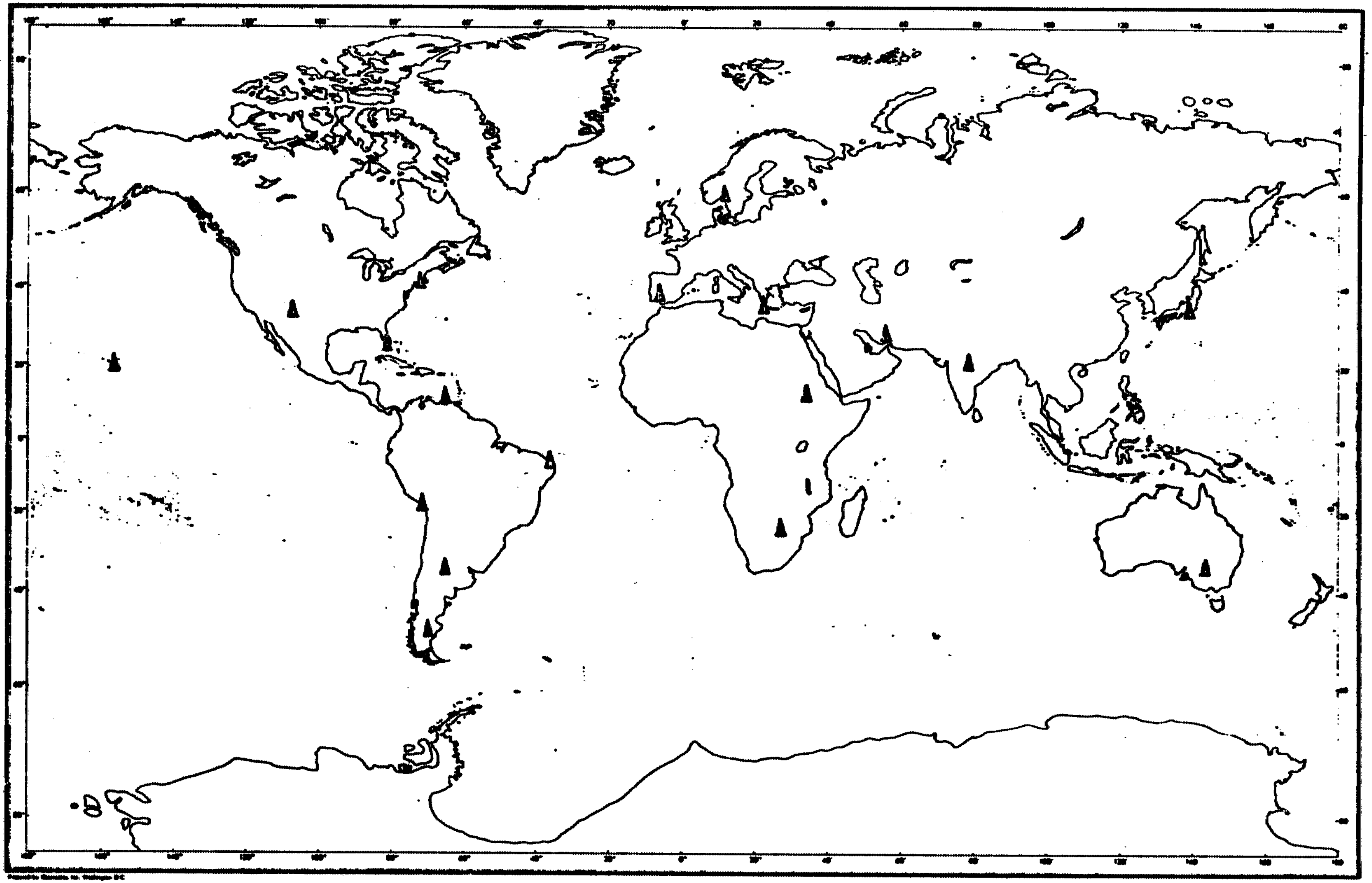


BC-4 NETWORK



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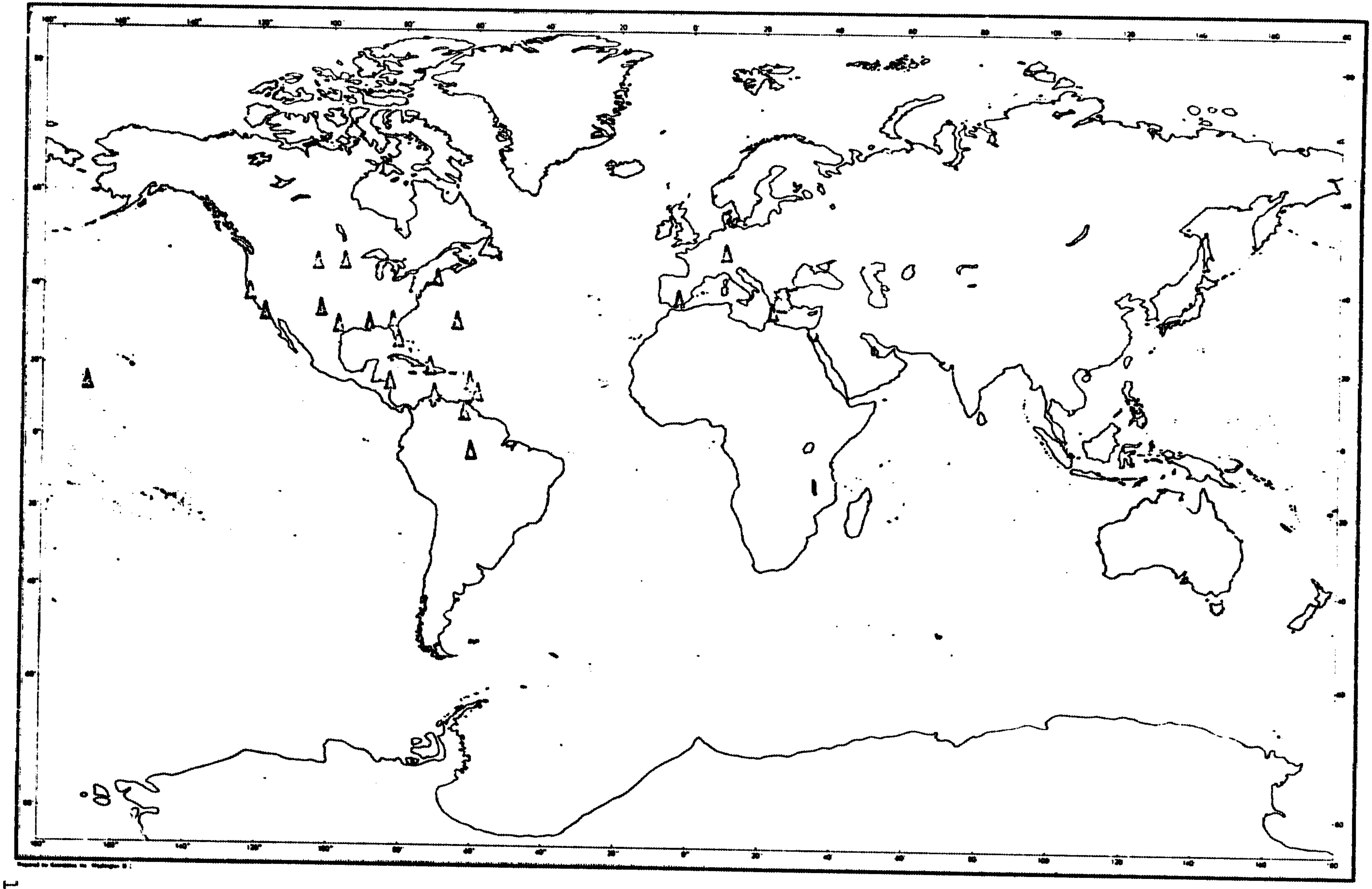

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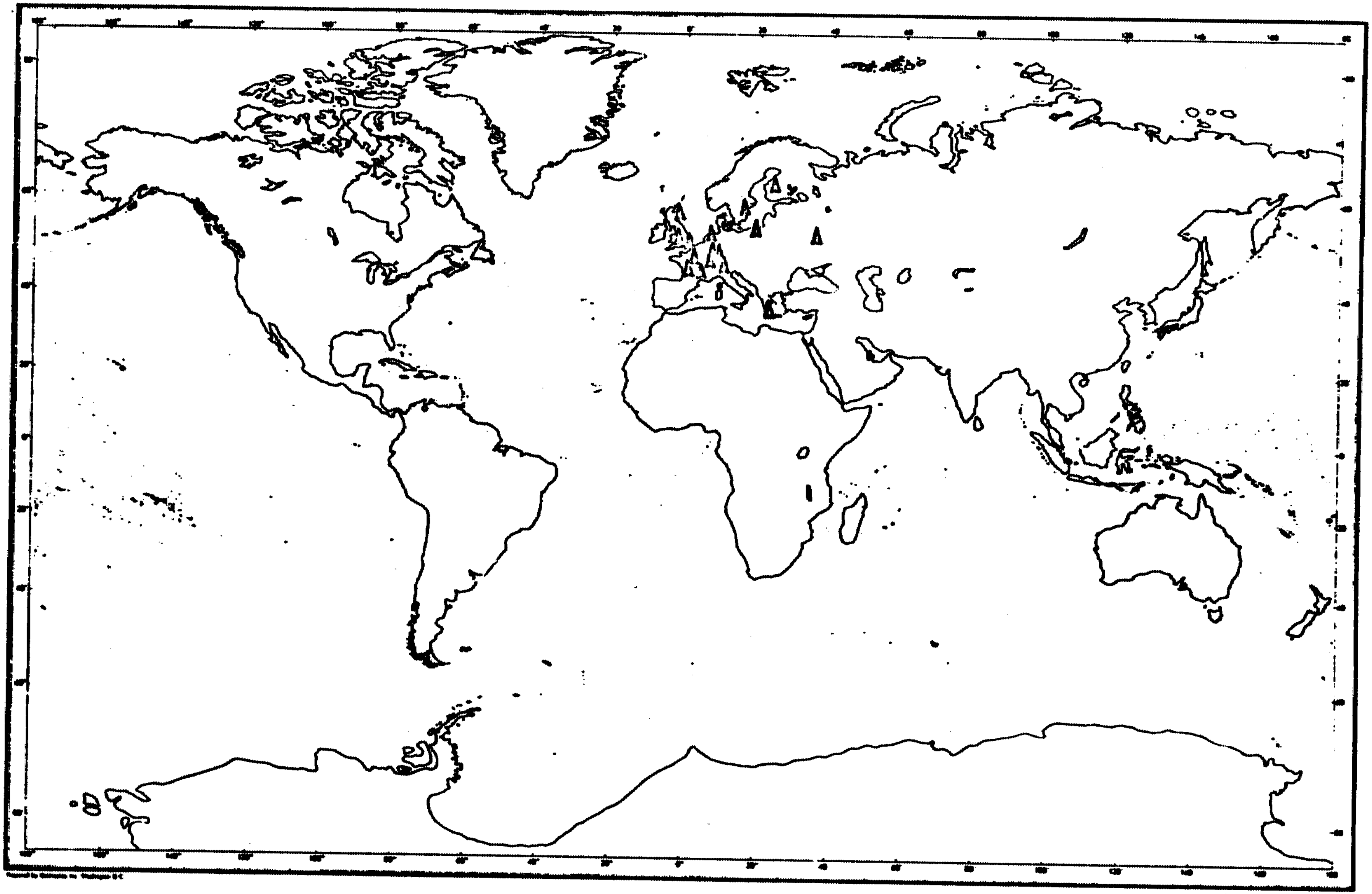

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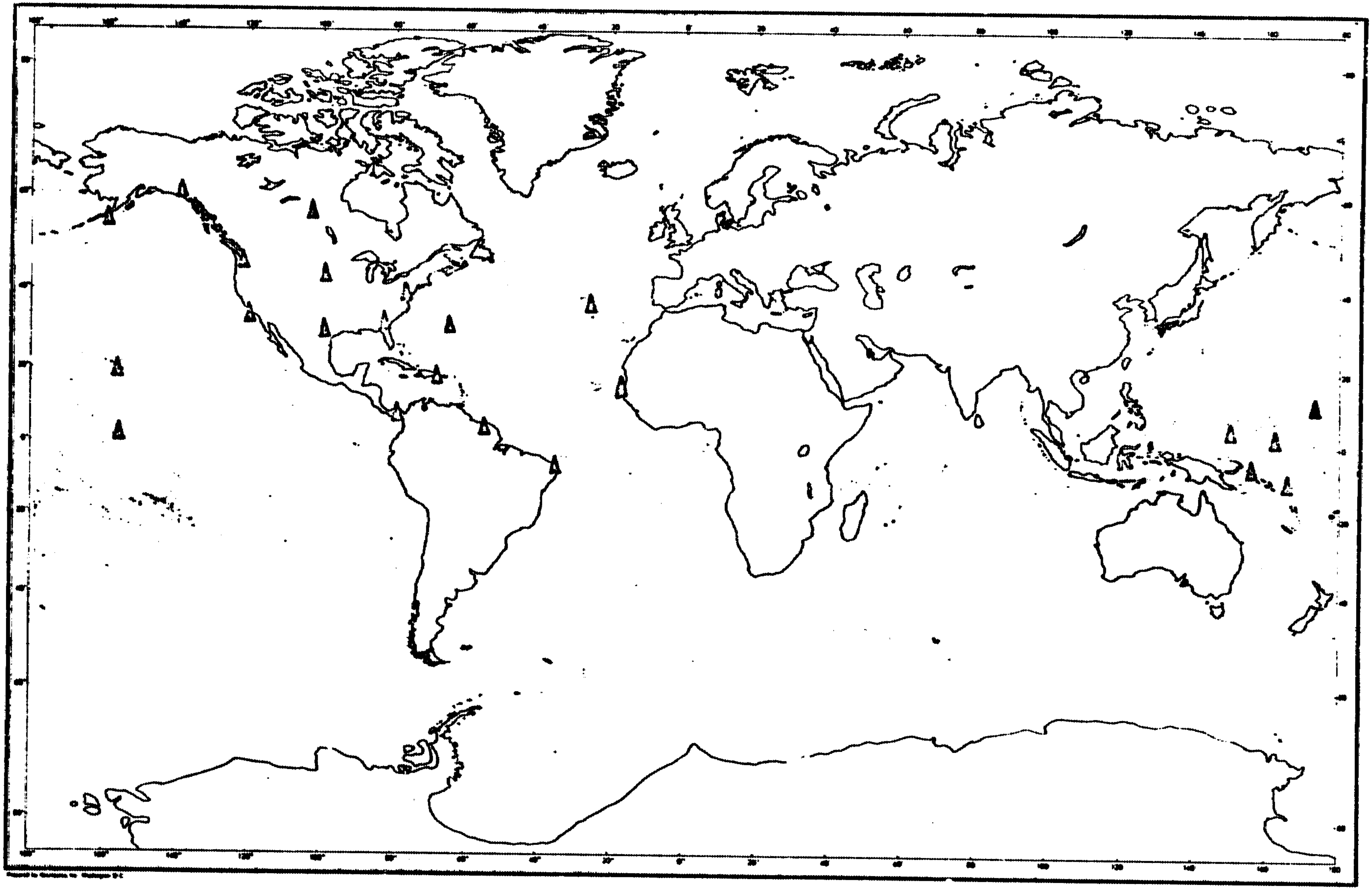
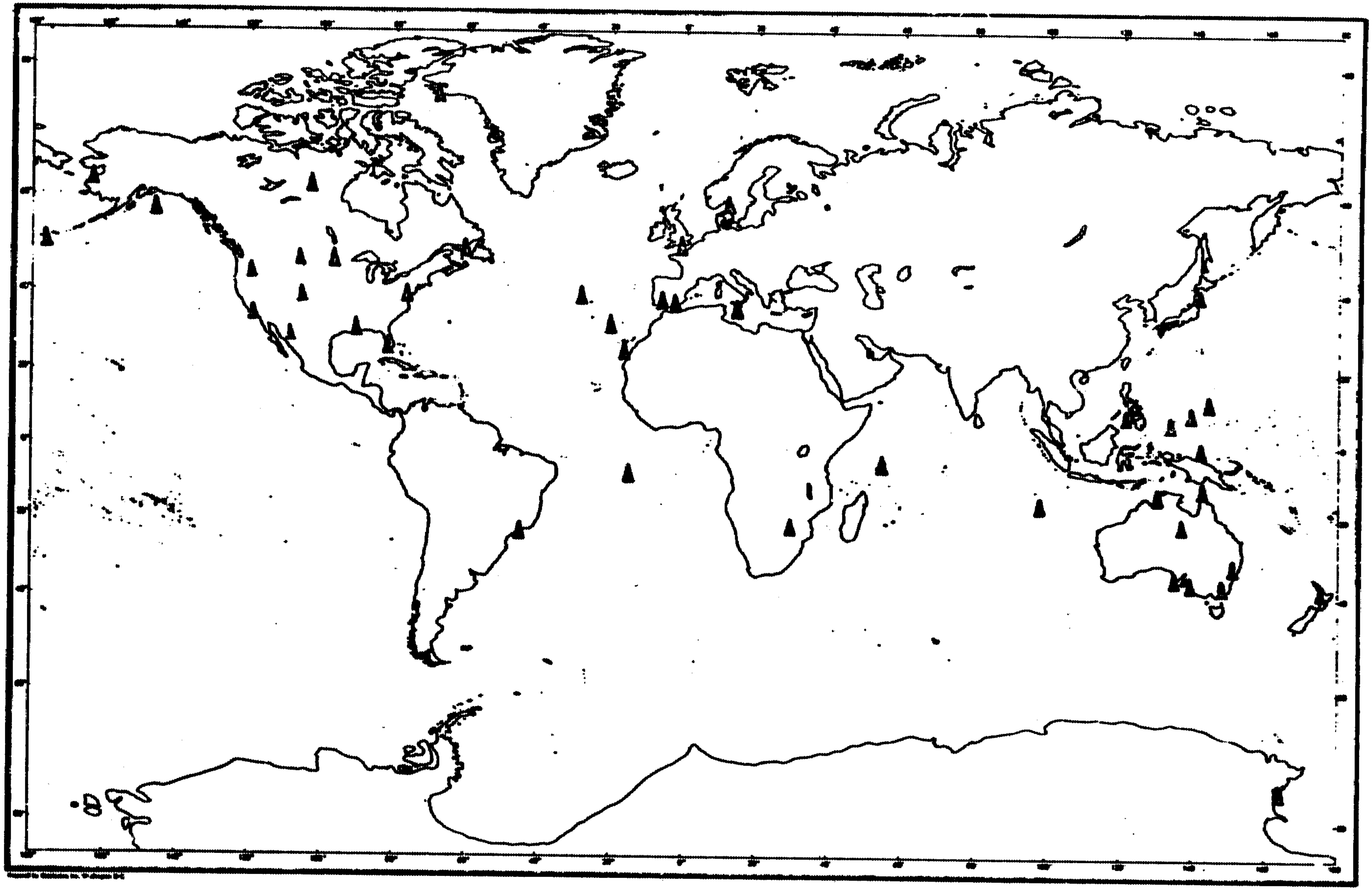
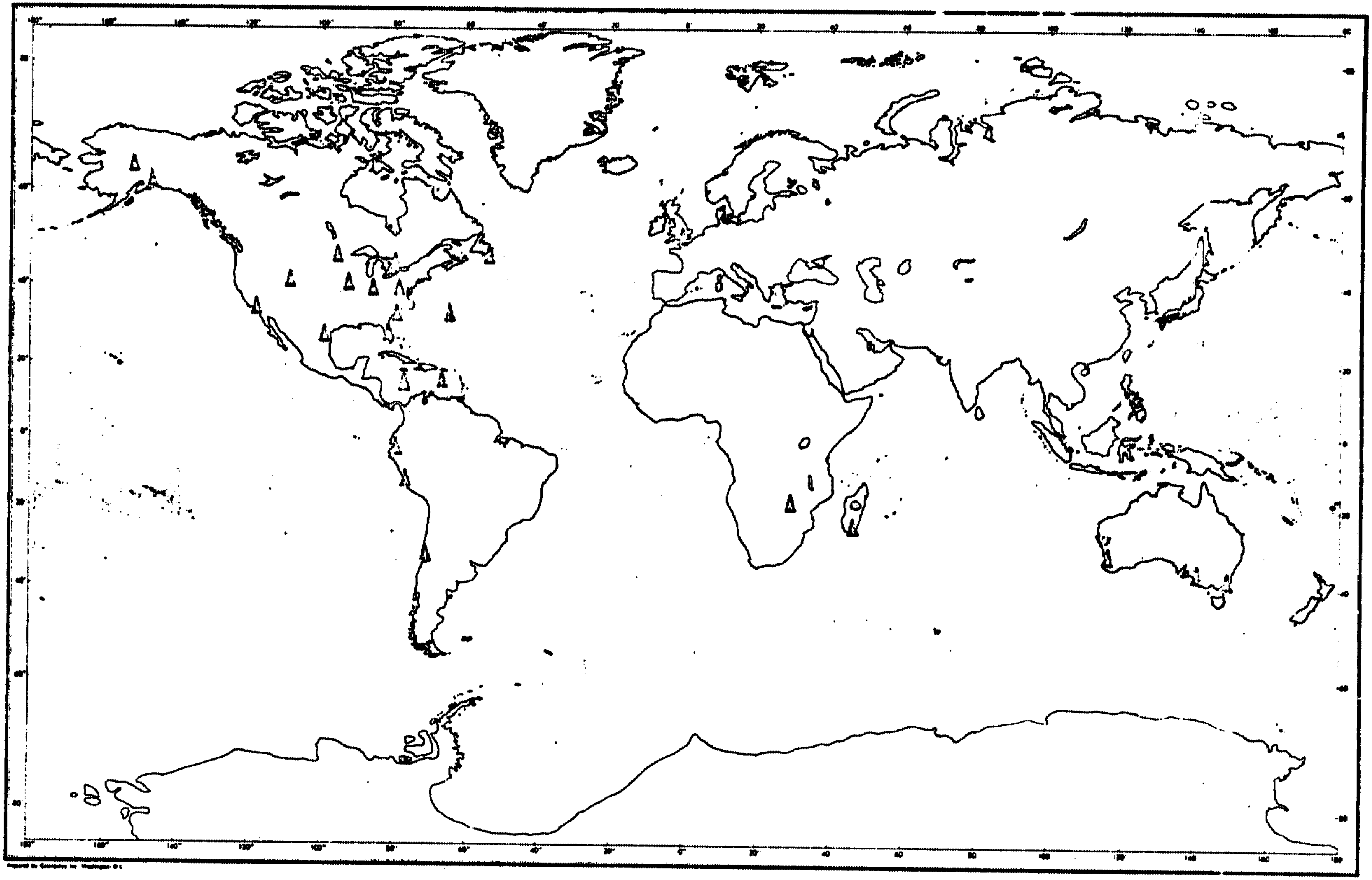


SECOR NETWORK



DOPPLER NETWORK



MOTS AND GRARR NETWORKS

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GEOS I Satellite Tracking Station Positions on the SAO Standard Earth (C-5)

Prepared
by
Wolf Research and Development Corporation
for
Goddard Space Flight Center
under Contract No. 9756 - 71, 71A

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TABLES

1. INTRODUCTION

The purpose of this paper is to present the a priori estimates of the geocentric positions of approximately one hundred stations that have participated in the GEOS-I Mutual Visibility Program. A brief explanation of their derivation is presented. These estimates were derived by shifting the local station datum coordinates on to the Smithsonian Astrophysical Observatory's (SAO) C-5 center of mass Standard Earth.

Section 2 presents a description of the shifts.

Section 3 discusses the shifts for stations on isolated datums.

Section 4 presents parameters for the local datums.

Section 5 presents the original and final station positions in geodetic and cartesian coordinates.

A detailed description of the method in Section 2 and 3 for shifting stations on to the C-5 Standard earth will be available in a forthcoming Goddard X-document.

2. COORDINATE TRANSFORMATION

The coordinates of the Baker-Nunn camera stations on the SAO standard earth are all known, having been derived by SAO through the reduction of approximately 35,000 satellite observations with wide orbital variety. All of the Baker-Nunn stations are connected to major datums and their coordinates are known. The coordinates of the Baker-Nunn stations are given in both ellipsoidal and three-dimensional cartesian coordinate systems.

The transformations to the SAO C-5 standard earth (a_e= 6378165, 1/f = 298.25) utilized the cartesian coordinates. This transformation was accomplished by comparing the original datum coordinates with the derived mass-centered coordinates. The "datum shift" is simply the total transformation to be applied to the original datum coordinates to obtain the new mass-centered coordinates. Once the "datum shift" has been derived for the Baker-Nunn station, this shift is then applied in a weighting scheme to derive the SAO standard earth coordinates for tracking stations that have positions given in the same original datum as the Baker-Nunn and are tied to the Baker-Nunn station through conventional surface surveys. A weighting scheme is used since the Baker-Nunn stations were allowed to adjust independently and subsequently where more than one Baker-Nunn station was located on a single datum, the individual stations show slightly different "datum shifts". The weighting scheme is inversely proportional to the distances between the Baker-Nunn stations and the tracking station to be transformed.

Geoid heights were obtained from geoid contour maps. If no geoid height could be ascertained, then the transformation used mean sea level of the station.

3. ISOLATED DATUMS

An ellipsoidal transformation is performed for a tracking station on an isolated datum such as the Tananarive datum. For these stations the ΔV, ΔV, and ΔW shifts are unknown and considered to be zero. The shifts are computed as follows:

$$\Delta N = (a\Delta f + f\Delta a)\sin^2\phi - \Delta a$$

$$\Delta\phi = 206265\ [(a\Delta f + f\Delta a)\sin 2\phi]/R_m$$

where

$$R_m = \frac{a(1-e^2)}{(1-e^2\sin^2\phi)^{3/2}}$$

a = 6378165 Meters
f = 1/298.25 (flattening)
Δa = 6378165 minus a_e of original survey ellipsoid
Δf = 1/298.25 minus f of original survey ellipsoid
ϕ = geodetic latitude of station in original datum
$e^2 = 2f-f^2 \quad (f = \frac{1}{298.25})$

4. PARAMETERS OF ORIGINAL DATUMS

In order to effect any transformation, the parameters of the original datums must be known as well as the geodetic latitude, longitude and height.

Below are listed the original datums and their parameters in which the stations were originally surveyed.

Datum Name	Semi-Major Axis	1/f
North American	6378206.4	294.9787
European	6378388.	297.0
Tokyo	6377397.2	299.1528
Argentina	6378388.	297.0
Mercury	6378166.	298.3
Madagascar	6378388.	297.0
Australian Nat'l.	6378160.	298.25
Old Hawaiian	6378206.4	294.9787
Indian	6377276.3	300.8017
Arc (Cape)	6378249.1	293.4663
1966 Canton Astro	6378388.	297.0
Johnston Island 1961	6378388.	297.0
Midway Astro 1961	6378388.	297.0
Navy Iben Astro 1947	6378206.4	294.9787
Provisional DOS	6378388.	297.0
Astro 1962, 65 Allen Sodano Lt.	6378388.	297.0
1966 SECOR ASTRO	6378388.	297.0
Viti Levu 1916	6378249.1	293.4663
CORREGO ALEGRE	6378206.4	294.9787
USGS 1962 ASTRO	6378206.4	294.9787
BERNE	6377397.2	299.1528

5. STATION POSITIONS

The following Tables (1-10) list first the cartesian coordinates in the original datum followed by the SAO C-5 coordinates.

Tables (11-20) list first the original surveyed ellipsoidal position and the datum followed by the SAO C-5 ellipsoidal position which is presently used in the data reduction program.

TABLE 1

SAO - OPTICAL

Name	Station No.	X (meters)	Y (meters)	Z (meters)	Datum
1ORGAN	9001	-1535725	-5167147	3400867	N.A.
		-1535761	-5167003	3401046	C-5
1OLFAN	9002	5056254	2716631	-2775468	Arc (Cape)
		5056134	2716489	-2775820	C-5
1OOMER	9003	-3983661	3743135	-3275679	Australian
		-3983756	3743107	-3275598	C-5
1SPAIN	9004	5105682	-555119	3769797	Europe
		5105601	-555233	3769680	C-5
1TOKYO	9005	-3946554	3365774	3698151	Tokyo
		-3946703	3366291	3698849	C-5
1NATOL	9006	1018270	5471237	3109767	Europe
		1018207	5471109	3109619	C-5
1QUIPA	9007	1942774	-5804204	-1797088	N.A.
		1942772	-5804087	-1796964	C-5
1SHRAZ	9008	3376973	4404130	3136414	Europe
		3376887	4403992	3136259	C-5
1CURAC	9009	2251830	-5817059	1326988	N.A.
		2251824	-5816924	1327166	C-5
1JUPTR	9010	976310	-5601550	2880068	N.A.
		976284	-5601398	2880247	C-5
1VILDO	9011	2280741	-4914695	-3355481	Argentina
		2280579	-4914577	-3355462	C-5
1MAUIO	9012	-5466112	-2404012	2242372	Old Hawaiian
		-5466064	-2404279	2242174	C-5
OSLONR	9426	3121370	592748	5512832	Europe
		3121280	592629	5512704	C-5
AUSBAK	9023	-3977649	3725148	-3303146	Australian
		-3977744	3725121	-3303065	C-5

TABLE 1 (cont.)

Name	Station No.	X (meters)	Y (meters)	Z (meters)	Datum
NATALB*	9029	5186691	-3653614	-654583	N.A.
		5186677	-3653479	-654421	C-5
AGASSI*	9050	1489768	-4467652	4287121	N.A.
		1489747	-4467510	4287293	C-5
COLDLK*	9424	-1264778	-3466885	5185264	N.A.
		-1264802	-3466744	5185435	C-5
EDWAFB*	9425	-2449989	-4624588	3634863	N.A.
		-2450017	-4624446	3635037	C-5
RIGLAT*	9428	3183995	1421714	5322880	Europe
		3183910	1421593	5322747	C-5
POTDAM*	9429	3800613	882119	5029044	Europe
		3800529	881999	5028912	C-5
ZVENIG*	9430	2886510	2156832	5245531	Europe
		2886428	2156710	5245394	C-5

*These SAO Station positions were derived by using the weighting scheme described in Section 2.

TABLE 2

SPEOPT - OPTICAL

Name	Station No.	X (meters)	Y (meters)	Z (meters)	Datum
IUNDAK	7034	-521679	-4242198	4718543	N.A.
		-521703	-4242055	4718713	C-5
1EDINB	7036	-828465	-5657605	2816640	N.A.
		-828490	-5657462	2816814	C-5
1COLBA	7037	-191261	-4967427	3983084	N.A.
		-191286	-4967285	3983257	C-5
1BERND	7039	2308226	-4873758	3394383	N.A.
		2308207	-4873617	339455	C-5
1PURIO	7040	2465089	-5535082	1985346	N.A.
		2465076	-5534945	1985519	C-5
1GSFCP	7043	1130742	-4831487	3993952	N.A.
		1130720	-4831344	3994125	C-5
1CKVLE	7044	380205	-4992848	3937659	N.A.
		380182	-4992705	3937832	C-5
1DENVR	7045	-1240450	-4760380	4048805	N.A.
		1240478	-4760237	4048979	C-5
1JUM24	7071	976293	-5601555	2880061	N.A.
		976267	-5601403	2880240	C-5
1JUM40	7072	976297	-5601549	2880072	N.A.
		976271	-5601397	2880251	C-5
1JUPC1	7073	976303	-5601545	2880068	N.A.
		976277	-5601393	2880247	C-5
1JUBC4	7074	976304	-5601545	2880076	N.A.
		976278	-5601393	2880255	C-5
1SUDBR	7075	692646	-4347227	4600299	N.A.
		692624	-4347085	460047[illegible]	C-5
1JAMAC	7076	1384188	-5905827	1966368	N.A.
		1384171	-5905686	1966540	C-5

TABLE 3

AIR FORCE - OPTICAL

Name	Station No.	X (meters)	Y (meters)	Z (meters)	Datum
ANTIGA	3106	2881872	-5372329	1868347	N.A.
		2881858	-5372192	1868518	C-5
GRNVLE	3333	-93222	-5324617	3498350	N.A.
		-93245	-5324473	3498524	C-5
GRVILL	3334	-84958	-5328100	3493285	N.A.
		-84982	-5327957	3493459	C-5
USAFAC	3400	-1275174	-4798165	3994038	N.A.
		-1275202	-4798023	3994212	C-5
BEDFRD	3401	1513182	-4463731	4282876	N.A.
		1513161	-4463589	4283048	C-5
SEMMES	3402	167290	-5482122	3244863	N.A.
		167267	-5481977	3245037	C-5
SWANIS	3404	642541	-6054110	1895518	N.A.
		642522	-6053968	1895690	C-5
GRDTRK	3405	191530	-5621245	2315617	N.A.
		1919513	-5621104	2315790	C-5
CURACO	3406	2251862	-5817042	1327005	N.A.
		2251856	-5816907	1327183	C-5
TRNDAD	3407	2979970	-5513661	1181004	N.A.
		2979958	-5513525	1181174	C-5
TWINOK	3452	-647883	-5117438	3739390	N.A.
		-647910	-5117296	3739464	C-5
ROTHGR	3453	3931622	658045	4962958	Europe
		3931539	657925	4962825	C-5
ATHNGR	3463	4613521	2029197	3896034	Europe
		4613441	2029074	3895897	C-5
TORRSP	3464	4849671	-289982	4119838	Europe
		4849590	-290099	4119713	C-5
CHOFUJ	3465	-3946476	3366244	3697793	Tokyo
		-3946625	3366761	3698491	C-5

TABLE 3 (cont.)

Name	Station No.	X (meters)	Y (meters)	Z (meters)	Datum
HUNTER	3648	832594	-5349690	3360414	N.A.
		832571	-5349544	3360589	C-5
JUPRAF	3649	976326	-5601521	2880117	N.A.
		976300	-5601369	2880296	C-5
ABERDN	3657	1186826	-4785340	4032705	N.A.
		1186805	-4785198	4032877	C-5
HOMEST	3861	961793	-5679315	2729709	N.A.
		961768	-5679166	2729886	C-5
CHYWYN	3902	-1234669	-4651355	4174612	N.A.
		-1234696	-4651213	4174787	C-5

TABLE 4

STADAN - OPTICAL

Name	Station No.	X (meters)	Y (meters)	Z (meters)	Datum
1BPOIN	1021	1118061	-4876471	3942793	N.A.
		1118039	-4876328	3942966	C-5
1FTMYR	1022	807883	-5652136	2833327	N.A.
		807858	-5651987	2833504	C-5
1OOMER	1024	-3977160	3725702	-3303132	Australia
		-3977255	3725675	-3303051	C-5
1QUITO	1025	1263614	-6255122	-69082	N.A.
		1263601	-6254988	-68920	C-5
1LIMAP	1026	1388815	-6088540	-1293432	N.A.
		1388807	-6088413	-1293287	C-5
1SATAG	1028	1769705	-5044753	-3468417	N.A.
		1769694	-5044624	-3468267	C-5
1MOJAV	1030	-2357214	-4646474	3668134	N.A.
		-2357242	-4646332	3668308	C-5
1JOBUR	1031	5084923	2670522	-2767849	ARC (Cape)
		5084803	2670320	-2768201	C-5
1NEWFL	1032	2602801	-3419301	4697476	N.A.
		2602782	-3419160	4697646	C-5
1COLEG	1033	-2299237	-1445840	5751627	N.A.
		-2299259	-1445700	5751796	C-5
1GFORK	1034	-521679	-4242197	4718543	N.A.
		-521703	-4242055	4718715	C-5
1WNKFL	1035	3983320	-48386	4964737	Europe
		3983237	-48505	4964606	C-5
1ROSMA	1042	647539	-5178082	3656533	N.A.
		647516	-5177937	3656707	C-5
1TANAN	1043	4092050	4434532	-2064612	Tananarive
		4091879	4434279	-2064767	C-5

TABLE 5

C&GS - OPTICAL

Name	Station No.	X (meters)	Y (meters)	Z (meters)	Datum
BELTVL	6002	1130798	-4830988	3994522	N.A.
		1130777	-4830845	3994695	C-5
ASTRMD	6100	1130816	-4830970	3994538	N.A.
		1130795	-4830827	3994711	C-5
TIMINS	6113	634519	-4181228	4758741	N.A.
		634497	-4181086	4758913	C-5

TABLE 6

NAVY TRANET - DOPPLER

Name	Station No.	X (meters)	Y (meters)	Z (meters)	Datum
LASHAM	2006	4005569	-71656	4946799	Europe
		4005486	-71776	4946667	C-5
SANHES	2008	4084014	-4209856	-2498933	Corrego Alegre
		4084166	-4210014	-2499142	C-5
PHILIP	2011	-3087865	5332447	1638097	Tokyo
		-3088014	5332964	1638795	C-5
SMTHFD	2012	-3942109	3468907	-3608342	Australia
		-3942204	3468880	-3608261	C-5
MISAWA	2013	-3779496	3024198	4138313	Tokyo
		-3779645	3024715	4139011	C-5
ANCHOR	2014	-2656169	-1544504	5570468	NA
		-2656190	-1544364	5570638	C-5
TAFUNA	2017	-6100005	-997516	-1568353	USGS 1962 ASTRO
		-6100005	-997516	-1568353	C-5
THULEG	2018	539387	-1388492	6180847	NA
		539367	-1388352	6181017	C-5
MCMRDO	2019	-1310731	310481	-6213364	Mercury
		-1310762	310421	-6213370	C-5
WAHIWA	2100	-5504191	-2223857	2325479	Old Hawaii
		-5504143	-2224124	2325281	C-5
LACRES	2103	-1555967	-5169504	3387330	NA
		-1556003	-5169360	3387509	C-5
LASHM2	2106	4005531	-71662	4946835	Europe
		4005448	-71781	4946704	C-5
APLMND	2111	1122567	-4823230	4006287	NA
		1122545	-4823087	4006460	C-5
PRETOR	2115	5052053	2725719	-2774355	Europe
		5051989	2725610	-2774515	C-5

TABLE 7

AMS - SECOR

Name	Station No.	X (meters)	Y (meters)	Z (meters)	Datum
HERNDN	5001	1088886	-4843081	3991661	NA
		1088864	-4842938	3991834	C-5
CUBCAL	5200	-2447563	-4776104	3435208	NA
		-2447591	-4775962	3435381	C-5
LARSON	5201	-2127657	-3786277	4655697	NA
		-2127682	-3786136	4655869	C-5
WRGTON	5202	-449777	-4600953	4380165	NA
		-449801	-4600811	4380339	C-5
GREENV	5333	-84973	-5328093	3493295	NA
		-84997	-5327950	3493469	C-5
TRUKIS	5401	-5576059	+2984593	822651	Navy IBEN ASTRO 1947
		-5576026	+2984576	822646	C-5
SWALLO	5402	-6097581	1486531	-1133574	1966 SECOR ASTRO
		-6097371	1486479	-1133534	C-5
KUSAIE	5403	-6074637	1854309	584756	ASTRO 1962, 65 Allen Sodano Lt.
		-6074425	1854244	584735	C-5
GIZZOO	5404	-5805647	2485478	-892157	Provisional DOS
		-5805445	2485392	-892126	C-5
TARAWA	5405	-6328119	784867	150552	1966 SECOR ASTRC
		-6327898	784840	150552	C-5
NANDIS	5406	-6070252	270257	-1932795	VITI LEVU 1916
		-6070203	270255	-1932779	C-5
CANTON	5407	-6304576	-917349	-306690	1966 CANTON ASTRO
		-6304356	-917317	-306688	C-5
JONSTN	5408	-6008188	-1111188	1824371	JOHNSTON ISLAND 1961
		-6007485	-1111151	1824308	C-5
MIDWAY	5410	-5619131	-258153	2996972	MIDWAY ASTRO 1962
		-5618953	-258145	2996876	C-5

TABLE 7 (cont)

Name	Station No.	X (meters)	Y (meters)	Z (meters)	Datum
MAUIHI	5411	-5468070	-2381140	2253375	Old Hawaiian
		-5468023	-2381407	2253177	C-5
FTWART	5648	794718	-5360197	3352909	NA
		794695	-5360051	3353084	C-5
HNTAFB	5649	832517	-5349741	3360372	NA
		832494	-5349595	3360547	C-5
HOMEFL	5861	963494	-5679880	2727945	NA
		963469	-5679731	2728122	C-5

TABLE 8

STADAN $R/\dot{R}$

Name	Station No.	X (meters)	Y (meters)	Z (meters)	Datum
CARVON	1152	-2328113	5299746	-2669476	Australian
		-2328153	5299690	-2669460	C-5
ROSRAN	1126	647213	-5178486	3655963	NA
		647190	-5178342	3656137	C-5
MADGAR	1122	4091559	4434388	-2065964	Tananarive
		4091387	4434137	-2066118	C-5

TABLE 9

STADAN - LASER

Name	Station No.	X (meters)	Y (meters)	Z (meters)	Datum
ROSLAS	7051	647209	-5178458	3656001	NA
		647186	-5178314	3656175	C-5
GODLAS	7050	1130704	-4831524	3993921	NA
		1130683	-4831381	3994094	C-5

TABLE 10

INTERNATIONAL OPTICAL

Name	Station No.	X (meters)	Y (meters)	Z (meters)	Datum
DELFTH	8009	3923486	300006	5003096	Europe
		3923402	299886	5002964	C-5
MALVRN	8011	3920251	-134625	5012852	Europe
		3920168	-134744	5012721	C-5
ZIMWLD	8010	4330631	567523	4632712	BERNE
		4331308	567505	4633101	C-5

TABLE 11

SAO - OPTICAL

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
1ORGAN	9001	32°25'24".560	253°26'51".17	1649.	N.A.
		32 25 24.705	253 26 48.299	1610.38	C-5
1OLFAN	9002	-25 57 33.850	28 14 53.910	1544.	Arc (Cape)
		-25 57 37.671	28 14 51.459	1560.5	C-5
WOOMER	9003	-31 06 07.26	136 46 58.70	162.0	Australian
		-31 06 04.1[illegible]	136 47 01.931	158.87	C-5
1SPAIN	9004	36 27 51.24	353 47 41.47	-11.0	Europe
		36 27 46.686	353 47 36.553	56.150	C-5
1TOKYO	9005	35 40 11.08	139 32 28.22	58.	Tokyo
		35 40 23.038	139 32 16.420	84.79	C-5
1NATOL	9006	29 21 38.90	79 27 25.61	1847.0	Europe
		29 21 34.388	79 27 27.050	1855.447	C-5
1QUIPA	9007	-16 28 05.09	288 30 22.84	2600.0	N.A.
		-16 27 58.042	288 30 24.022	2479.39	C-5
1SHRAZ	9008	29 38 17.96	52 31 11.80	1578.0	Europe
		29 38 13.599	52 31 11.208	1561.27	C-5
1CURAC	9009	12 05 21.55	291 09 42.55	23.	N.A.
		12 05 24.933	291 09 43.973	-33.86	C-5
1JUPTR	9010	27 01 13.00	279 53 12.92	26.6	N.A.
		27 01 14.235	279 53 12.954	-36.450	C-5
1VILDO	9011	-31 56 36.53	294 53 39.82	598.	Argentina
		-31 56 36.353	294 53 36.115	636.424	C-5
1MAUIO	9012	20 42 37.49	203 44 24.11	3027.0	Old Hawaiian
		20 42 25.660	203 44 33.230	3027.970	C-5
AUSBAK	9023	-31 23 30.82	136 52 39.02	141.0	Australian
		-31 23 27.691	136 52 42.233	137.404	C-5
OSLNOR	9426	60 12 40.380	10 45 08.740	585.0	Europe
		60 12 38.880	10 45 02.263	573.208	C-5

TABLE 11 (cont)

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
NATALB*	9029	05°55'50".000	324°50'18".000	42.00	N.A.
		05 55 43.490	324 50 21.300	24.449	C-5
AGASSI*	9050	42 30 20.970	288 26 28.710	193.000	N.A.
		42 30 20.511	288 26 29.791	138.211	C-5
COLDLK*	9424	54 44 38.020	249 57 25.850	597.	N.A.
		54 44 37.268	249 57 21.901	548.453	C-5
EDWAFB*	9425	34 57 50.680	242 05 11.390	784.	N.A.
		34 57 50.170	242 05 07.804	754.741	C-5
RIGLAT*	9428	56 56 54.000	24 03 42.000	5.900	Europe
		56 56 52.374	24 03 37.494	-15.657	C-5
POTDAM*	9429	52 22 55.000	13 04 01.000	111.500	Europe
		52 22 52.333	13 03 55.806	106.139	C-5
ZVENIG*	9430	55 41 37.700	36 46 03.000	145.000	Europe
		55 41 36.174	36 46 00.178	114.472	C-5

*These SAO station positions were derived by using the weighting scheme described in Section 2.

TABLE 12

SPEOPT - OPTICAL

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
1UNDAK	7034	48°01'21".400	262°59'21".560	255	N.A.
		48 01 20.810	262 59 19.553	201.466	C-5
1EDINB	7036	26 22 45.440	261 40 09.030	67.1	N.A.
		26 22 46.352	261 40 07.347	15.801	C-5
1COLBA	7037	38 53 36.070	267 47 42.120	271.68	N.A.
		38 53 35.819	267 47 40.856	218.246	C-5
1BERMD	7039	32 21 48.830	295 20 32.560	21.000	N.A.
		32 21 48.944	295 20 34.189	28.409	C-5
1PURIO	7040	18 15 26.220	294 00 22.170	58.7	N.A.
		18 15 28.307	294 00 23.633	+5.912	C-5
1GSFCP	7043	39 01 15.010	283 10 19.930	54.5	N.A.
		39 01 14.787	283 10 20.392	-1.291	C-5
1CKVLE	7044	38 22 12.500	274 21 16.810	187.1	N.A.
		38 22 12.335	274 21 16.287	131.383	C-5
1DENVR	7045	39 38 48.030	255 23 41.190	1796.1	N.A.
		39 38 47.544	255 23 38.529	1751.606	C-5
1JUM24	7071	27 01 12.770	279 53 12.310	25.52	N.A.
		27 01 14.000	279 53 12.308	-38.244	C-5
1JUM40	7072	27 01 13.170	279 53 12.490	25.69	N.A.
		27 01 14.398	279 53 12.492	-38.057	C-5
1JUPC1	7073	27 01 13.110	279 53 12.720	22.1	N.A.
		27 01 14.339	279 53 12.726	-41.781	C-5
1JUBC4	7074	27 01 13.330	279 53 12.760	25.7	N.A.
		27 01 14.558	279 53 12.763	-38.003	C-5
1SUDBR	7075	46 27 20.990	279 03 10.350	281.5	N.A.
		46 27 20.527	279 03 10.358	224.178	C-5
1JAMAC	7076	18 04 31.980	283 11 26.528	485.9	N.A.
		18 04 34.202	283 11 27.039	423.993	C-5

TABLE 13

AIR FORCE - OPTICAL

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
ANTIGA	3106	17°08'51".680	298°12'37".410	+7.8	N.A.
		17 08 53.888	298 12 39.194	-42.950	C-5
GRNVLE	3333	33 28 48.970	268 59 49.170	45	N.A.
		33 28 49.158	268 59 48.120	-9.212	C-5
GRVILL	3334	33 25 31.950	269 05 11.350	43.5	N.A.
		33 25 32.145	269 05 10.304	-10.753	C-5
USAFAC	3400	39 00 22.440	255 07 01.010	2191	N.A.
		39 00 21.990	255 06 58.326	2147.202	C-5
BEDFRD	3401	42 27 17.530	288 43 35.030	88	N.A.
		42 27 17.069	288 43 36.142	33.275	C-5
SEMMES	3402	30 46 49.350	271 44 52.370	79.7	N.A.
		30 46 49.853	271 44 51.641	23.475	C-
SWANIS	3404	17 24 16.570	276 03 29.870	83.4	N.A.
		17 24 18.903	276 03 29.715	18.611	C-5
GRDTRK	3405	21 25 47.050	288 51 14.030	7.7	N.A.
		21 25 48.696	288 51 15.037	-48.546	C-5
CURACO	3406	12 05 22.110	291 09 43.760	23	N.A.
		12 05 25.493	291 09 45.165	-34.219	C-5
TRNDAD	3407	10 44 32.780	298 23 23.670	269.5	N.A.
		10 44 36.167	298 23 25.433	210.908	C-5
TWINOK	3452	36 07 25.690	262 47 04.480	312.400	N.A.
		36 07 25.580	262 47 02.682	262.4	C-5
ROTHGR	3453	51 25 00.000	9 30 06.000	351.900	Europe
		51 24 57.054	9 30 00.583	352.253	C-5
ATHNGR	3463	37 53 30.000	23 44 30.000	16	Europe
		37 53 26.073	23 44 26.736	23.094	C-5
TORRSP	3464	40 29 18.530	356 34 41.240	588	Europe
		40 29 14.102	356 34 36.062	635.450	C-5
CHOFUJ	3465	35 39 57.000	139 32 12.000	49	Tokyo
		35 40 08.967	139 32 00.199	75.472	C-5

TABLE 13 (cont)

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
HUNTER	3648	32°00'05".870	278°50'46".360	17.7	N.A.
		32 00 06.320	278 50 46.329	-40.216	C-5
JUPRAF	3649	27 01 14.800	279 53 13.720	26.4	N.A.
		27 01 16.029	279 53 13.722	-37.369	C-5
ABERDN	3657	39 28 18.970	283 55 44.56	4.5	N.A.
		39 28 18.713	283 55 45.101	-51.178	C-5
HOMEST	3861	25 30 24.690	279 36 42.690	18.4	N.A.
		25 30 26.022	279 36 42.703	-44.419	C-5
CHYWYN	3902	41 07 59.200	255 08 02.650	1890.2	N.A.
		41 07 58.619	255 07 59.941	1845.282	C-5

TABLE 14

STADAN - OPTICAL

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
1BPOIN	1021	38°25'49".630	282°54'48".230	5.53	N.A.
		38 25 49.448	282 54 48.658	-50.366	C-5
1FTMYR	1022	26 32 51.890	278 08 03.930	19.58	N.A.
		26 32 53.081	278 08 03.806	-42.482	C-5
1OOMER	1024	-31 23 30.072	136 52 11.059	152.81	Australian
		-31 23 26.965	136 52 14.254	148.783	C-5
1QUITO	1025	- 0 37 28.000	281 25 14.810	3649.	N.A.
		- 0 37 22.639	281 25 15.238	3554.619	C-5
1LIMAP	1026	-11 46 44.430	282 50 58.230	155.	N.A.
		-11 46 37.569	282 50 58.864	34.049	C-5
1SATAG	1028	-33 09 07.660	289 19 51.350	922.	N.A.
		-33 08 58.769	289 19 52.591	705.3	C-5
1MOJAV	1030	35 19 48.090	243 06 02.730	905.4	N.A.
		35 19 47.579	243 05 59.186	874.9	C-5
1JOBUR	1031	-25 52 58.860	27 42 27.930	1530.	ARC
		-25 53 02.706	27 42 25.416	1546.25	C-5
1NEWFL	1032	47 44 29.740	307 16 43.370	104.0	N.A.
		47 44 28.738	307 16 46.676	58.465	C-5
1COLEG	1033	64 52 19.720	212 09 47.170	162.5	N.A.
		64 52 17.783	212 09 37.297	139.113	C-5
1GFORK	1034	48 01 21.400	262 59 21.560	253.9	N.A.
		48 01 20.811	262 59 19.553	200.268	C-5
1WNKFL	1035	51 26 44.120	359 18 14.620	62.0	Europe
		51 26 40.670	359 18 08.355	76.0	C-5
1ROSMA	1042	35 12 06.930	277 07 41.010	914.	N.A.
		35 12 07.031	277 07 40.811	857.322	C-5
1TANAN	1043	-19 00 27.097	47 18 00.461	1377.94	Tananarive
		-19 00 33.261	47 17 58.893	1355.87	C-5

TABLE 15

C&GS - OPTICAL

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datu
BELTVL	6002	39°01'39"030	283°10'26"940	45.3	N.A.
		39 01 38.808	283 10 27.400	-10.543	C-5
ASTRMD	6100	39 01 39.720	283 10 27.830	45.0	N.A.
		39 01 39.498	283 10 28.297	-10.748	C-5
TIMINS	6113	48 33 56.170	278 37 44.540	290.	N.A.
		48 33 55.706	278 37 44.494	232.137	C-5

TABLE 16

NAVY TRANET - DOPPLER

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
LASHAM	2006	51°11'10".620	358°58'30".510	182.	Europe
		51 11 07.127	358 58 24.251	196.812	C-5
SANHES	2008	-23 13 01.740	314 07 50.590	608.*	Correga Alegre
		-23 12 59.602	314 07 50.590	608.	C-5
PHILIP	2011	14 58 57.790	120 04 25.980	8.0	Tokyo
		14 59 16.422	120 04 21.617	-70.750	C-5
SMTHFD	2012	-34 40 31.310	138 39 12.390	39.0	Australian
		-34 40 28.163	138 39 15.665	31.437	C-5
MISAWA	2013	40 43 04.630	141 20 04.690	-10.0	Tokyo
		40 43 14.632	141 19 51.453	38.875	C-5
ANCHOR	2014	61 17 01.980	210 10 37.460	61.6	N.A.
		61 16 59.601	210 10 28.605	44.532	C-5
TAFUNA	2017	-14 19 50.190	189 17 13.960	6.0*	USGS 1962 Astro
		-14 19 46.487	189 17 13.960	6.0	C-5
THULEG	2018	76 32 18.620	291 13 46.720	43.0	N.A.
		76 32 20.725	291 13 51.078	-7.515	C-5
MCMRDO	2019	-77 50 51.000	166 40 25.000	-43.0	Mercury
		-77 50 50.586	166 40 35.024	-29.177	C-5
WAHIWA	2100	21 31 26.860	202 00 00.630	380.0	Old Hawaiian
		21 31 14.954	202 00 09.836	368.313	C-5
LACRES	210.	32 16 53.400	253 14 55.500	1212.9	N.A.
		32 16 53.571	253 14 52.600	1174.187	C-5
LASHM2	2106	51 11 12.320	358 58 30.210	187.0	Europe
		51 11 08.823	358 58 23.956	201.875	C-5
APLMND	2111	39 09 47.880	283 06 06.750	148.7	N.A.
		39 09 47.648	283 06 07.207	92.867	C-5
PRETOR	2115	-25 56 46.090	28 20 53.000	1417.0	Europe
		-25 56 49.978	28 20 50.674	1595.0	C-5

*MSL

TABLE 17

AMS - SECOR

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
HERNDN	5001	38°59'37".690	282°40'16".680	119.1	N.A.
		38 59 37.472	282 40 17.089	64.027	C-5
CUBCAL	5200	32 48 00.000	242 52 00.000	101.0	N.A.
		32 47 59.740	242 51 56.556	71.396	C-5
LARSON	5201	47 11 00.000	240 40 00.000	354.4	N.A.
		47 10 58.765	240 39 55.682	319.010	C-5
WRGTON	5202	43 39 00.000	264 25 00.000	481.3	N.A.
		43 38 59.495	264 24 58.271	428.211	C-5
GREENV	5333	33 25 32.340	269 05 10.780	43.6	N.A.
		33 25 32.535	269 05 09.738	-10.632	C-5
TRUKIS	5401	7 27 39.307	151 50 31.282	5.950*	Navy Iben Astro 1947
		7 27 37.318	151 50 31.282	5.950	C-5
SWALLO	5402	-10 18 21.420	166 17 56.790	9.52 *	1966 SECOR Astro
		-10 18 20.380	166 17 56.790	9.52	C-5
KUSAIE	5403	5 17 44.432	163 01 29.881	7.5 *	Astro 1962, 65, Allen Sodano Lt
		5 17 43.889	163 01 29.881	7.5	C-5
GIZZOO	5404	-8 05 40.580	156 49 24.825	49.53 *	Provisional DOS
		-8 05 39.756	156 49 24.825	49.53	C-5
TARAWA	5405	1 21 42.130	172 55 47.268	7.360*	1966 SECOR Astro
		1 21 41.990	172 55 47.268	7.360	C-5
NANDIS	5406	-17 45 31.012	177 27 02.833	17.65 *	Viti Levu 1916
		-17 45 24.419	177 27 02.833	17.65	C-5
CANTON	5407	-2 46 28.900	188 16 43.470	6.11 *	1966 Canton Astro
		-2 46 28.704	188 16 43.470	6.11	C-5

*MSL

TABLE 17 (cont)

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
JOHNSTN	5408	16°43'51".681	190°28'41".550	6.6*	Johnston Island 1961
		16 43 50.053	190 28 41.550	6.6*	C-5
MIDWAY	5410	28 12 32.061	182 37 49.530	6.1	Midway Astro 1961
		28 12 29.605	182 37 49.530	6.1	C-5
MAUIHI	5411	20 49 37.004	203 31 52.770	32.130	Old Hawaiian
		20 49 25.147	203 32 01.886	31.612	C-5
FTWART	5648	31 55 18.410	278 26 00.260	29.9	N.A.
		31 55 18.867	278 26 00.183	-27.901	C-5
HNTAFB	5649	32 00 04.040	278 50 43.170	27.0	N.
		32 00 04.496	278 50 43.131	-30.957	C-5
HOMEFL	5861	25 29 21.180	279 37 39.350	18.9	N.A.
		25 29 22.514	279 37 39.370	-44.0	C-5

*MSL

TABLE 18

STADAN - R/R

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
CARVON	1152	-24°54'14".858	113°42'55".056	38.0	Australian
		-24 54 12.294	113 42 58.548	10.545	C-5
ROSRAN	1126	35 11 45.050	277 07 26.230	880.0	N.A.
		35 11 45.151	277 07 26.020	823.53	C-5
MADGAR	1122	-19 01 13.320	47 18 09.450	1403.63	Tananarive
		-19 01 19.412	47 18 07.964	1382.56	C-5

TABLE 19

STADAN - LASER

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
ROSLAS	7051	35°11'46".600	277°07'26".230	879.0	NA
		35°11'46".701	277°07'26".020	822.471	C-S
GODLAS	7050	39°01'13".680	283°10'18".050	55.8	NA
		39°01'13".456	283°10'18".510	0.067	C-S

TABLE 20

INTERNATIONAL OPTICAL

Name	Station No.	Latitude	Longitude	Geodetic Height (meters)	Datum
DELFTH	8009	52°00'09".240	4°22'21".230	23.0	Europe
		52°00'06".122	4°22'15".301	28.955	C-5
MALVRN	8011	52°08'39".120	358°01'59".490	111.0	Europe
		52°08'35".681	358°01'53".034	125.293	C-5
ZIMWLD	8010	46°52'41".770	7°27'57".560	898.44	BERNE
		46°52'36".737	7°27'52".547	907.44	C-5

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The Mutual Visibility Flash Schedule System

by

F. J. Lerch
Mission and Trajectory Determination Branch
Mission and Trajectory Analysis Division
Tracking and Data Systems Directorate
Goddard Space Flight Center

and

S. J. Moss
Applied Sciences Department
Wolf Research and Development Corporation
College Park, Maryland

Presented at GEOS Program Review Meeting
NASA Headquarters, Washington, D.C.
December 15, 1967

THE MUTUAL VISIBILITY FLASH SCHEDULE SYSTEM

The MVFS system, known variously as the MVP and MVE system, was developed for GEOS-I active optical beacon scheduling with major emphasis on intervisible observations of the satellite from optical and electronic tracking systems.

The system consists of several sub-systems; these are:

1. An acquisition program which determines all potential events for optical and/or electronic systems taking into consideration instrumentation constraints (image size, minimum elevation angle, moon angle, etc.). This program computes potential events every minute at the mid-point of a potential flash sequence (on the 12th second for a seven flash sequence).
2. A weighting scheme which assigns to each event with at least one optical participant a relative weight. This weight is computed based on a various criteria which I will discuss later. I will, however, mention at this point that it is through this weighting scheme that the principal investigators and the agencies which they represent can influence the schedule produced.
3. The application of camera reload time constraints to the weighted potential events.

4. The application of satellite power and memory constraint on the potential events.. These comprise the major computational and logical portions of the program. The schedule select in this process is presented to users in detail in many forms, essentially one for every taste. I want to point out that MVFS system under the direction of Frank Lerch the GSFC-OCE has been under constant development before, during and after the useful life of GEOS-I optical beacons in an attempt to meet the many facets of the geodetic program.

Let me now return to the weighting scheme and briefly review what criteria were used during GEOS-I and what new features are now available. Weights were assigned based on:

1. Number of participating optical sites in an event.
2. Number of participating electronic sites in an event.
3. Range, azimuth, elevation histories from a given site.
4. The ability of the stations in an event to determine the satellite position.
5. Various weights to distribute flashes in a somewhat uniform manner over the earth and around the orbit.
6. Special event weights.

Initially the interest in the use of GEOS was in mutually visible events and the MVFS system reflected this. As we have heard here in the past few days, the interest now tends more toward dynamical geodetic determinations. For this reason two new weights have been added to the weighting scheme. The first is a weight tending to schedule observations distributed in mean anomaly in a given orbit. The second is what we call a geographical weighting scheme which schedules at least one flash in each geographical area over which the satellite passes during a specifiable period. These areas are also specifiable. Finally, we have added special weights for pre-selected station combinations in pairs, triplets and quadruplets.

To aid the investigators in assessing the operational week's schedule, a summary of this schedule is presented in the Information Bulletin. The table of contents of this document is included to illustrate the information available to the user.

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GEOS-I OPERATIONS SCHEDULED

Robert E. Dwyer
Member, Aerospace Sciences Division
Communications & Systems, Incorporated
Falls Church, Virginia

GEOS PROGRAM REVIEW MEETING
12-14 December 1967

NASA HEADQUARTERS
400 Maryland Avenue, SW
Washington, D. C.

GEOS - 1
OPERATIONS SCHEDULED

SOURCE OF INFORMATION
- GEODETIC OPERATIONS CONTROL CENTER (GOCC)
- NASA-GODDARD SPACE FLIGHT CENTER

NETWORKS/SYSTEMS
- OPTICAL BEACON
- LASER
- GRARR
- SECOR
- DOPPLER
- MINITRACK

GEOS-1 MISSION LIFETIME - BY-SYSTEM
(LAUNCH - 6 NOVEMBER '65)

SYSTEM	FROM	TO	PROBLEM
OPTICAL BEACON	7 DEC. 65	1 DEC. 66	COMMAND SYSTEM FAILURE NEGATED FURTHER OPERATIONS
GRARR	18 NOV. 65	1 DEC. 66	
972 MHz DOPPER	NOV. 65	14 JAN. 67	INTERMITTENT COMMAND SYSTEM RESPONSE ALLOWED TURN-OFF-NO TURN-ON CAPABILITY
MINITRACK	6 NOV. 65	14 JAN. 67	SPURIOUS COMMAND SYSTEM RESPONSE EFFECTED TURN-OFF
SECOR	18 NOV. 65	8 FEB. 67	HANG-UP IN ON MODE EFFECTED SENSING SWITCH TURN-OFF — NO TURN-ON CAPABILITY
DOPPLER (162 MHz & 324 MHz)	NOV. 65	STILL OPERATING	
LASER	NOV. 65	STILL OBSERVABLE	

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OPTICAL (7 DEC. 65 TO 1 DEC. 66)

TOTAL FLASH SEQUENCES SCHEDULED BY MVES	14,278
TOTAL SEQUENCES NOT EXECUTED AS PROGRAMMED	785
TOTAL SEQUENCES AVAILABLE FOR OBSERVATION	13,493
TOTAL SINGLE STATION OBSERVATIONS SCHEDULED	60,874
REPORTED OBSERVATIONS TAKEN	19,968
% OBSERVATIONS TAKEN	33%
REPORTED OBSERVATIONS NOT TAKEN (WEATHER, ETC.)	28,685
NO REPORT FILED WITH GOCC	12,221

OPTICAL BY NETWORK

NETWORK	NO. OF INSTRUMENTS	SCHEDULED	PHOTO TAKEN	PHOTO NOT TAKEN	NO REPORT FILED	% OBSERVATIONS TAKEN
GSFC MOTS	10	10,420	4,741	5,235	444	46%
GSFC SPEOPT	9	9,756	4,452	4,734	570	46%
SAO (PRIMARY AND SECONDARY)	20	21,026	6,819	10,765	3,442	32%
USAF	13	9,177	3,286	3,949	1,942	36%
USC & GS	13	977	133	710	134	14%
INTERNATIONAL	13	9,518	537			

COMPLETE STATISTICS NOT AVAILABLE - .
HOUTE PROVINCE, FRANCE & ZIMMERWALD,
SWITZERLAND HAVE SUBMITTED APPROX.
1600 obs. TO DATA CENTER (APPROX. 250 SEQUENCES)

GSFC SPEOPT AND MOTS OPTICAL STATISTICS

SCHEDULED OBSERVATIONS	19,924
PLATES TAKEN	9,500 (48% OF SCHEDULED OBSERVATIONS)
PLATES WITH FLASHES	5,576 (28% OF SCHEDULED OBSERVATIONS) (59% OF PLATES TAKEN)

SCHEDULED OPS. VS PLATES TAKEN - PROBLEMS - PREDOMINATELY DUE TO WEATHER

PLATES TAKEN VS PLATES WITH FLASHES PROBLEMS—MARGINAL WEATHER & CAMERA EQUIPMENT PROBLEMS SUCH AS POOR FOCUS & OPERATOR ERROR.

LASER SYSTEMS
(NOV. '65 - PRESENT)

GSFC - 17 SUCCESSFUL TRACKS REPORTED DURING GRARR/LASER INTERCOMPARISON AT ROSMAN

USAF - NONE REPORTED

SAO - 65 SUCCESSFUL TRACKS YIELDING 299 OBSERVATIONS

RADIO SYSTEMS

	MINUTES AVAILABLE	PASSES SCHEDULED	MINUTES OF INTERROGATION SCHEDULED
GRARR (18 NOV. 65 TO 1 DEC. 66)	21,936	1,389	21,879
SECOR (18 NOV. 65 TO 8 FEB. 67)	26,977	873 (QUAD)	13,256
DOPPLER (NOV. 65- OCT. 67)	50,305 DATA RUNS (STATION PASSES) ARCHIVED		
GSFC MINITRACK (6 NOV. 65- 14 JAN. 67)	16,271 DATA POINTS (STATION AXIS CROSSINGS)		

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GEOS-I MOTS OPERATIONS

David W. Harris

Goddard Space Flight Center

Prepared For

GEOS PROGRAM REVIEW MEETING
12-14 December 1967

NASA HEADQUARTERS
400 Maryland Avenue, SW
Washington, D. C.

GEOS-I MOTS OPERATIONS

David W. Harris
12/12/67

MOTS operations at the NASA STADAN sites and at the contracted SPEOPT stations were both very successful with only a few poor weather stations contributing little data. The following table 1 represents the complete operation for all the GSFC operated or contracted cameras.

TABLE 1

Network and Station	Operational Assignments A	Plates Exposed P	P/A	Plates With Flashes F	F/A	F/P
STADAN						
BPOINT	1025	541	53%	241	24%	45%
FTMYRS	948	683	72%	457	48%	67%
OOMERA	510	365	72%	203	40%	56%
QUITOE	580	34	6%	5	1%	15%
LIMA	583	6	1%	0	0%	0%
SATAG	643	305	47%	132	21%	43%
MOJAVE	959	670	70%	513	53%	77%
JOBURG	700	519	74%	403	58%	78%
MADAG	268	88	33%	61	23%	69%
NEWFLD	874	168	19%	38	4%	23%
COLEGE	116	58	50%	24	21%	41%
WINFLD	1088	243	22%	104	10%	43%
ROSMAN	1142	560	49%	300	26%	54%
TOTAL	9436	4240	45%	2481	26%	59%
SPEOPT						
EDINB	856	511	60%	387	45%	76%
COLBA	1280	624	49%	459	36%	74%
BERMD	904	431	48%	211	23%	49%
PURIO	660	439	67%	259	39%	59%
GSFCP	1147	401	35%	199	17%	50%
DENVR	1273	708	56%	369	29%	52%
CKVLE	431	76	18%	1	1%	1%
JUM24	369	236	64%	48	13%	20%
JUM40	366	229	63%	132	36%	58%
JUPTH	366	227	62%	73	20%	32%
JUBC4	210	88	42%	43	20%	49%
SUDBRY	726	310	43%	234	32%	75%
JAMAC	503	242	48%	182	36%	75%
UNDAK	1397	738	53%	498	36%	67%
TOTAL	10488	5260	50%	3095	30%	59%
MOTS TOTAL	19924	9500	48%	5576	28%	59%

GEOS-I MOTS OPERATIONS

One of the first camera experiments performed took place at the SAO Baker-Nunn station at Jupiter, Florida where a MOTS 40" focal length, MOTS 24" focal length, NASA BC-4 300 mm focal length, SAO K-50, Air Force PC-1000 and NASA Pth-100 (1000 mm focal length) cameras were collocated with the Baker-Nunn camera. The experiment was to perform two objectives. By use of a stellar photometer to measure the atmospheric extinction, an attempt was made to determine how much light intensity at the film plane would be required from the flashing lamps for a successful image. The second objective was to intercompare the position determination of the flashing lamps as recorded on film to detect, if possible, any bias introduced in any or all the camera systems or plate reduction methods. The positional intercomparison has not been completed as yet. There are some results available from the camera coefficient study and it may be that the new values will be used in the GEOS-B Mutual Visibility Program. The graph presented in figure 1 depicts the amount of light necessary to record a useful image for the MOTS 40" and Baker-Nunn cameras using the "apriori" camera coefficients and the newer Jupiter results.

Of the more than 5,000 successful GEOS-I plates obtained during the satellite lifetime, results from 1494 already reside at the data center. Certain priorities for reduction of the plates were determined by John Berbert as one of the Principal Investigators. These are:

1. Jupiter Intercomparison plates.
2. Selected Tananarive-Joburg passes for a station location determination of the Madagascar Range and Range Rate site.
3. Four selected January 1966 passes for which Secor and Rosman Range and Range Rate data was simultaneously taken.
4. A series of passes for which simultaneous GSFC Laser and Range and Range Rate data is available.
5. Selected observations useful for the recovery of station locations used in the short arc intercomparison experiment.
6. Selected December 1965 and January 1966 passes for long arc intercomparison investigation studies.
7. Plates taken during passes for which SAO laser data exists.
8. Selected U.S. short arc passes during which a large bulk of electronic data from different systems was obtained.
9. Selected intermediate arc passes (up to 6 orbits) where world-wide tracking was abundant.
10. Selected long arc passes (more than 6 orbits) where world-wide data is available for extended periods.

Table 2 presents the degree of data reduction completed for the various priorities as of October 31, 1967.

GEOS-I MOTS OPERATIONS

TABLE 2

Description	Total Plates		Reduced
Jupiter Experiment	223		221
Joburg-Tanan.	33		33
4 Passes Jan 1966	19		19
Laser-Rosman Passes	67		65
Station Location Recovery	268		261
Dec'65 - Jan'66 passes	61		57
SAO Laser	208		204
Short Arc Passes	1046		635
Intermediate Arc Passes		Being chosen now	
Long Arc Passes		Being chosen now	
Remaining Plates with no special priority as of 10/31/67	3653		789
Totals	5578		2284

It must be pointed out that not all the plates available will be reduced and that under present constraints only plates falling into one of the various priorities will undergo reduction.

The plates are reduced at New Mexico State University and the resultant right ascension and declination positions are returned to the GSFC to undergo a data validation procedure prior to submittal to the Data Center. The procedure consists of comparing the reduced positions to positions determined for the same time from a Minitrack orbit. The data must fall within the gates derived for the following three tests:

1. Bias: The difference in right ascension and declination from the Minitrack derived right ascension and declination.

2. Slope: The angle the reduced lamp flashes make with the Minitrack derived orbit.

3. Sigma: The residual associated with the reduced positions after a straight line fit is made to the individual biases.

If a plate fails any of the three tests, the outlying lamp flash is removed from the solution and the data is re-validated. If a whole plate is deemed unreliable from the validation process the data is never submitted to the data center.

GEOS-I MOTS OPERATIONS

Of the approximately 2200 plates received from the reduction agency, only about 35 have been completely rejected in data validation.

The average residual of the flashes submitted to the Data Center has been on the order of 1".

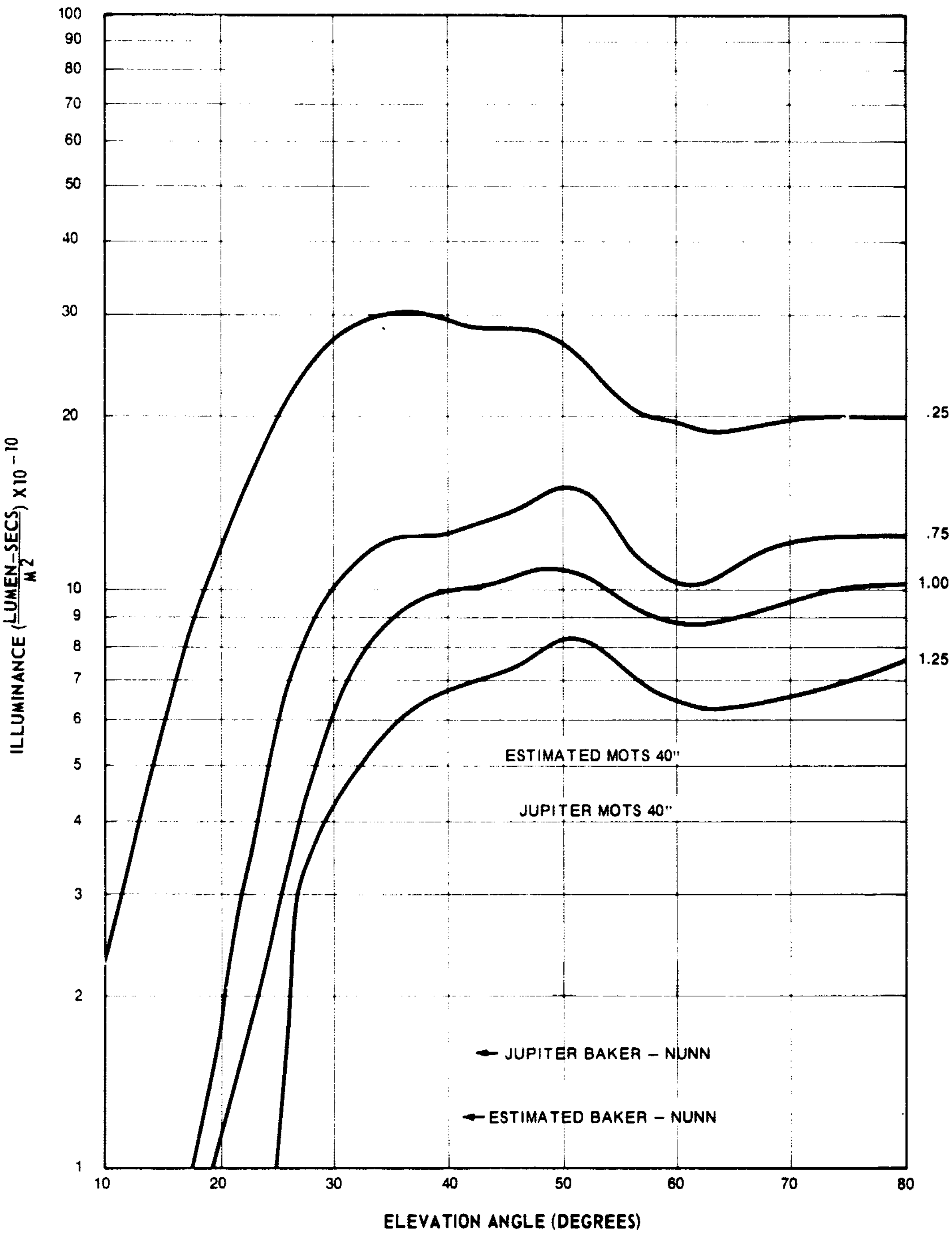

Figure 1. Illuminance vs. Evaluation Angle (Three Lamps Flashing, Subsatellite Altitude 1500 Km)

GODDARD RANGE AND RANGE RATE STATUS REPORT

Patrick Norris

Radio Corporation of America

Prepared For

GEOS PROGRAM REVIEW MEETING
12-14 December 1967

NASA HEADQUARTERS
400 Maryland Avenue, SW
Washington, D. C.

GODDARD RANGE AND RANGE RATE STATUS REPORT

Patrick Norris

Radio Corporation of America

Over the 12-month operational period of GEOS-A, a total of 954 data passes were obtained by the three operational GRARR S-Band stations. Two methods for validating these passes were developed.

The first of these consisted of differentially correcting the initial estimates of the position of GEOS-A (obtained from Minitrack-derived orbits) by using the range-rate portion of the GRARR data. The arc length used in this reduction was equal to the time span of the data pass under consideration - less than one sixth of a revolution. Measures of range bias and noise and range-rate noise were determined and used as criteria in deciding on the validity or otherwise of the data pass. Range noise of 30 meters and range-rate noise of 50 cms/sec were used as cutoff points in this decision process.

The other validation method consisted of obtaining two-day orbital solutions using GRARR and Minitrack data. The GRARR residuals to this orbit were then examined and rejection or acceptance of data passes was based on these residuals. A range error of ± 150 meters or a range-rate error of ± 0.5 meters per second resulted in the rejection of the whole GRARR pass.

As a result of these two procedures, 497 passes of data (52.1% of the total) have been sent to the National Space Sciences Data Center. These were made up of 428 passes from Rosman, North Carolina; 35 passes from Tananarive, Malagasy Republic; and 34 passes from Carnarvon, Australia. As a percentage of total passes from each station, these figures are 64.2%, 21.2, and 27.9% respectively.

Analysis of these two validation procedures indicated that many passes which were rejected were in fact of sufficient quality to allow their inclusion in the Data Center. Therefore, a further

233 passes (24.4% of the total) will be sent to the Data Center in the near future. This will raise the final GEOS-A station success rates to 88.6%, 44.8%, and 53.3% for Rosman, Tananarive, and Carnarvon, respectively.

The GRARR data was smoothed prior to this validation process so as to provide a range, range-rate, an X-angle, and a Y-angle at 32-second intervals. The average pass length was 14 minutes for Rosman, 6½ minutes for Tananarive, and 7½ minutes for Carnarvon.

More precise determinations of GRARR accuracy than were provided by the validation process have been obtained by comparing GRARR/GEOS-A data with data from other geodetic tracking systems - SAO, MOTS, and AF cameras, TRANET, SECOR, NASA laser. These intercomparisons indicate that from GEOS-A launch through March, 1966, all three GRARR stations provided ranging data with an RMS accuracy of 4 cms/sec. The range errors were generally reducible to a bias and timing error with values less than 6 meters and 3 milliseconds leaving about 7 meters of random error. The range-rate errors generally took the form of a scaling error of several parts per million, and 2 cms/sec of random error. More detailed results on these error model investigations will be presented by other GSFC speakers.

At the end of March, GRARR data from all stations deteriorated in quality. From this time onwards, noise figures for range and range-rate were 30 meters and 15 cms/sec, respectively, for validated data. This deterioration was preceded by a period during which the GRARR transponder on GEOS-A sustained temperatures below the level specified for the instrument (-10°C). Diurnal temperature variations of 25 degrees centigrade were also present at this time. Unusually large solar activity peaks ($K_p > 7$) were also reported from this period. Transponder temperature and solar activity indices for the GEOS-A operational period are shown in Figures 1 and 2.

In addition to loss of accuracy, the GRARR data from this period developed an asymmetric property associated with warm-up. This phenomenon was first reported by SAO and is confirmed by results at the GSFC. The range noise was greater at the start of a pass than at the center or end of a pass, being about 40 meters and 8 meters respectively. A spacecraft transponder problem would seem to be indicated. However, in October, November 1966, a return to the original data quality occurred at Rosman, but not at Carnarvon or Tananarive, thus casting doubt on the thesis that the earlier deterioration was solely a spacecraft problem.

As a result of the investigations made using GRARR/GEOS-A data, and because of problems encountered therein, various recommendations concerning (1) spacecraft pre-launch testing, (2) station operating procedures, and (3) data pre-processing, have been made and are being implemented for GEOS-B. Some of the recommendations are:

1. The transponder filter characteristics should be measured in the form of (a) attentuation versus frequency; (b) phase shift versus frequency.
2. (i) Pre- and post-pass calibration data should be taken for each pass and included on the data tape.

   (ii) Uplink carrier frequency should be monitored on a per-pass basis.
3. (i) Pre- and post-pass calibration information should be incorporated into the pre-processing program for range and range-rate.

   (ii) Spacecraft transponder delay as a function of range-rate should be applied.

   (iii) Refraction corrections should be applied to both range and range-rate using station-measured atmospheric information for the troposphere and CRPL predictions for the ionosphere.

(iv) Error in synchronization between ground station clock and WWV received should be accounted for.

A set of programs designed to provide more timely information on data quality is currently under development. It is hoped to make use of these in a non-rigorous way for GEOS-B. A natural fallout from this effort will be a more timely placement of GRARR/GEOS-B data in the Data Center.

The inclusion of the station in Alaska in the GEOS-B tracking network should result in an increase in the overall geodetic capability of the GRARR system.

FIGURE I
GRARR Transponder Temperature

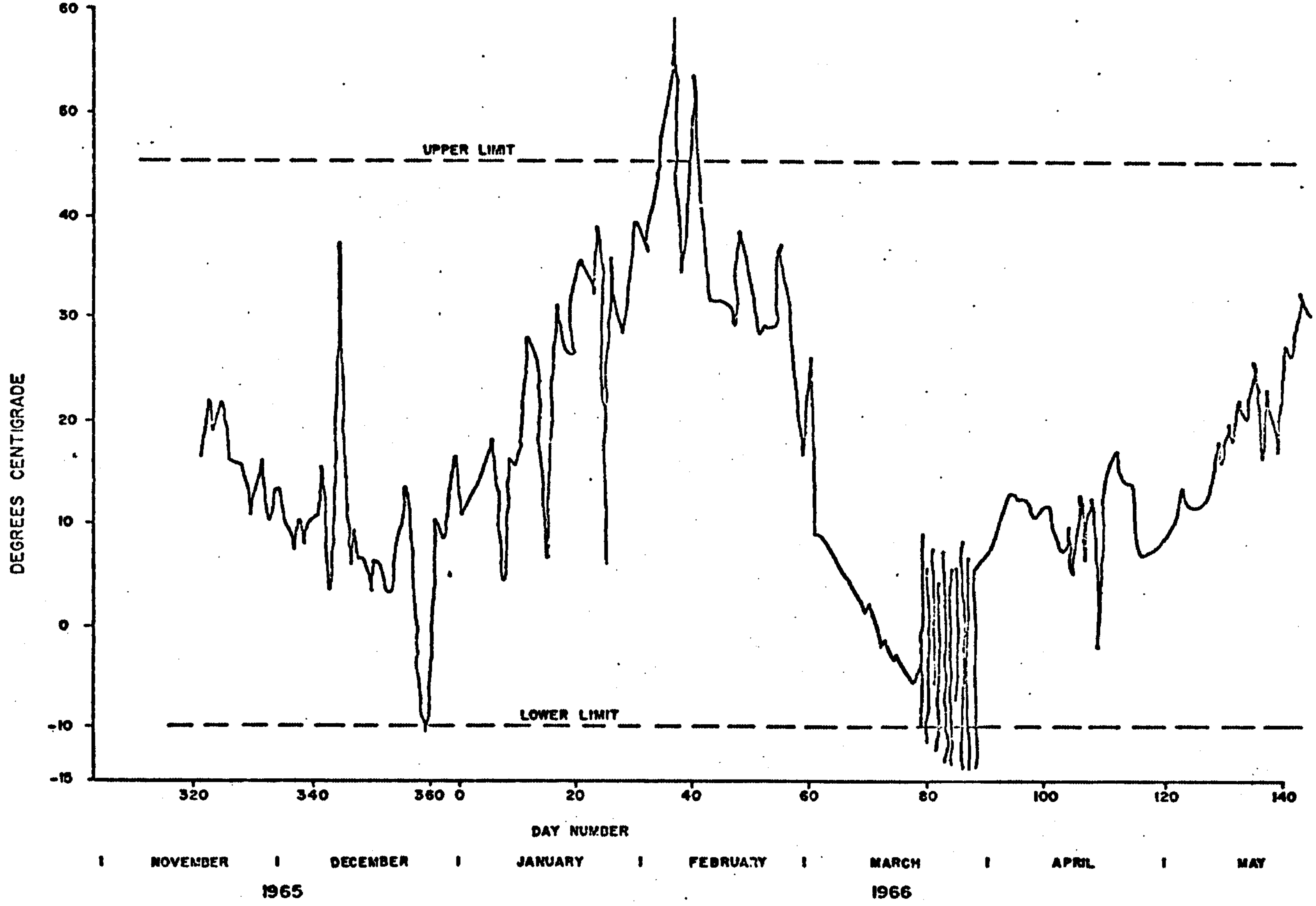

FIGURE I (Cont)

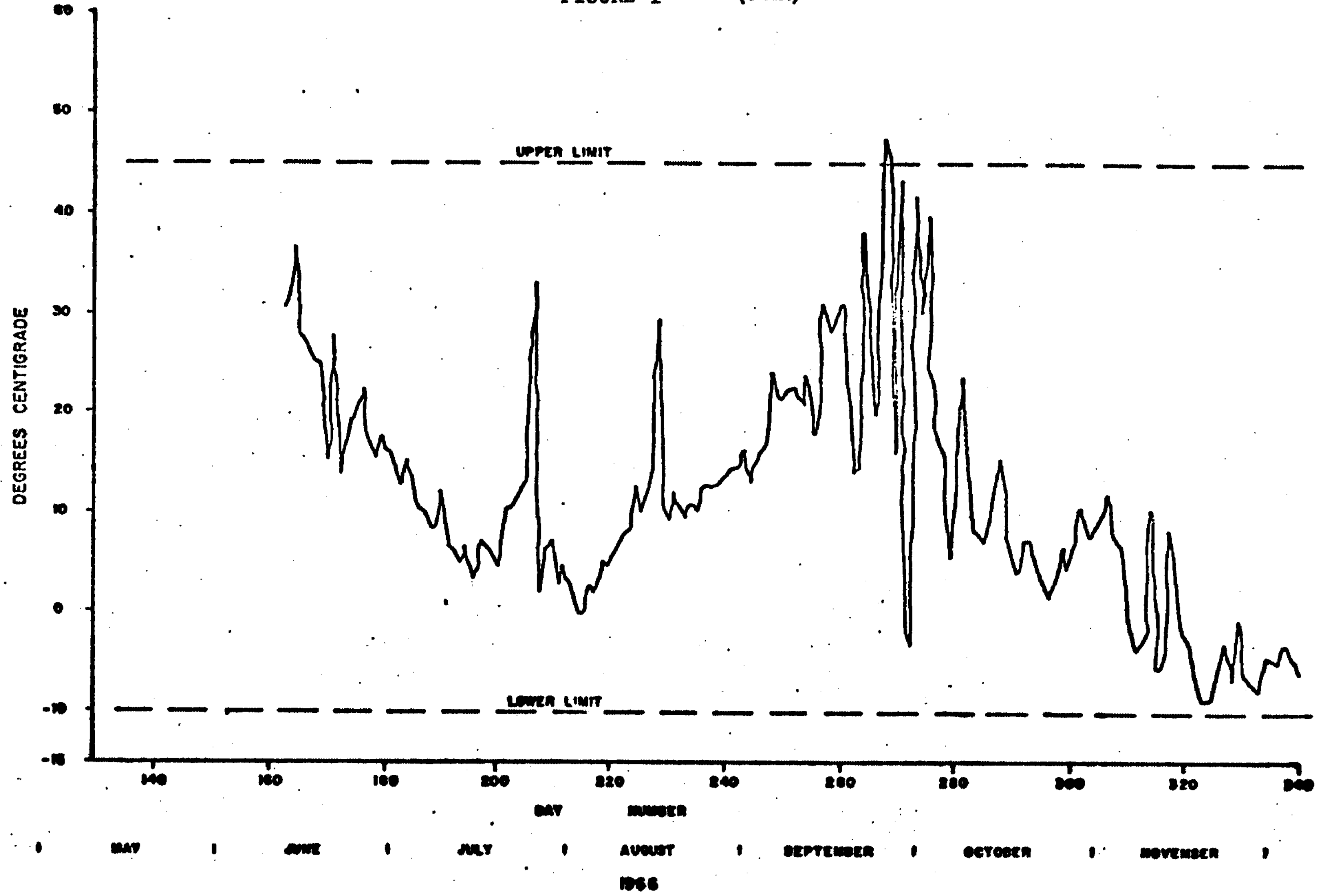

FIGURE II
Solar Activity Indicies for November 1965 to November 1966

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GEODETIC SATELLITE DATA SERVICE
GEOS-A REDUCED DATA RECEIVED AND PROCESSED

J. R. Johns

Goddard Space Flight Center

Prepared For

GEOS PROGRAM REVIEW MEETING
12-14 December 1967

NASA HEADQUARTERS
400 Maryland Avenue, SW
Washington, D. C.

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GEODETIC SATELLITE DATA SERVICE
GEOS-A REDUCED DATA RECEIVED AND PROCESSED
as of
December 8, 1967

OPTICAL NETWORK

Network	Observations	Passes	Plates	Period Covered
SAO Optical*	9,980	1,430	2,187	Nov 8, 1965-Nov 29, 1966
NASA Minitrack Optical Tracking System*	10,464	1,288	1,608	Nov 18, 1965-Nov 20, 1966
US Air Force Optical*	4,640	549	724	Nov 25, 1965-Nov 3, 1966
US Coast & Geodetic Survey Optical	46	7	7	Nov 28, 1965-Apr 21, 1966
International Optical*	1,591	165	231	Dec 8, 1965-Oct 22, 1966

ELECTRONIC NETWORK

US Navy Doppler*	490,752	14,386		Nov 14, 1965-May 5, 1967
NASA Range and Range Rate**	23,551	561		Nov 17, 1965-Nov 27, 1966
NASA Minitrack*	14,436	9,609		Nov 6, 1965 -Nov 27, 1966
SAO Laser*	299	65		Jan 29, 1966-Oct 13, 1966
US Army SECOR* (Reduced by GIMRADA)	43,330	90		Jan 11,1966 -May 1, 1966

* Catalog prepared
** Catalog under preparation

J. R. Johns

GEODETIC SATELLITE DATA SERVICE
GEOS Station Pass Catalogs
Prepared and Distributed
as of
December, 1967

Network	Publication Date	Period of Data
Minitrack Network	July, 1966	11/6/65-7/4/66
Supplement #1	September 16, 1966	7/4/66-9/4/66
Supplement #2	February 1, 1967	9/5/66-1/14/67
Smithsonian Astrophysical Observatory Optical; International Optical; Smithsonian Astrophysical Laser; U.S. Army SECOR	March, 1967	11/8/65-4/25/66
U.S. Air Force Optical	September 20, 1966	12/11/65-5/20/66
U.S. Air Force Optical	May, 1967	11/25/65-11/30/66
U.S. Navy Doppler	November 1, 1966	5/3/65-5/10/66
Supplement #1	March 29, 1967	5/11/66-12/31/66
NASA Minitrack Optical Tracking System	November, 1967	11/18/65-11/20/66

GEODETIC SATELLITE DATA SERVICE
GEOS-A Special Mutual Visibility Catalogs
Prepared and Distributed
as of
December, 1967

	Publication Date	Period of Data
GEOS-A Special Mutual Visibility	February, 1967	11/6/65-12/1/65
Supplement #1	January 25, 1967	12/1/65-12/31/65
Supplement #2	March 1, 1967	1/1/66-1/31/66
Supplement #3	March 17, 1967	2/1/66-2/28/66
Supplement #4	March 14, 1967	3/1/66-3/31/66
Supplement #5	March 28, 1967	4/1/66-4/30/66
Supplement #6	May 1, 1967	5/1/66-5/31/66
Supplement #7	April 28, 1967	6/1/66-6/30/66
Supplement #8	May 10, 1967	7/1/66-7/31/66
Supplement #9	May 5, 1967	8/1/66-8/31/66
Supplement #10	May 15, 1967	9/1/66-9/30/66
Supplement #11	August 21, 1967	10/1/66-10/31/66
Supplement #12	August 22, 1967	11/1/66-11/31/66
Supplement #13	August 24, 1967	12/1/66-12/31/66
Supplement #14 (Final)	August 16, 1967	1/1/67-1/31/67

THE OPERATION OF THE NATIONAL SPACE SCIENCE DATA CENTER

NSSDC 67-41

OCTOBER 1967

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FOREWORD

The need to prepare and preserve space science data for use and further study is vital to many scientists and engineers. To help fill this need, NASA's National Space Science Data Center collects data from all space science flight experiments. At the present time, scientific satellites alone, exclusive of picture-taking, are generating 8×10^{11} bits per year. The goal of the Data Center effort is maximum dissemination and use of these data.

This document has been prepared to inform interested parties about (a) the forms in which data are collected, (b) the present activities and use of the Data Center, and (c) some of our future plans.

James I. Vette

Dr. James I. Vette
Director
National Space Science Data Center

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LIST OF FIGURES

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THE OPERATION OF THE NATIONAL SPACE SCIENCE DATA CENTER

BACKGROUND

Before describing the operation of the National Space Science Data Center, it may be useful to take a look at the data involved. It has become apparent in the last few years that satellite measurements produce a tremendous amount of data to be processed and analyzed. The need for and use of this data by groups other than the scientists and engineers involved in the specific experiments are very great. Our understanding of the complex natural phenomena observed in space is far from complete. Consequently, the preservation of the basic data for further study in the future is vital to many scientists. Some other uses for this data will be presented later. The fact that satellite experiments are expensive and require 3-5 years between instrument design and return of data means that the information acquired by these space techniques is an expensive commodity. It is imperative, then, that means be established to promote maximum dissemination and utilization of the data.

To get on common ground in describing these data, it should be pointed out that there are several different categories in which the various space projects can be placed. Scientific experiments measure those quantities which will lead to a general understanding of the natural phenomena. On the other hand, engineering measurements are vital to the advancement of techniques and procedures which lead to more sophisticated, reliable, and useful spacecraft and systems. The applications satellites for communication, navigation, weather, and other operational needs form a significant portion of the present effort. Then there are the biomedical experiments which are conducted as part of the manned program and are important for achieving suitable ecological systems.

As can be seen, the great diversity of information that comes from satellites requires a dissemination system that can be responsive to the user community. In this context, the National Space Science Data Center, or NSSDC for short, is concerned with most of the scientific data obtained from space probes, satellites, sounding rockets, stratospheric balloons, and high-altitude aircraft. It is responsible for the acquisition, organization, storage, retrieval, announcement, and dissemination of this information. NSSDC was established by NASA in 1965 as an extension of a local data center activity at the Goddard Space Flight Center. By restricting the activities to the scientific class of space data, the proper lines of communication with the generators as well as the users of the data can be maintained. Encompassing too diverse a group would complicate staffing and management of the operation. The Data Center is a central facility within this restricted framework. The scope of operations is national in the sense that the space science data generated by all agencies and research groups are collected. The resulting data bank is available to all requesters.

Bearing in mind the goal of maximum dissemination and utilization of these data, this paper describes the general flow of space science data, discusses the activities of NSSDC, and examines some Data Center problems and their possible solutions.

THE FLOW OF SPACE SCIENCE INFORMATION

First, it may be instructive to examine the origin and overall flow of this kind of data and information in order to clarify the role that the Data Center is fulfilling. A good starting point is with an orbiting spacecraft as a typical generator of space science data and then following the sequential process usually required to translate this data into useful information which can be understood by others. The diagrams given in Figures 1 and 2 illustrate the steps involved.

All of the data obtained by various instruments are telemetered to the receiving station in a coded form and are recorded on analog magnetic tape. In some cases specialized equipment at the receiving stations converts the data directly to a meaningful form. This is true, for example, in the Surveyor Program where the primary pictures are made from the data as they are received at the ground station. It should be noted that the raw data on the analog tapes include the outputs from many different experimental sensors as well as information about the performance of spacecraft systems. Examples would include power supplies, on-board clocks, command modes, transmitters, solar panels, spin rate, and, in some cases, measurements by aspect or orientation devices. At this point the data may be degraded by telemetry noise, improper satellite system or experiment performance, or by ground station operations.

The analog tapes are then sent to a central processing center where they are converted in most cases into digital tapes. They are quality checked and the noise is removed where possible. It is here the spacecraft performance and time measurements are decoded and converted to standard units. The resultant edited tape is often called the master digital data tape. In special cases the scientific satellite programs generate data which are made available to the scientific community immediately; many of the picture-taking satellites such as Ranger, Surveyor, and Lunar Orbiter fall in this category. However, the majority of experiments are performed by a principal investigator, who has sole responsibility for the design, construction, and calibration of the instrument and for the initial interpretation of the data. For a period of several years he controls the availability of the data to others and can have exclusive rights to it.

FIGURE 1
DIAGRAM OF SATELLITE DATA FLOW FROM ORBITING SPACECRAFT THROUGH CENTRAL PROCESSING FACILITIES

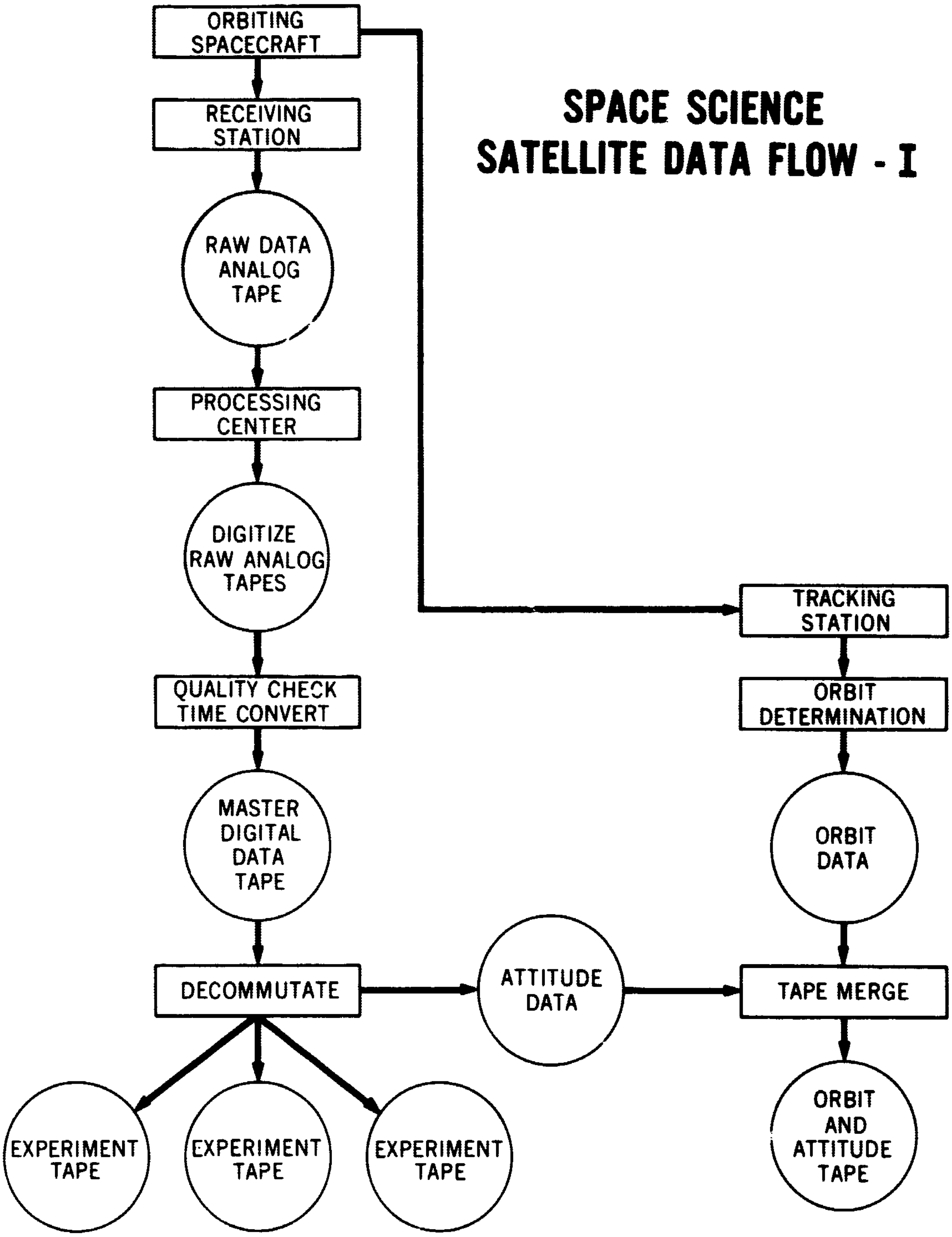
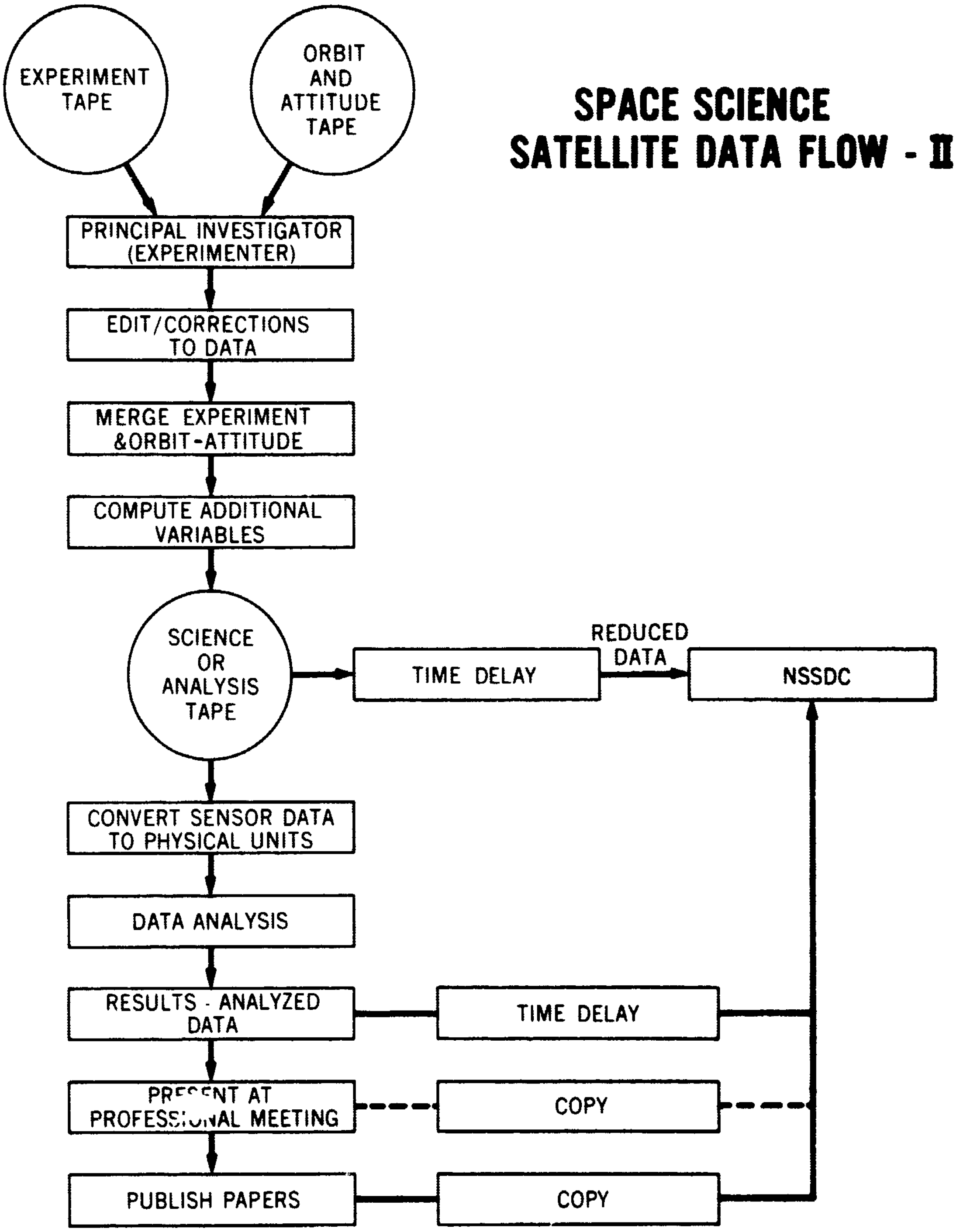


FIGURE 2
DIAGRAM OF SATELLITE DATA FLOW FROM EXPERIMENTER THROUGH ANALYSIS TO FINAL PUBLICATION
The phases where data is collected by NSSDC are shown.



In these cases the information pertaining to each individual experiment is stripped off the master tape onto separate tapes which are sent directly to the appropriate principal investigator. These experimenters are located in universities, government laboratories, NASA field centers, and in private industry. During this decommutation of the master tape, certain items of information such as spacecraft attitude are placed on a separate tape which will be merged with the orbit data as soon as the position of the satellite can be determined from the tracking data. This orbit-attitude tape is also sent to each experimenter.

The data processing at the principal investigator's facility involves editing out those periods in which the data are useless because of telemetry noise or malfunctions. It also involves applying correction factors to convert sensor response to standard conditions of temperature, voltage, amplifier gain, etc. This corrected data is merged with the satellite ephemeris and attitude data; generally, additional variables derived from positional information and used in data analysis are computed at this time. The resultant information usually appears on a digital tape commonly called a science or analysis tape. Hopefully at this point none of the basic information content of the experiment has been destroyed. The data in this form, usually called reduced data, are what NSSDC attempts to collect. Other scientists active in the specialized fields, given the detailed characteristics of the instrument, then can independently interpret the data for their own purposes. As pointed out earlier there is a time delay of 2-3 years before this data is made available to the Data Center. However, for programs such as the picture-taking satellites, the photographs are available several months after launch. The negatives are considered the reduced data for this class of experiments.

In order to proceed to the data analysis phase the experimenter must convert the detector or instrument response to a physically meaningful quantity. This normally includes a calculation using the calibrated instrument response and some assumptions about the various phenomena being observed. Frequently, models of the physical processes are used; some of these later prove to be incorrect. It is really at this point that the interpretation of the results commences. Consequently, for certain purposes, it is important to obtain the data for future users prior to this step. This point should be explained more completely. The data analysis process is one that varies considerably from experiment to experiment and from laboratory to laboratory. The results of this analysis represent the interpretation of the experiment by the principal investigator and his co-workers and display the scientific meaning from their point of view. These results are communicated to colleagues and other interested parties through oral presentations at professional meetings and through publication in scientific journals.

These results, which are called analyzed data, are very useful to many other scientists and engineers since they represent the judgment of outstanding experts in the field. Therefore, the Data Center includes this type of information in its collection efforts. These data may include charts, graphs, photographs, and tables; examples of these appear in published works but usually there are too many to be published in their entirety.

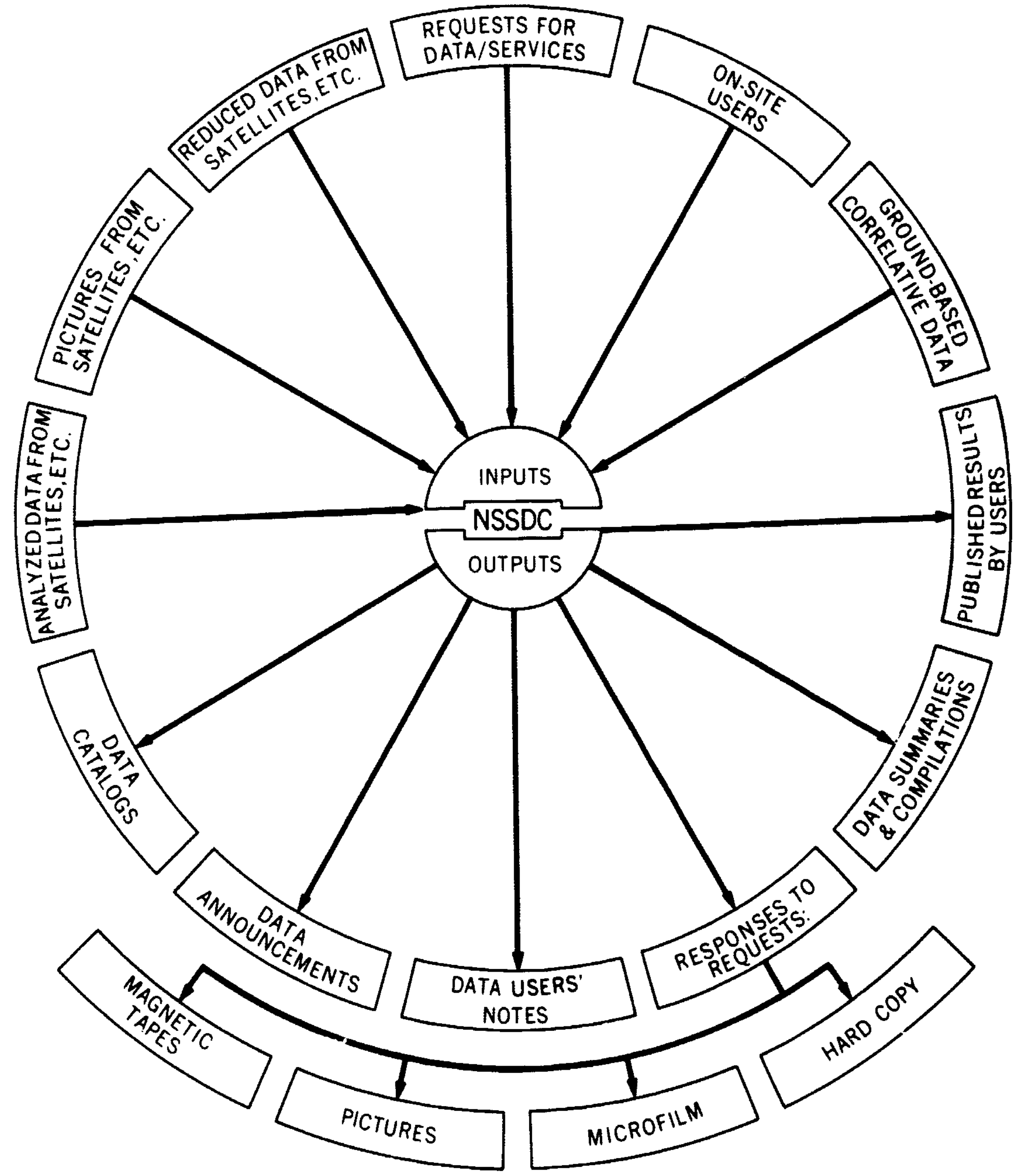
ACTIVITIES OF THE NATIONAL SPACE SCIENCE DATA CENTER

Now that it has been shown where the Data Center fits into the general scheme of space science data, the NSSDC operation merits a closer look. It should be apparent by now that the acquisition of data in the proper forms requires people who are familiar with the instruments, data processing, and the interpretations of the data. Thus, professional people who have specialized in the various space science disciplines are necessary to the successful operation of the Data Center. Furthermore, the proper documentation describing the instrument quantitatively and giving the results of calibrations must be obtained or the data may well be useless to other scientists and users.

This total acquisition is critical, as pointed out before, because the data obtained by space science experiments are extremely useful to others engaged in space activities. The engineer and system planner require a knowledge of the space environment in order to design the spacecraft subsystems and to perform the trade-off calculations necessary in obtaining the most efficient total operation. Most of the knowledge of the space environment comes directly from scientific measurements. However, the reduced or analyzed data is not in the proper form to be utilized directly by other than space science specialists. In fact, it is necessary to study the analyzed data (and in some cases to perform additional analyses with the reduced data) from many experiments in order to obtain a fairly complete description of the space environment. This translation of reduced or analyzed data into data summaries or compilations is a natural professional activity for those Data Center personnel involved in the data acquisition. Some of this is being done now, but there will be more activity as the staff and professional competence grow.

To be specific about the activities of the Data Center, the most important inputs and outputs are shown in Figure 3. Besides the data obtained by space experiments, which have already been described, the results of many ground-based measurements are useful in the interpretation of flight results. For example, primary and secondary effects of the molecules, atoms, ions, electrons, and photons detected in space have been measured by ground-based instruments for many years; whereas our present ability to place sensors in orbit has extended the capability of measuring natural phenomena. The correlations of the

FIGURE 3
A SUMMARY OF THE ACTIVITIES AND PRODUCTS
OF THE NATIONAL SPACE SCIENCE DATA CENTER



ACTIVITIES OF THE
NATIONAL SPACE SCIENCE DATA CENTER

two types of measurements greatly increase our understanding of the complex, stochastic phenomena encountered. Thus, the raw materials for the Data Center are comprised of space science data and ground-based correlative data; this latter information is generally obtained from other data centers, particularly those run by ESSA,* which specializes in its acquisition and distribution.

To enhance the dissemination of the available data, catalogs which contain a cumulative listing are published semiannually. In cases where recently acquired data sets have a wide interest, a special data announcement is published as soon as possible. Based upon documentation provided by the experimenter, by his data processing people, and by the published articles, a Data Users' Note is written by the NSSDC staff and reviewed by the principal investigators. This document provides the key information for the use of the data by other scientists. The Data Center has facilities for visiting scientists to perform studies on-site or to select those sets to be sent to their institutions for further study.

Requests for data through catalog and on-site selection result in the production of magnetic tapes, cards, pictures, microfilm, or copies of written, graphical, and tabular material. To demonstrate the growth of the use of NSSDC and to indicate the present level of activity, the number of completed requests as a function of time are shown in Figure 4. A breakdown of the requests during the past 6 months into various types is shown in Table 1. It can be seen that lunar and terrestrial photographs constitute a large portion of the present output. It should be remarked that correlative data are only distributed to NASA personnel since other data centers serve as the national distribution points.

To show the request output in still another way, Table 2 lists the materials which have been supplied during the period 1 June - 18 August 1967. The backlog or requests in process are also given. The practice to date has been to supply small requests free of charge if the use of the data is for non-commercial purposes. Costs of reproduction are charged for all other requests.

THE USE OF THE DIGITAL COMPUTER

Although the Data Center has been in existence for 2-1/2 years, extensive use of the digital computer has been undertaken only recently. Much of the data collected in the beginning was not in digital form, and a manual operation sufficed. At the present, several different computer-oriented projects are being implemented.

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*Environmental Science Services Administration.

FIGURE 4
THE GROWTH OF NSSDC USERS
The availability of Lunar pictures produced the rapid increase in early 1967.

NSSDC REQUESTS FOR 4-WEEK INTERVALS

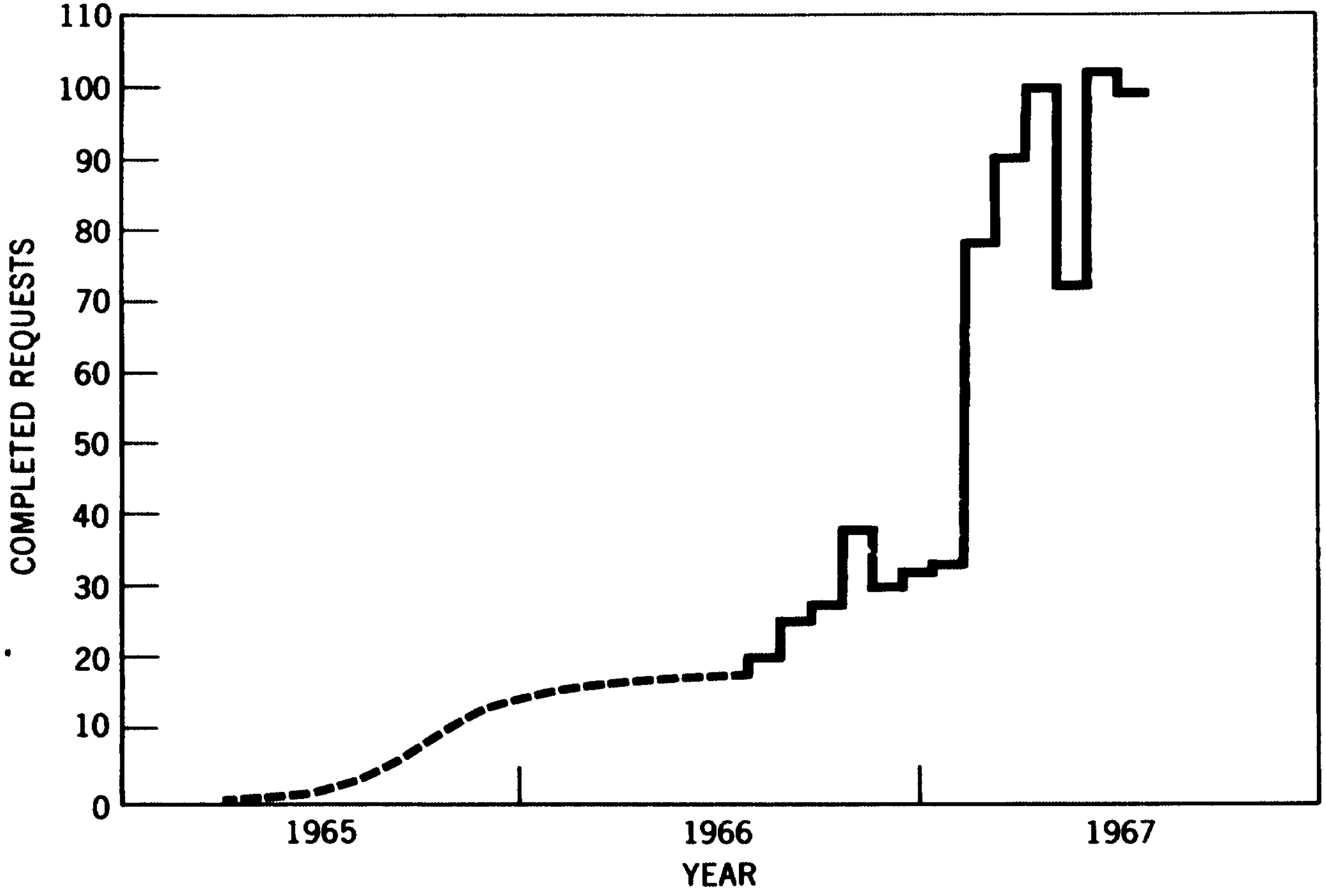

TABLE 1
NSSDC FRACTIONAL BREAKDOWN OF COMPLETED REQUESTS

TYPE OF REQUEST	PERCENTAGE OF TOTAL NUMBER
REDUCED DATA	19.1
CORRELATIVE DATA	19.6
CLOUD & EARTH PICTURES	20.9
LUNAR PICTURES	40.4

TABLE 2
NSSDC REQUEST OUTPUTS

MEDIUM	UNIT	REQUESTS COMPLETED BETWEEN 6/1/67 - 8/18/67	REQUESTS IN PROCESS
DIGITAL MAGNETIC TAPE	2400' REEL	98	449
PUNCHED CARD	CARD	40,176	1,394
COMPUTER PRINTOUT	SHEET	7,850	1,224
MICROFILM	REEL	294	985
HARD COPY	PAGE	4,853	3,400
PHOTO - LUNAR ORBITER SURVEYOR GEMINI NIMBUS	POSITIVE, NEGATIVE, OR TRANSPARENCY	956 215 386 700	6,800 19,000 277 661

A request accounting, status, and history file is being developed to handle requests more efficiently. This system will provide an immediate status for any request and estimate the time necessary for completion. It will generate standard reports on the number of requests received and processed, generate automatic action reminders, identify the work queues, and maintain a request log. Statistical studies will be made on this request file to determine the frequency of demand for given data sets, the types of outputs requested, and the identification of the various users.

Quite naturally, an information storage and retrieval system is also being developed. All of the information deposited in the Data Center will be entered into this system. Appropriate search terms such as investigator, satellite (or other vehicle), instrument type, time period, and other keywords will be used. A good working knowledge of the various scientific disciplines and the forms of data requests are necessary to provide effective inputs to this system.

One of the most challenging problems that faces the Data Center operation is that of handling the vast array of magnetic tapes that will be supplied in the future. In order to bring this problem into proper focus, an estimate of the amount of scientific data generated by satellites as a function of time is shown in Figure 5.

The data that has been collected so far mainly covers the time period prior to 1965. The exceptions to this are the lunar and terrestrial pictures; all of those photographs taken by Gemini, Surveyor (I & III), and Lunar Orbiter (I, II, III, and IV) are available. It can be seen that large amounts of data will be handled within the next few years. Best estimates indicate that within three years 10,000 reels of magnetic tape will be deposited annually. The present holdings at NSSDC and estimated annual inputs are listed in Table 3.

Because the main sources of data for NSSDC are spread throughout this country and abroad, a wide variety of tape formats produced on various computers are anticipated. Roughly 500-1000 space science experiments are handled by 50-100 groups throughout the United States (a few dozen experiments have been performed by foreign scientists in conjunction with NASA). Unfortunately, magnetic tape is not a good long-term archival medium compared to photographs or printed matter. Although the quantitative lifetime of reliable storage on tape is not known, two to three years is all that is expected for high reliability.

Since tape damage or loss of data can occur during usage, it is necessary to maintain a spare copy. Consequently, a digital data base consisting of 30,000 tapes implies storage facilities for 60,000 tapes and the overhead expense of generating 20-30,000 tapes annually. It is obvious that any system of this

FIGURE 5

YEARLY GENERATION OF SPACE SCIENCE DATA BY SATELLITES

These totals do not include the data from pictures.

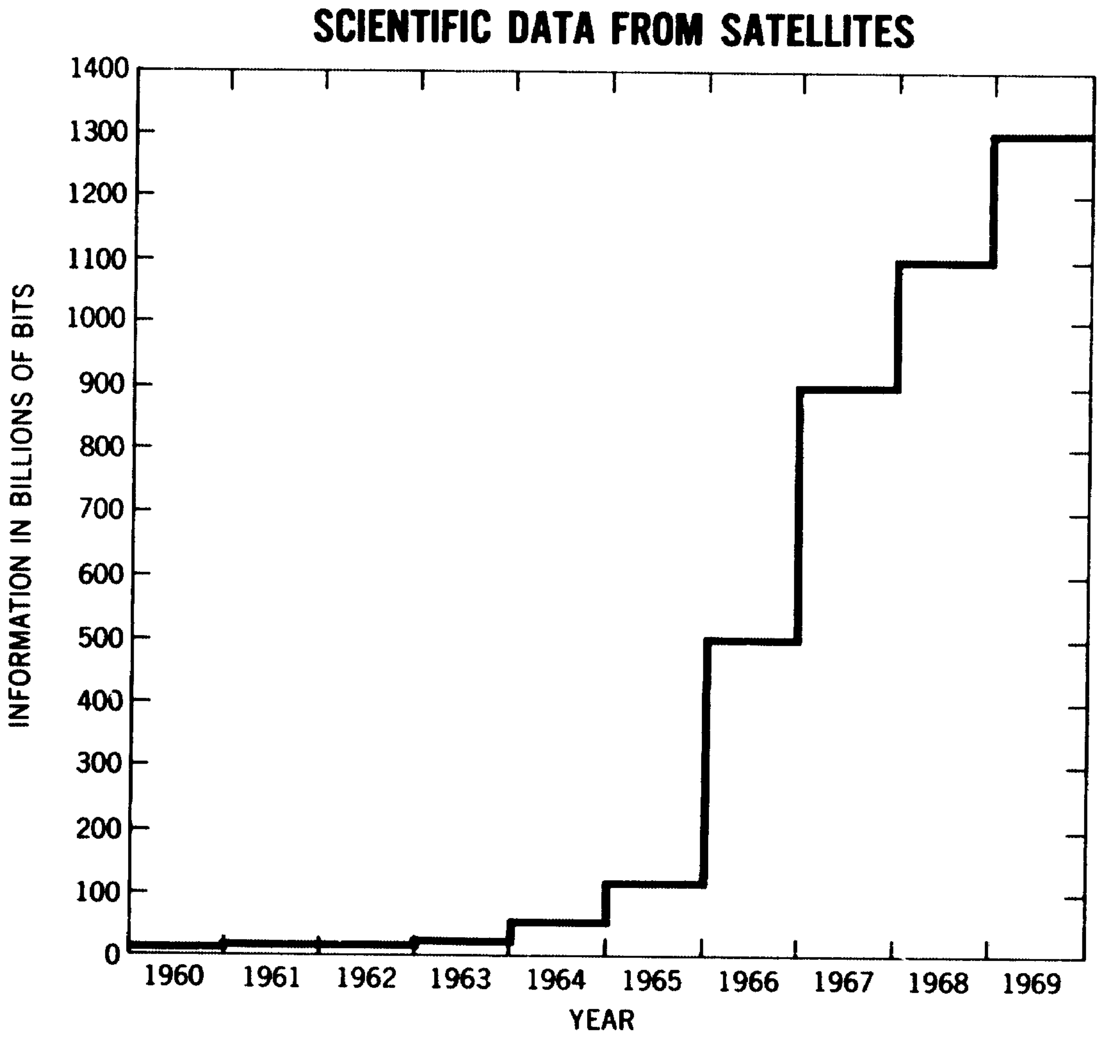

TABLE 3
VOLUME OF DATA AT NSSDC
Present (August 1967) and Projected, Annually (January 1970)

MEDIUM	ON HAND	INCOMING
SHEETS AND BOUND VOLUMES, SHEETS	175,000	100,000
ROLL CHARTS, LINEAR FEET	360,000	150,000
DIGITAL MAGNETIC TAPES, 1/2"x2400'	291	10,000
ANALOG MAGNETIC TAPES, 1/2"x2400'	1,035	0
MICROFILM, 100-FT ROLLS	7,800	2,000
PHOTOGRAPHIC FILMS:		
9-1/2" WIDTH, LINEAR FEET	14,000	4,000
70-mm WIDTH, LINEAR FEET	33,200	12,000
4- x 5-INCH, EACH	2,100	1,000
16- x 20-INCH, EACH	93	--
20- x 24-INCH, EACH	2,200	800
PHOTOGRAPHIC PRINTS:		
8- x 10-INCH	600	500
11- x 14-INCH	200	300
16- x 20-INCH	93	--
20- x 24-INCH	2,200	800

magnitude must pack the data efficiently to minimize the number of tapes. To do this, it is necessary to convert all incoming tapes to a standard internal format. Although this requires the development of computer software to process every incoming tape, the advantages are numerous. A quality check of the incoming data can be made. Errors or omissions can be discussed with the supplier of the data; hopefully these can be cleared up immediately instead of trying to obtain the information several years later from the principal investigator. As a minimum, the discrepancies can be flagged. All maintenance and system quality control programs can be written to handle a standard set of tapes rather than a heterogeneous mixture. Requests for data on magnetic tape can be processed by reformatting the tape so it can be handled efficiently at the requester's facility. Work on such a standard format is in progress but it will be 6-12 months before the system will be operational.

With the amount of information increasing at a great rate, thought also must be given to retiring from the active base or compressing that data which is not being used. Within the next 5 years higher density storage techniques for digital data should be readily available. Several different processes are under development which will result in volume reductions of 100 up to 40,000 over standard

556 characters-per-inch magnetic tape. Reductions of this size will help to solve the storage problem. The photographic or metal film used in these processes also provide archival media which require much less maintenance than magnetic tape.

Besides the technological improvements, it should be possible to compress the actual data. First, a study of the data utilization through the request history file will provide insight into which items of information can be removed from the active data base. A preliminary study has indicated that the derived variables, which accompany the basic data, average about 10 times as many bits as the sensor measurements. Since these variables are very important in most analyses, they are not removed when the data is first deposited at NSSDC. However, for data that receives very little use, the removal of the variables would produce a large reduction in volume. A user of the data in this form could recalculate those variables from the original information.

There is another area of possible data compression. Most of the space science data can be broken up into two different types. One is the ambient, quiet time, background information and the other is the disturbed time, event information. There are many different events (many are related) such as magnetic storms, solar flares, and solar proton, electron, and X-ray events. These and other events are of extreme interest. However, the background information constitutes the majority of the scientific information obtained since the beginning of the space age. As newer instruments become available which have better time, energy, or spectral resolution, the fine details of the older background data will not be needed. Time averages of this background data can then be made over hours or even days. This averaged data will still be useful in determining the long-term changes which are apparent in the solar-geophysical phenomena.

Thus, there appear to be several ways to cope with the data explosion in this area of interest. By keeping the active data base to a reasonable size, the maintenance costs will be reduced. This will free resources for application to the storage and analysis of newer data.

SUMMARY

The National Space Science Data Center provides the means for analysis and dissemination of space science data beyond that provided by the primary experimenters and their co-workers. Because of the large amounts being generated and analyzed, it is necessary to be selective in the data that constitutes the active base if it is to be put to optimum use in the future. In this context, the computer is a useful tool for management and administrative control of the operation; it is mandatory for the processing of magnetic tapes and the implementation of information storage and retrieval systems.

The Data Center has to have professionals in the space science disciplines to: (a) acquire the data in the proper form from the experimenters, (b) maintain the appropriate interface with the scientific community, (c) provide the proper entries for the storage and retrieval system, and (d) translate the data into forms useful to the engineering and management communities. Although scientific societies have recognized the importance of the compression and exchange of information through data or information centers, more space science professionals are needed in this activity now; many more will be needed in the future.

GSDS DATA PROCESSING

GENERAL

The Geodetic Satellite Data Service (GSDS), a group within the National Space Science Data Center (NSSDC) established specifically to handle GEOS observational and related data, will conduct data-exchange activities among principal investigators associated with the GEOS program during the "exclusive use period" (exclusive use period is the time interval during which only the principal investigators will have access to the data). After a length of time, the geodetic data will be made available to the qualified scientific community upon request. The control and dissemination of such data will then become a function of the NSSDC.

DATA EXCHANGE

The principal data-exchange activities are the receipt, logging, storage, control, and distribution of observational data prepared by the major observing networks. All large-volume contributors will submit their data on magnetic tapes. Participation in the data exchange requires the principal investigators to first have submitted data before requesting data.

The GSDS will perform required liaison with the observers to correct obvious data errors and to inform observers of infractions of reporting formats. The GSDS will also perform required liaison with the principal investigators and upon request, provide processed data (no raw data) from the GSDS storage system. The investigators will be informed of available data by means of periodic GSDS reports. The GSDS will also be in contact with other GSFC organizations associated with the GEOS project and will provide reports on the data received, enabling GOCC to evaluate the performance of the individual observers.

DATA RECEIPT, QUALITY CONTROL, AND STORAGE (FIGURE 1)

a. Tapes or cards received at GSDS, with accompanying inventory sheets.

b. Visually inspected for damage, obvious mishandling, etc.

c. Submitted to computer program for quality control checking. The data for each station pass will follow one of the three routes below:

- Data appear to be acceptable. Entire pass accepted.
- Data questionable. Entire pass tentatively accepted subject to results of manual analysis.
- Data unquestionable incorrect. Entire pass referred to submitting network for corrective action.

d. Observations accepted in item c above are merged into the GEOS data files and announced in the catalogs.

The quality control program prepares station pass summary cards for the acceptable data. These are used to prepare two types of reports:

a. Control Reports, to aid GOCC in their operations evaluation.

b. Data Catalogs, to allow the investigators to select data of interest for analysis.

DATA DISTRIBUTION (FIGURE 2)

Data will be sent to qualified investigators on the basis of catalog orders. These data will be copies from the GSDS data files and shipped to the investigators on magnetic tapes containing card-image records. Cards will be prepared only for small-volume optical data requests.

GSDS REPORTS (FIGURE 3)

GSDS Control Reports and Data Catalog supplements will be issued as data become available.

a. Data Receipt Summary: Totals by station of the amount and span of data received, both to date and during the current reporting period.

b. Stations Not Reporting List: A list of stations from which GSDS has not received data for a certain time period, for example, the preceding three months.

c. Data Distribution Summary: Totals, by reporting network, of data sent to each investigator to date.

d. Participating Stations List: A list of station names, positions, datums, participation dates, etc., with special note of changes occurring during the reporting period.

e. Station Pass Catalog: A list, for each network, of passes received by GSDS during the reporting period. They will contain for each pass, start and end times, station and satellite positions, number of observations, etc. Each list will be in chronological order by pass start time.

f. Mutual Visibility Catalog: A single time-ordered listing, for all networks, of all passes. In addition to the items for each pass mentioned in item e above, it will contain a graphic display for all periods of mutual visibility. The supplements to this catalog will not necessarily reflect recently received data, but rather will be issued for those time periods for which all the data from all networks have been received. When all of the preprocessing networks are reporting to the GSDS on a regular basis, supplements to this catalog will be prepared and issued monthly.

g. Correct Data List: A list, by network, of each pass of corrected data (as defined in paragraph 10.4.4, item c) citing the nature of the correction that GSDS has received during the current reporting period. The correct data list will allow the investigators to keep their catalogs up to date.

h. Special Mutual Visibility Catalog: Same as item f except it is prepared from the station reports, received at GOCC, on observational data taken but not reduced. Published on a monthly basis when all networks have submitted their station reports to GOCC. These catalogs will be used to determine what data should be reduced.

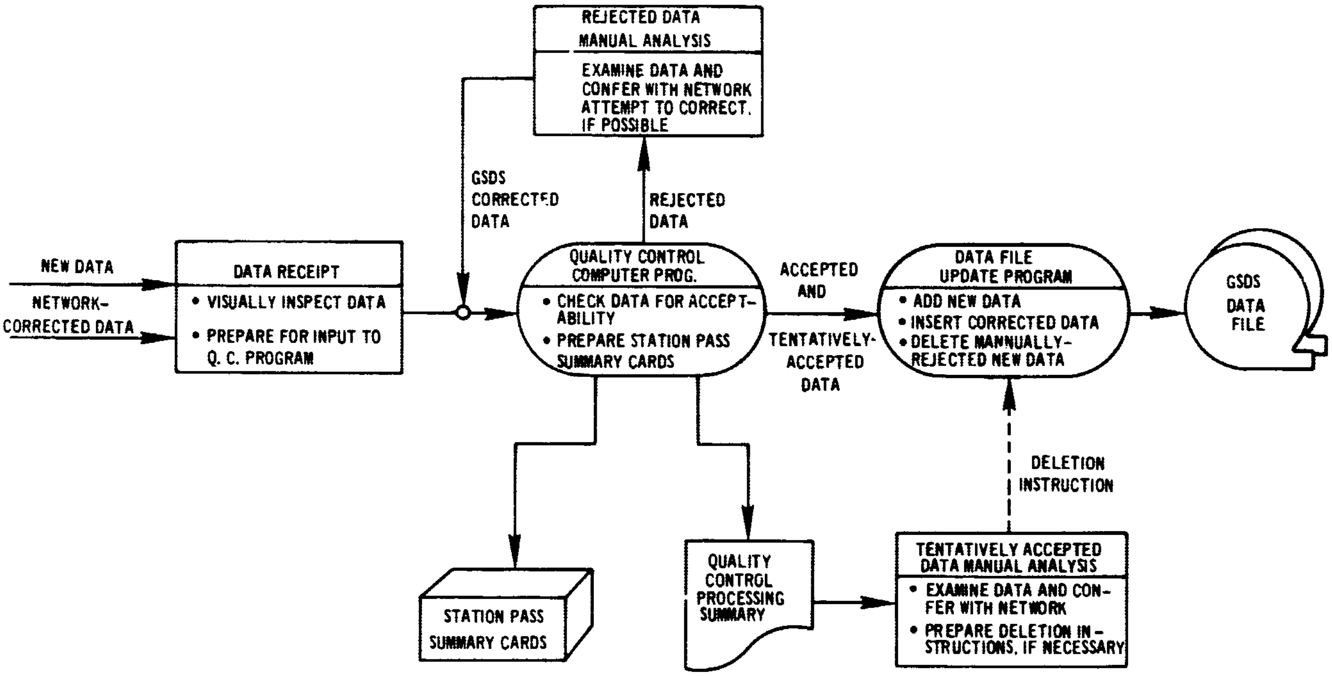

Figure 1. GSDS Data Receipt, Quality-checking and Storage, Operations Diagram

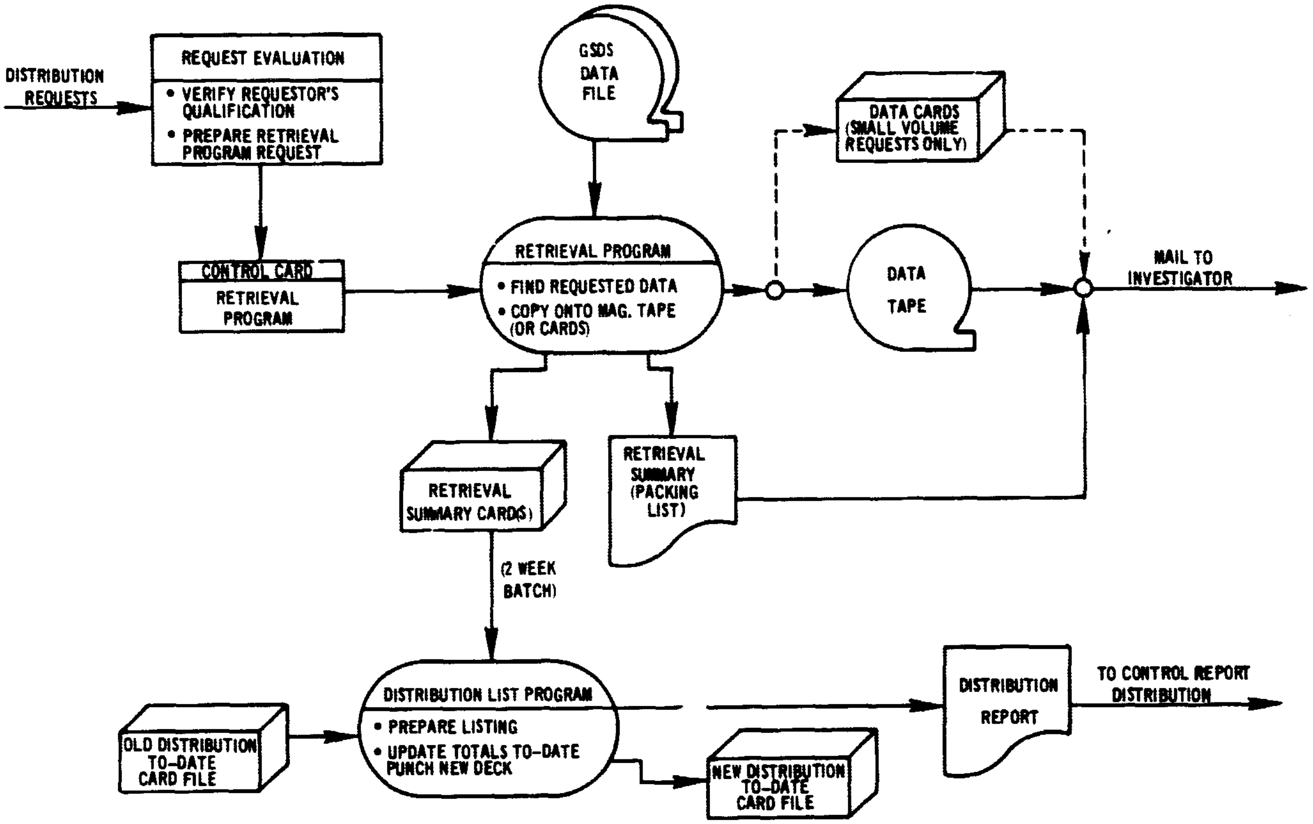

Figure 2. GSDS Data Distribution Operations Diagram

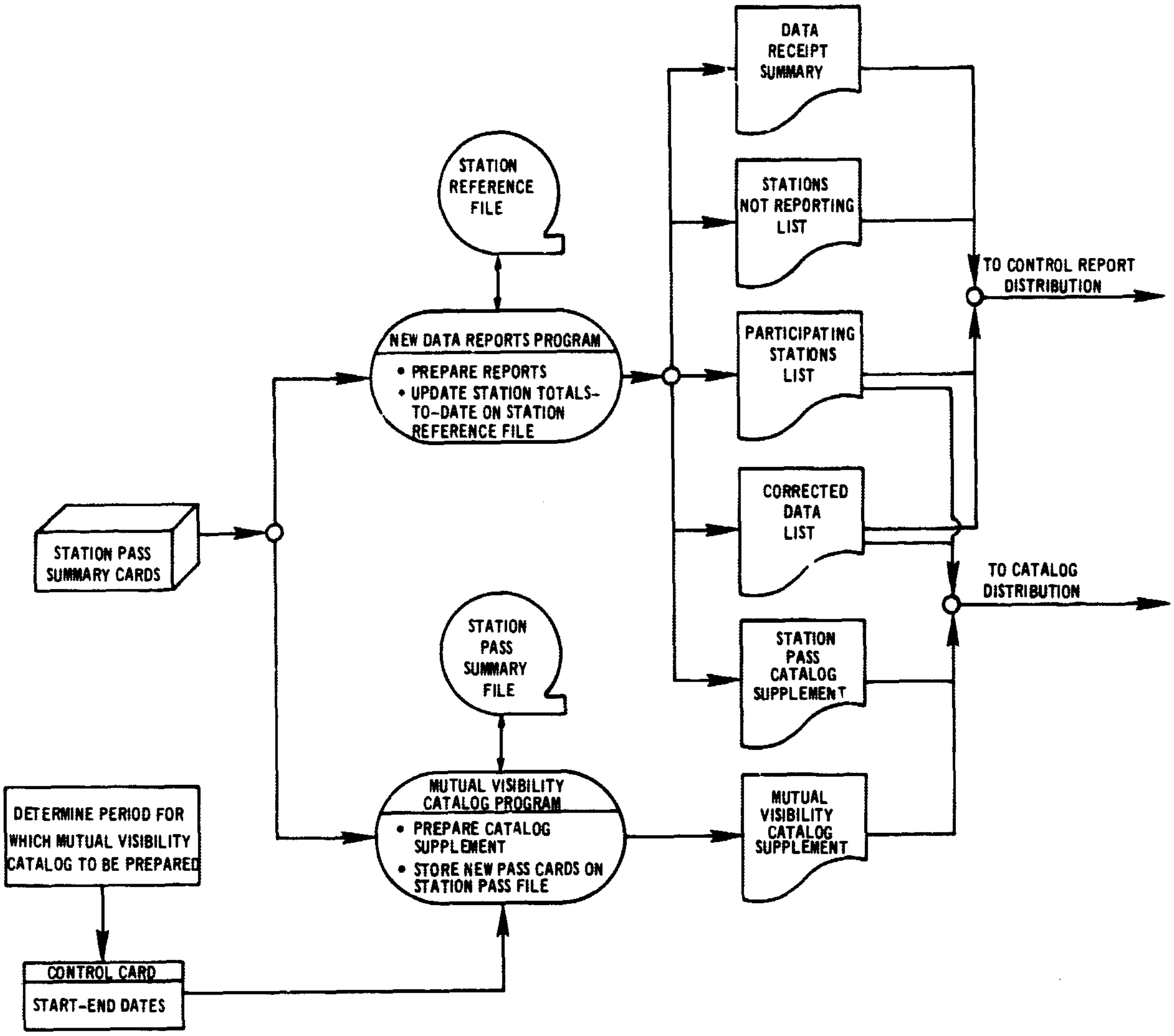

Figure 3. GSDS Report Generation, Operations Diagram

GEOS-B SPACECRAFT DESCRIPTION

Dr. George Weiffenbach

Johns Hopkins University/Applied Physics Laboratory

Prepared For

GEOS PROGRAM REVIEW MEETING
12-14 December 1967

NASA HEADQUARTERS
400 Maryland Avenue, SW
Washington, D. C.

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GEOS-B SPACECRAFT DESCRIPTION

Dr. George Weiffenbach
Johns Hopkins University/Applied Physics Laboratory

Introduction

The GEOS-B spacecraft is scheduled for launch from the Western Test Range on the 10th of January 1968. The spacecraft is essentially the same basic design as the GEOS-A with the exception of several improvements and additional geodetic instrumentation. The planned orbit will have an apogee of 850 n. mi., a perigee of 594 n. mi. and an inclination of 106 degrees. The Thrust Augmented Thor Delta with an FW-4 third stage is the launch vehicle.

Orbital Considerations

The apogee altitude planned for GEOS-B is somewhat lower than the actual GEOS-A apogee. The lower altitude is expected to result in a factor of two lower radiation environment. This coupled with decay of the artificial belt, will result in a lower overall radiation degradation than experienced by GEOS-A. The planned orbit has a lower eccentricity than the GEOS-A orbit, which will improve the ability of the passive gravity gradient stabilization system to maintain the satellite in a vertical orientation. The main concern associated with the new orbit is the regression rate of the line of nodes. The retrograde orbit of 106^{o} inclination coupled with the planned apogee and perigee result in a nodal precession of approximately -1.41 degrees per day, as compared with a +2.75 degrees per day for GEOS-A. This motion is in the same direction as the earth's rotation about the sun thus the relative motion between the orbital plane and the sun line is only .4 degrees per day. This will result in situations where the orbital plane and hence the satellite will have a given attitude with respect to the sun for long periods of time, thus the thermal gradient problem can be more serious than for GEOS-A.

GEOS-B Spacecraft

The GEOS-B spacecraft is a gravity-gradient-stabilized, solar-cell-powered unit which carries electronic and optical geodetic instrumentation. A list of the geodetic investigation instrumentation systems are given below:

- Optical beacons
- C-Band radar transponders
- Passive radar reflector
- SECOR transponder
- GRARR transponder
- Laser reflectors
- Doppler beacons

The nongeodetic instrumentation systems include:

- Laser detector
- Minitrack interferometer beacons

Figure 1 shows the GEOS-B configuration which consists of a rigid box in the form of an octahedron topped by a truncated pyramid. The flat area, which faces earthward, carries the four flashing lights, the laser corner reflectors, the passive radar reflector, the laser detector, one small conical antenna for the GRARR system, two small button antennas for the two C-Band transponder systems, and a broad-band logarithmic spiral antenna painted on a 24-inch diameter hemisphere. The board-band antenna is used for all other frequencies.

The more powerful FW-4 third stage and the planned orbit result in an increased payload capability over that for the GEOS-A mission. The relaxed weight constraints have allowed an increase in weight of about 25%.

The power supply subsystem is essentially the same as GEOS-A, however, several improvements have been made. The solar panels have been rewired in hopes of avoiding the intermittent power loss experienced with GEOS-A. Better electrical insulation has been added and the solar cell by-pass diodes have been removed from the panels and placed inside the satellite, to avoid the wide temperature excursion. A solar array monitor has been added to each of the power supplies to provide a means of estimating the integrated current that has been delivered by the solar panels. This will allow better utilization of the power available.

The attitude control subsystem consists of an extendable gravity gradient boom, magnetically anchored damper and electromagnets.

This subsystem changes the orientation of the spacecraft from its initial postlaunch attitude to one in which the optical beacon and directional antennas (+Z axis) always point towards the center of the earth.

The spacecraft will be mechanically despun to approximately 1 rpm, prior to separation, by release of despin weights from the adapter section.

After spacecraft separation, the spacecraft will be further despun magnetically and then aligned with the earth's magnetic field by energizing a Z-axis electromagnet. When the spacecraft is in a vertical position over the north magnetic pole, it will be gravity-gradient-stabilized by extending the semirigid metal boom and end-mass with the magnetically anchored damper in the Z direction, away from the earth.

The boom mechanism contains 60 feet of silver-plated beryllium copper tape 0.002 inches thick, 40 feet of which will be extended, and which will assume a cylindrical shape one-half inch in diameter.

The relaxed weight constraints have allowed the use of a heavier end mass which should improve stabilization performance.

Because of the anticipated thermal gradient problem, a heat pipe has been added to GEOS-B. This is a hollow tube with a fluid inside which is evaporated at one end and condensed at the other. A wick, consisting of a piece of aluminum screening inside the tube, is used to return the fluid from the condenser end to the evaporator end by capillary action. These devices have extremely high conductivities. One of these connects the SECOR and C-Band transponders, and another the C-Band and S-Band transponders.

Geodetic Instrumentation

GEOS-B is equipped with three systems which are identical to those on GEOS-A, these are (1) doppler system consisting of three transmitters operating on frequencies of 162, 324 and 972 MHz, (2) an Army SECOR (sequential collation of range) system and (3) the GSFC Range and Range Rate transponder.

In addition, GEOS-B is also provided with a pair of redundant C-Band transponders and a passive array of dipoles. The C-Band transponder is to be used for range radar calibration and data recording for experimentation to determine the accuracy of the system for geometric and gravimetric geodesy investigations. One transponder has approximately 5 microseconds of internal time delay; the other has near-zero internal delay. This difference is designed to make real-time identification of the transponder easier for the C-Band participants. The transponder output is nominally 500 watts peak and can handle pulse repetition rates from 160 to over 1,000. The receiver sensitivity is approximately -65 dBm.

The system receives power from the transponder battery and must time-share the available power.

The C-Band passive reflector is used in conjuction with the C-Band transponders to allow a precise calibration of in-orbit transponder internal time delay and to provide passive C-Band tracking capabilities. As the reflector is passive, it will require no power.

GEOS-B, like its predecessor GEOS-A, is equipped with a passive array of laser corner reflectors. The location of these arrays on the earthward side of the spacecraft has been modified to make room for the passive C-Band array. However, the total laser array has been increased about 20% over the GEOS-A configuration. There is also a laser detector mounted on one of the panels to detect the reception of CW laser signals at the satellite. This is for examining atmospheric irregularities, scintillations, et cetera.

GEOS-B has four optical beacons similar to those flown on GEOS-A. The intensity of these lamps is about 13% lower than on GEOS-A. This is due to electrolytic capacitors which are being utilized.

Other Modifications

GEOS-A encountered memory problems which have been hypothesized as being caused by arcing within the optical system. After injection into orbit and prior to gravity gradient stabilization, GEOS-A had an interial attitude such that the bottom of the satellite looked directly at the sun. It is believed that the tilecoat base on the lamp was carbonized by the focused sunlight from the reflectors and thus provided a conductive path. When the high voltage ($\sim$ 15,000 volts) trigger was applied to the lamp, noise spikes were generated which got into the memory circuits. All Laboratory attempts to reproduce this effect have failed, thus a sledge hammer approach to the problem has been used. The lamp bases are now made of uncoated aluminum oxide, which is less vulnerable to charring. Furthermore, a stabilization magnet has been added to the spacecraft to enable magnet stabilization prior to gravity gradient capture. In addition, the digital logic has been slowed up and in some case gates added so that the circuitry will not accept a noise spike.

One of the two redundant oscillator oven temperature control units failed on GEOS-A. This system has been completely redesigned. The new design uses a proportional oven control with a thermistor sensor in a bridge circuit to control the temperature. A similar design has been flown on two navigation satellites and operated satisfactorily in orbit for over six months, as well as extensive ground test.

A slight modification has been made to the pulse deletion network in the satellite clock. On GEOS-A pulses were deleted after the oscillator frequency had been divided by 49. On GEOS-B a pulse deletion circuit is placed between the two 7 to 1 dividers, thus improving the clock control resolution from 9.8 microseconds to 1.4 microseconds.

The GEOS-A spacecraft was lost because of a failure of the command subsystem. In spite of this no changes have been made to the design of this subsystem. Similar command systems have flown on a number of satellites to date without any failures. The failure on GEOS-A is believed to be due to failure of a single component and the probability of a reoccurrence of this is extremely low. Even though no design changes have been made, extra care will be taken in the installation and testing of same.

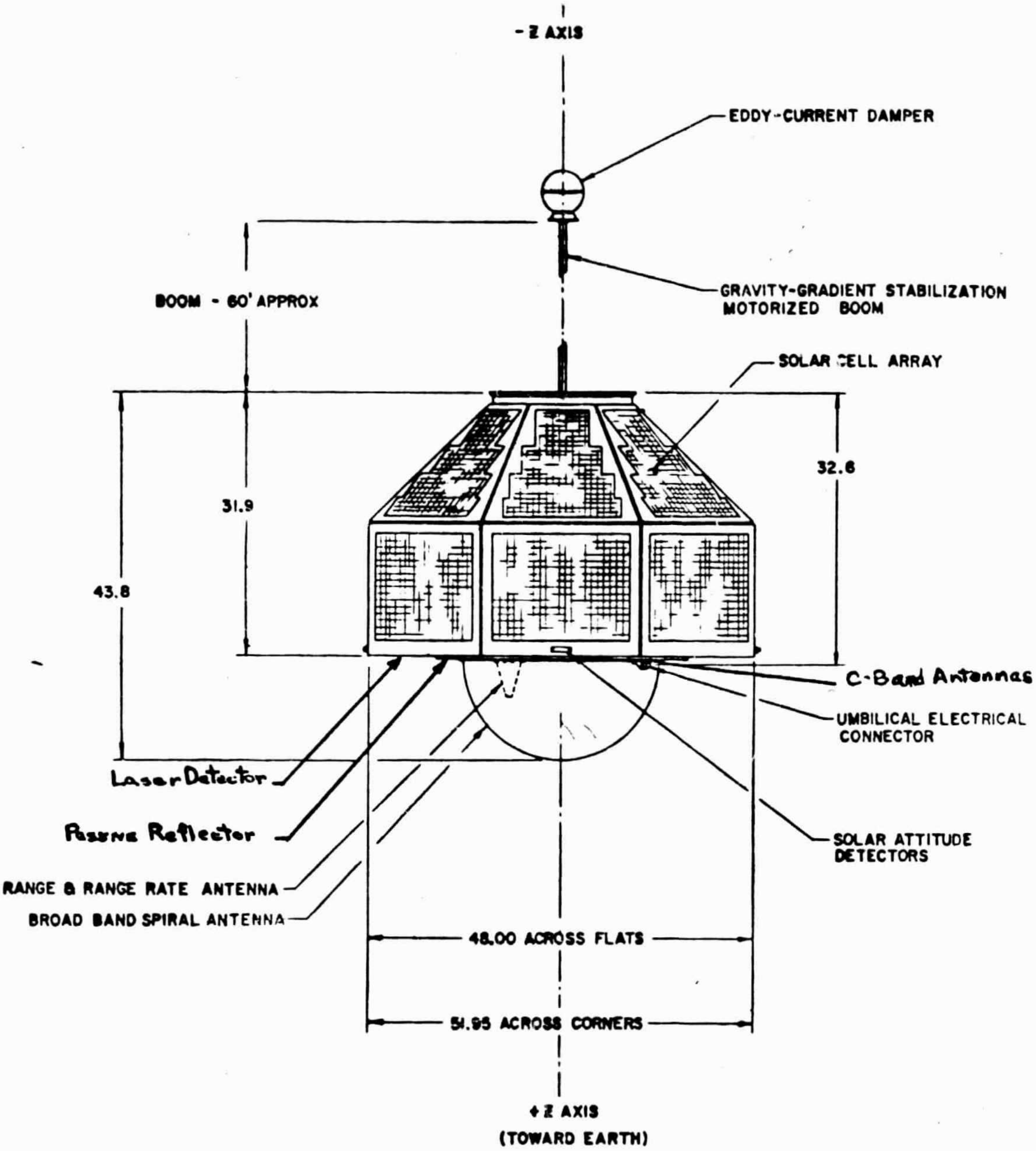

Figure 1. GEOS-B Configuration

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GEOS-B LAUNCH WINDOW CONSIDERATIONS

Forrest H. Stieg
Member, Aerospace Sciences Division
Communications & Systems, Incorporated
Falls Church, Virginia

GEOS PROGRAM REVIEW MEETING
12-14 December 1967

NASA Headquarters
400 Maryland Avenue, SW
Washington, D. C.

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INTRODUCTION

The purpose of this paper is to present analyses leading up to the selection of a time for launching the GEOS-B satellite on or about the 17th day of January 1968.

The GEOS-B will be launched from the Western Test Range (WTR) atop a Thrust Augmented Delta (TAD) with an FW-4 upper stage. The launch azimuth will be 201 degrees. The final orbit will have an apogee of 850 n. mi., a perigee of 594 n. mi. and an inclination of 106 degrees (74 degrees retrograde).

The GEOS-B satellite is equipped with several electronic geodetic instruments, i.e., Doppler, Range and Range Rate, SECOR and C-Band systems. In addition, the spacecraft has both an active and passive optical system, i.e., flashing lamps and laser retroreflectors respectively. The operation of only the optical systems is sensitive to the launch window selection.

OBSERVATIONAL REQUIREMENTS

Before a specific ground station can photograph a flashing lamp sequence, the camera must be in the earth's shadow and the satellite must be visible from the camera's location. A laser observation requires the same conditions to exist, however, it is also necessary that the satellite be simultaneously exposed to the sunlight. The reflected sunlight is used to optically acquire the satellite, thus enabling precise pointing of the narrow laser beam. Figure 1 is an illustration of these requirements.

Cameras for photographing the flashing lamps are located between the 65 degree northern and 50 degree southern latitudes. However, laser sites are located primarily in the northern hemisphere between the 20th and 40th degree latitudes. Certain principal investigators have requested simultaneous flashing lamp and laser observations in the mid-northern latitudes early in the spacecraft's life. This is required to enable spacecraft qualification and checkout. There is also a preference that the satellite not be placed into an intial 100% sunlit orbit. This is a spacecraft thermal consideration.

SIGNIFICANCE OF LAUNCH WINDOW

The slow nodal regression of the GEOS-B retrograde orbit will cause some portions of the earth to have good satellite visibility for long periods of time and conversely other portions will have poor visibility for long periods. Hence, the selection of the proper launch window is of prime importance to provide optimum coverage for the observation networks. The GEOS-B retrograde orbit has a nodal regression rate of about 1.43 degrees per day in the same direction as the earth's rotation about the sun. Thus the relative rotation of the orbit plane with respect to the sun line is only about 0.43 degrees per day. The initial placement of the orbit plane with respect to the sun is determined by the time of day of the launch. Depending upon these initial conditions, certain portions of the earth will be unable to view the orbital plane under the required sunlight conditions. As long as these conditions prevail no observations will be feasible from these locations. Not until the combined effects of the plane's nodal regression and the seasonal change in the sun's direction will these initial conditions change. Such a change of status may take several months. Consequently, the selection of the launch window will have a profound effect upon the mission effectiveness of the GEOS-B satellite.

For example, a launch at approximately 1400 hours GMT (0600 hours WTR) will initially place the orbit's line of nodes normal to the sun's direction with the top of the plane tilted towards the sun. Figure 2 is an illustration of this point. For a launch at 0200 hours GMT (1800 hours WTR), the orbit's initial placement would be rotated 180 degrees from the previous example (see Figure 3). Launches at noon or at midnight would initially place the plane almost parallel to the sunlight. From the illustrations it can be noted that the time of launch determines the initial orbit's location in reference to the sun line. Furthermore, as time progresses, the orbit plane will rotate and the sun's declination will vary seasonally. The orbit plane and sun line relationship determine the flashing lamp and laser observation schedules. Observers which are in the required sun's shadow and can simultaneously see the satellite under the above described conditions will be able to obtain geodetic data from GEOS-B. This is illustrated in Figures 2 and 3.

METHODS OF ANALYSIS

A computer program has been prepared to simulate the approximate conditions which will exist. The program was initiated by first determining the sun's vector and the location of the orbit's ascending node. This is determined from the day of the year and the time of day at which the launch occurs. Once these are established, the satellite and ground site are progressively incremented through one complete day. At each interval a test was made to determine first, if the station has the required sun declination, second, if the satellite is in view of the station and third, if the satellite is exposed to the sun light. Tallies were made of the total amount of time that acceptable flashing lamp and laser observations exist. At completion of the day these totals were printed out and the program was advanced ahead a given number of days in the year. New sun and ascending node vectors were computed and the above process repeated. This was continued until the desired time interval had been analyzed.

ASSUMPTIONS AND LIMITATIONS

A complete analysis of all the possible times of launch and station location combinations requires a great many computer runs. Consequently, it was essential that a rapidly running program be developed. A decision was made to sacrifice some accuracy for program speed.

A 700 n. mi. circular orbit has been assumed in this analysis. For an elliptical orbit, such as planned for GEOS-B, stations located beneath the orbit's apogee would have the benefit of a slower moving satellite and a larger observation arc.

Both factors result in an increase in pass time. The opposite effect prevails beneath the perigee. This variation would first favor one hemisphere, then the other as the line of apsides rotates with time (1.6 degrees per day for the GEOS-B orbit). The analysis in this report will not consider this point, however, the GEOS-B orbital eccentricity is only .0306 and the resulting error will be minimal.

The data presented within this report have analyzed only one station per latitude. Two or more stations with different longitudes at the same latitude could experience slightly different accumulative observation times in the same day, however, their average over a several day period would tend to be the same. This variation will not be evident due to the single station assumption.

The majority of the computer runs have utilized a two minute daily computation interval and two weeks between the days analyzed. Shorter intervals could have been used to obtain better accuracy at the expense of increased computer time.

In summary, the flashing lamp and laser observation times per day, presented in this report, are not definitive. The intent of the analysis is to present comparative values, observational trends and general effects of various launch windows.

ANALYSES RESULTS

A series of computer runs were made to analyze the 17

January 1968 launch day. One year observation schedules were computed for northern latitudes of 65°, 40° and 15°, and for southern latitudes of 10°, 30° and 50°. The average flashing lamp coverage for the complete year was computed and is plotted in Figure 4 for each latitude. A similar plot for the laser coverage is contained in Figure 5. These figures contain several points of interest. These are:

a) The launch window selection has a marked effect upon the lamp and laser coverage, particularly at higher latitudes.

b) No launch window exists which will provide optimal northern and southern hemisphere coverage simultaneously.

c) Two launch windows, 0200 and 1700 hours GMT, provide the best coverage, as defined above.

These figures provide some insight into the selection of a window, however, do not provide all the information necessary. The distribution of coverage during the year is of particular interest. The best coverage is desired early in the year for reliability purposes. Figures 6 and 7 are plots of the average flashing lamp and laser coverage for the first half year after launch. Greater variations now exist and there is some shifting of the curves, however, the launch windows of 0200 and 1700 hours GMT still appear to be the best available.

Figures 8 and 9 are plots of the coverage as a function of time after the launch for 0200 and 1700 hours GMT respectively. Both windows provide good initial coverage for both the active and passive optical system around the 40° northern latitude. The 0200 hours GMT window provides slightly better first half year flashing lamp coverage in the northern hemisphere, however, the reverse is true for the southern hemisphere, where coverage is zero for the first ten weeks after launch. The 0200 hours window provides better laser coverage initially, however, drops steadily as the year progresses. The 1700 hours window provides only fair laser coverage during the majority of the year then is very good during the last quarter.

A modified version of the program was run to examine the percent sunlight conditions for these two windows. Figure 10 is a plot of these. The 0200 hours window will not place the satellite into an orbit which is initially exposed to 100% sunlight. However, the combined effects of nodal regression and sun vector variation will cause this condition to exist in a couple of weeks, after which, 100% sunlight will prevail for two or three months. The 1700 hours window will place the satellite into a 100% sunlit orbit initially. However, this condition will exist only a short time (a week or two).

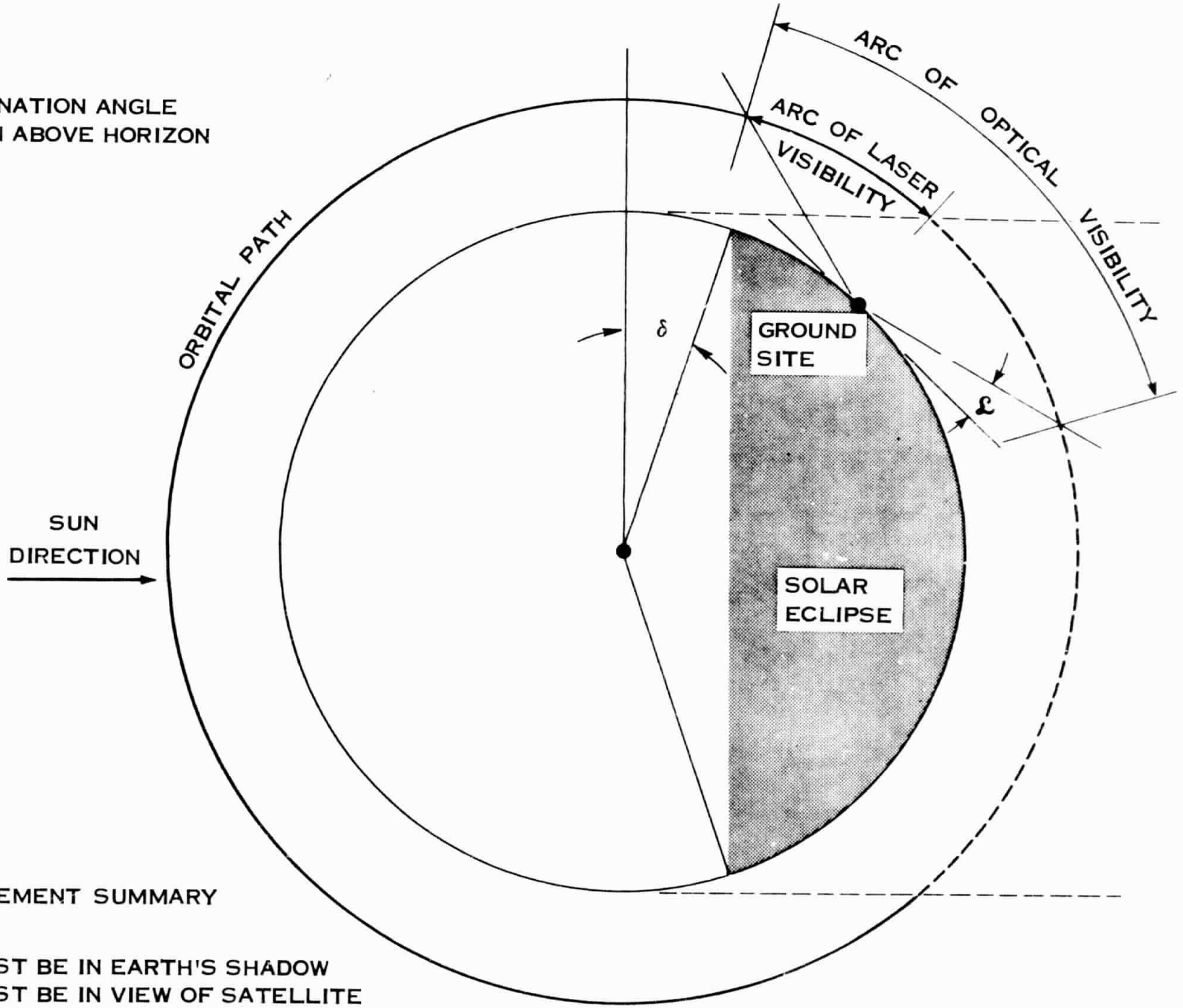
CONCLUSIONS

The optical systems are very sensitive to the time of day at which the GEOS-B satellite is placed into orbit. There is no launch time which will simultaneously meet all the mission requirements. The two windows which provide the best coverage are 0200 hours and 1700 hours GMT. Each window has certain advantages as well as some disadvantages. The selection of one over the other should be based upon the final status of the observer networks.

The windows are reasonably insensitive to a slight change in the launch day, however, for a variation of more than one week, additional analyses should be conducted. The launch window should open approximately fifteen minutes before the selected time and remain open about thirty to forty-five minutes.

Caution should be taken in the use of these data. As indicated earlier there are several assumptions used to speed calculations. Furthermore, variation in the flight trajectory and/or final orbit will also cause some modifications in the results. The data, as presented, are intended to provide the trend in coverage and sunlight conditions but not quantitative results.

NOTES:
δ — SUN DECLINATION ANGLE
ℒ — ELEVATION ABOVE HORIZON



REQUIREMENT SUMMARY

FLASHING LAMP
1) OBSERVER MUST BE IN EARTH'S SHADOW
2) OBSERVER MUST BE IN VIEW OF SATELLITE

LASER
1) OBSERVER MUST BE IN EARTH'S SHADOW
2) OBSERVER MUST BE IN VIEW OF SATELLITE
3) SATELLITE MUST BE EXPOSED TO SUNLIGHT

Figure 1. REQUIREMENTS FOR OPTICAL AND LASER COVERAGE

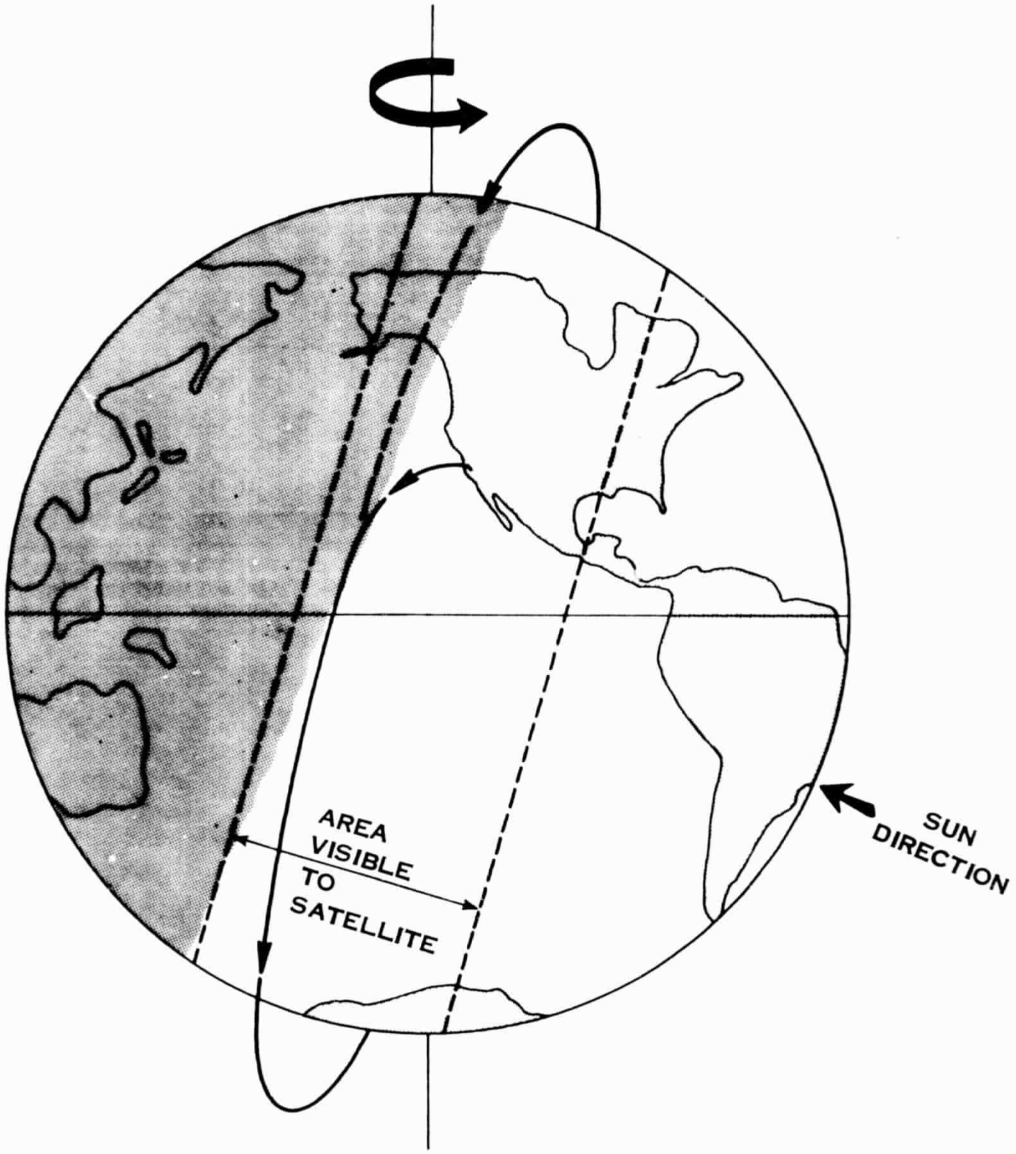


Figure 2. Initial Conditions for 1400 Hrs UT Launch 17 Jan 68

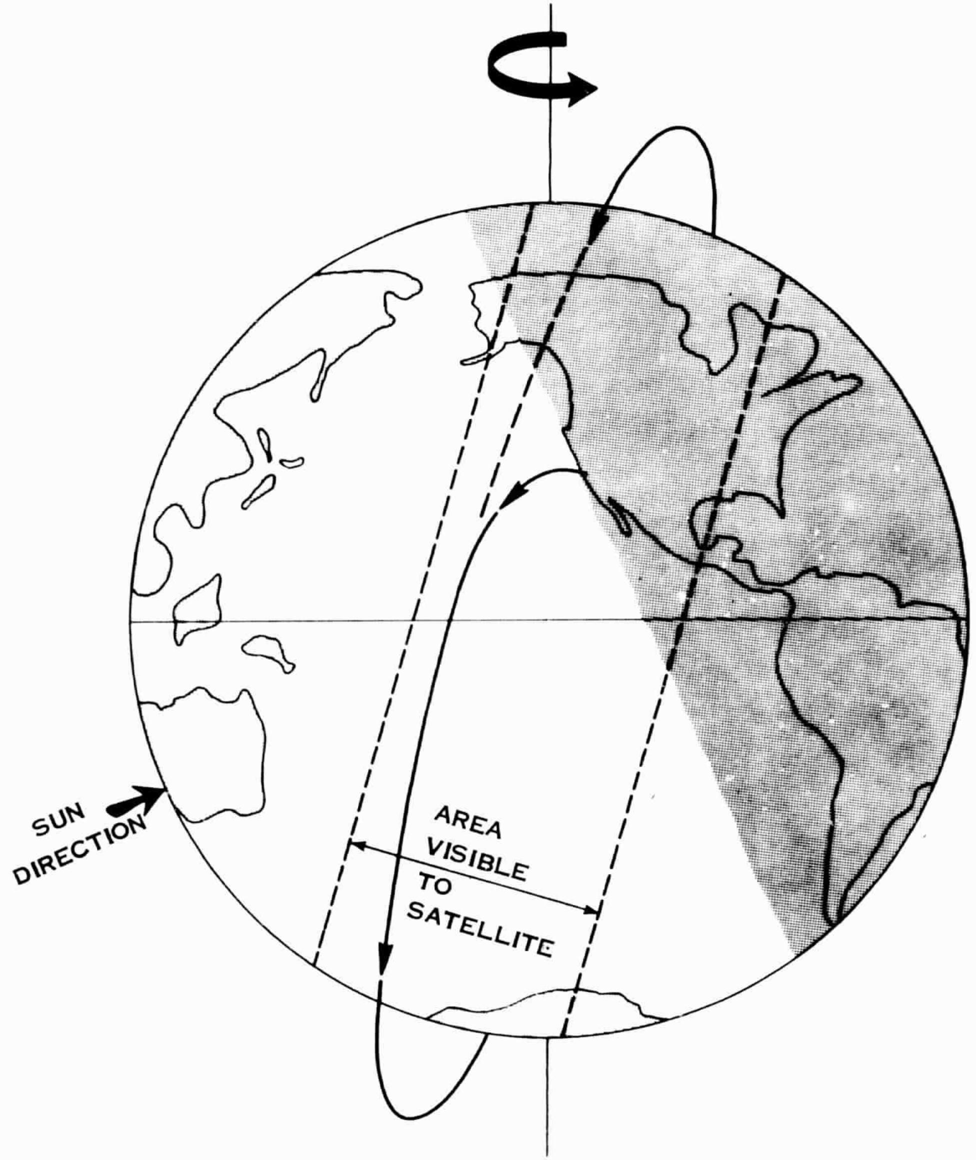


Figure 3. Initial Conditions for 0200 Hrs UT Launch 17 Jan 68

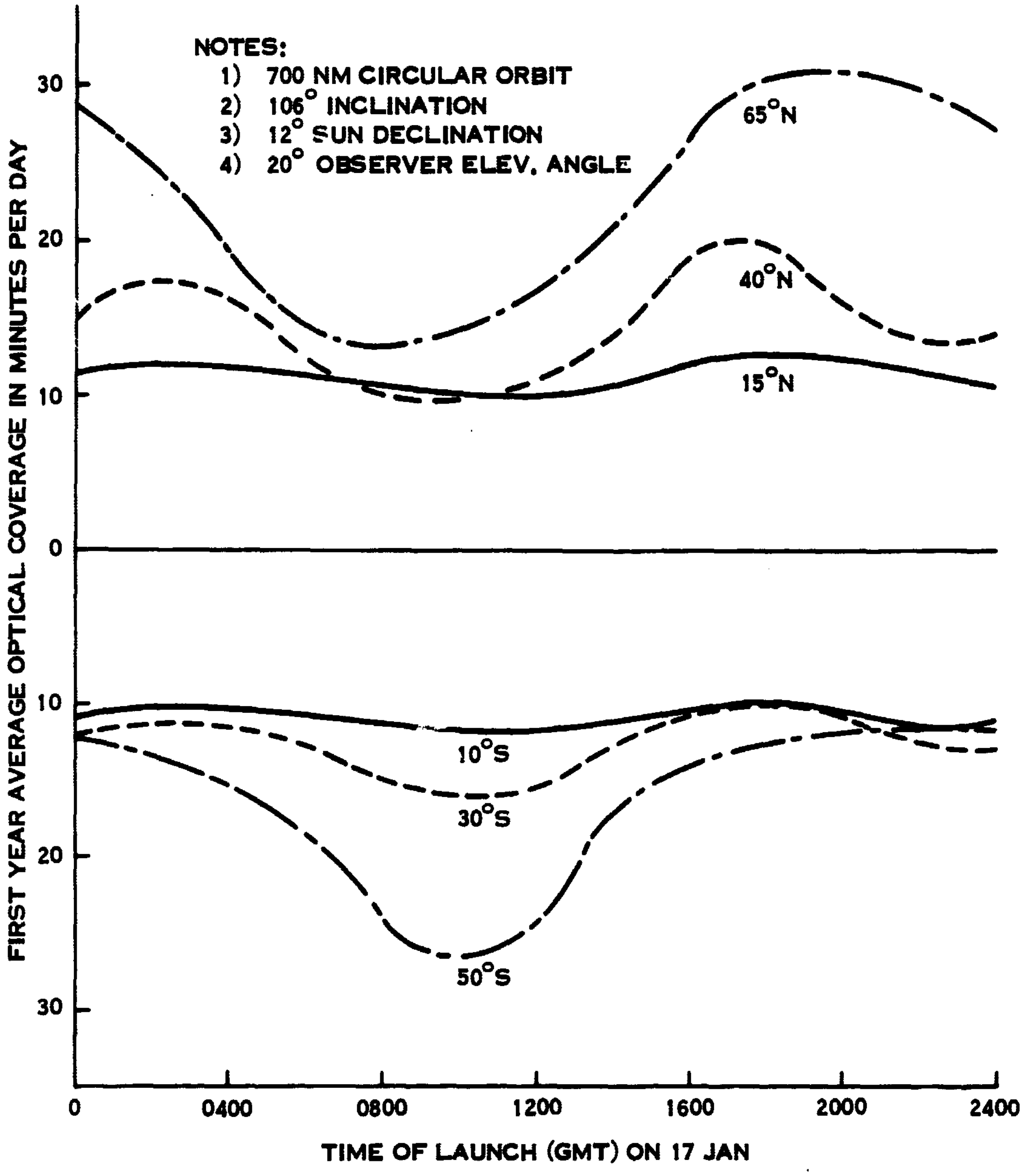


Figure 4. FIRST YEAR AVERAGE OPTICAL COVERAGE

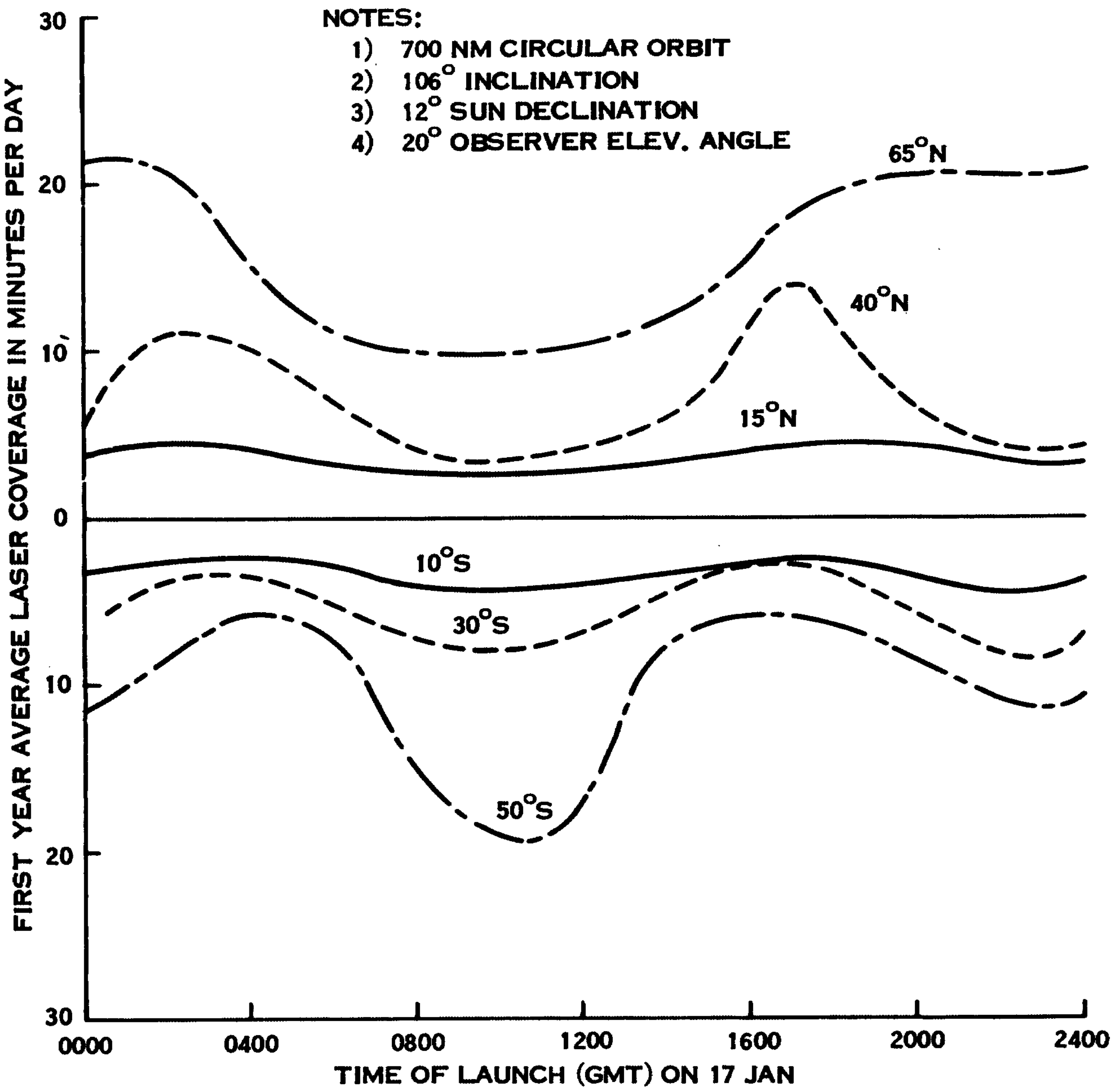


Figure 5. FIRST YEAR AVERAGE LASER COVERAGE

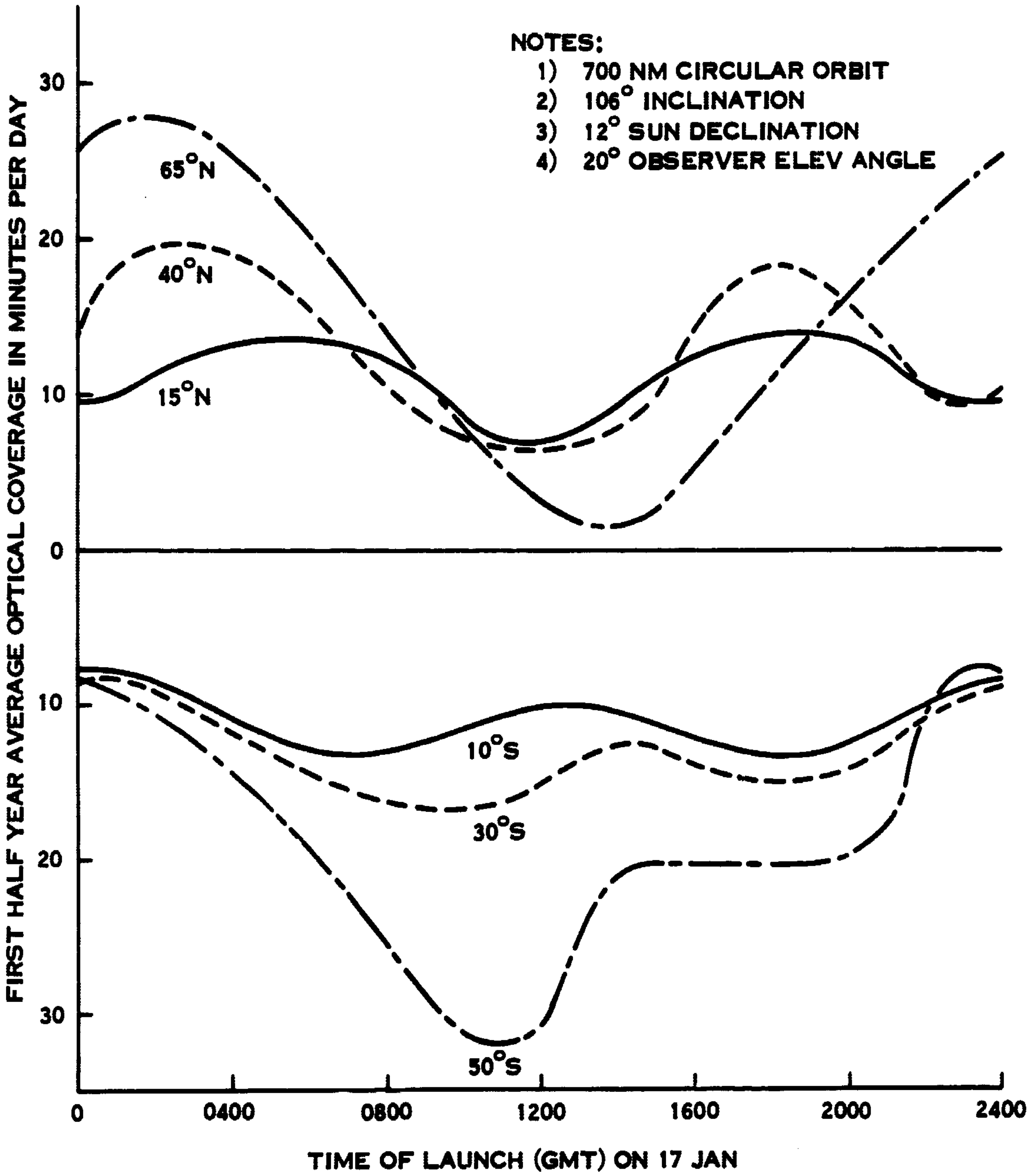


Figure 6. FIRST HALF YEAR AVERAGE OPTICAL COVERAGE

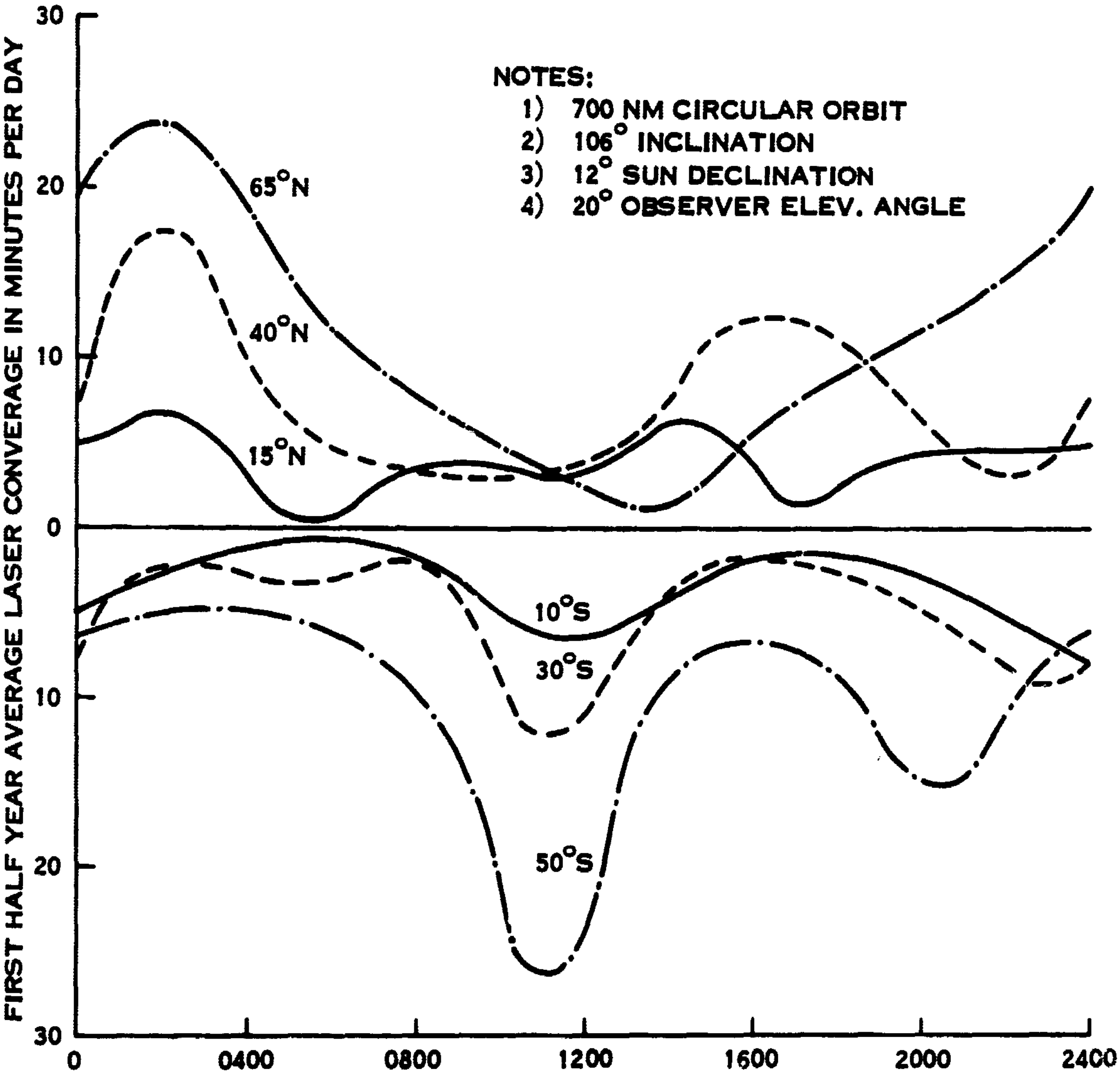


Figure 7. FIRST HALF YEAR AVERAGE LASER COVERAGE

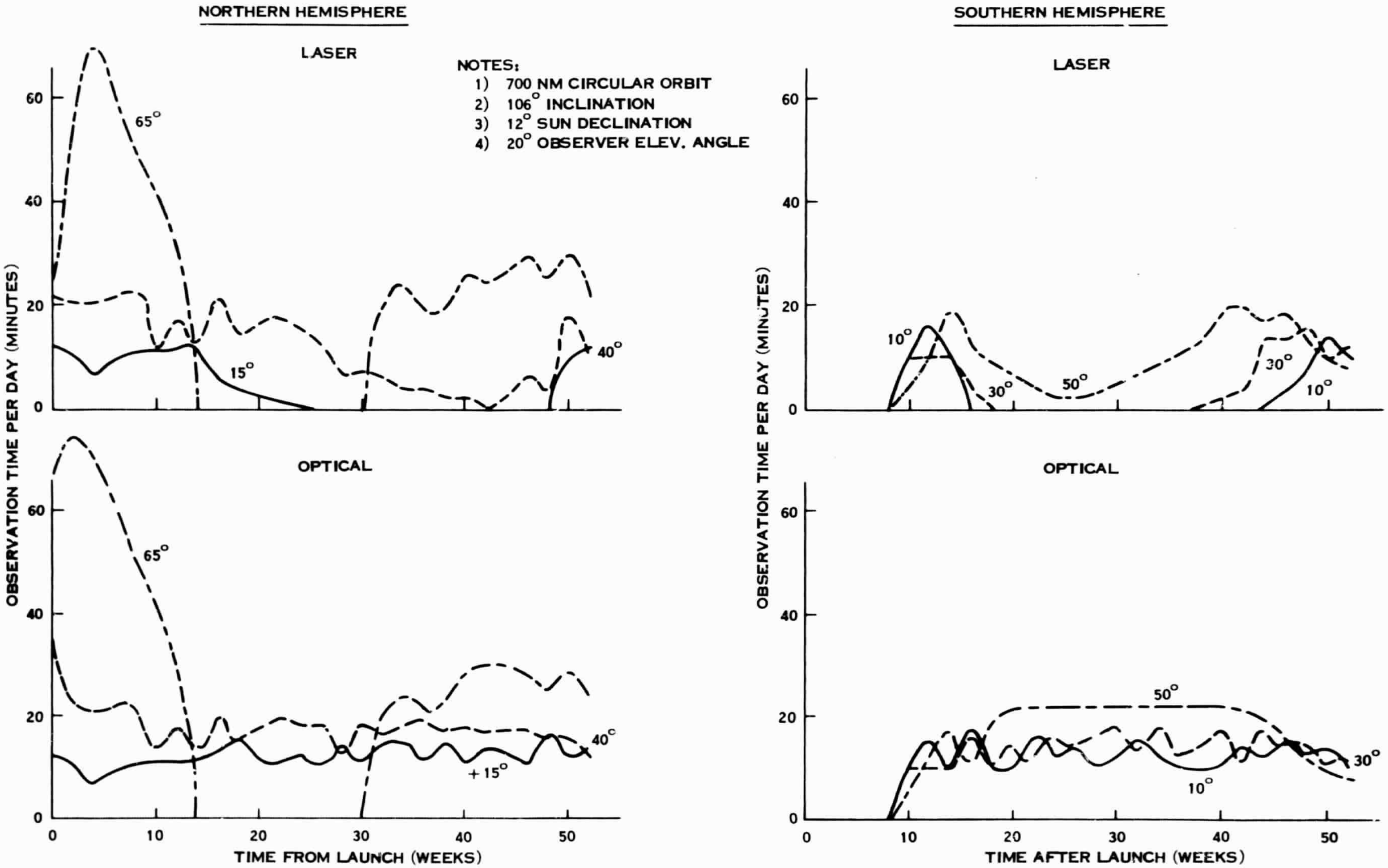


Figure 8. LASER AND OPTICAL COVERAGE VS OBSERVATION LATITUDE AND TIME FOR 0200 HRS ZULU 17 JAN LAUNCH

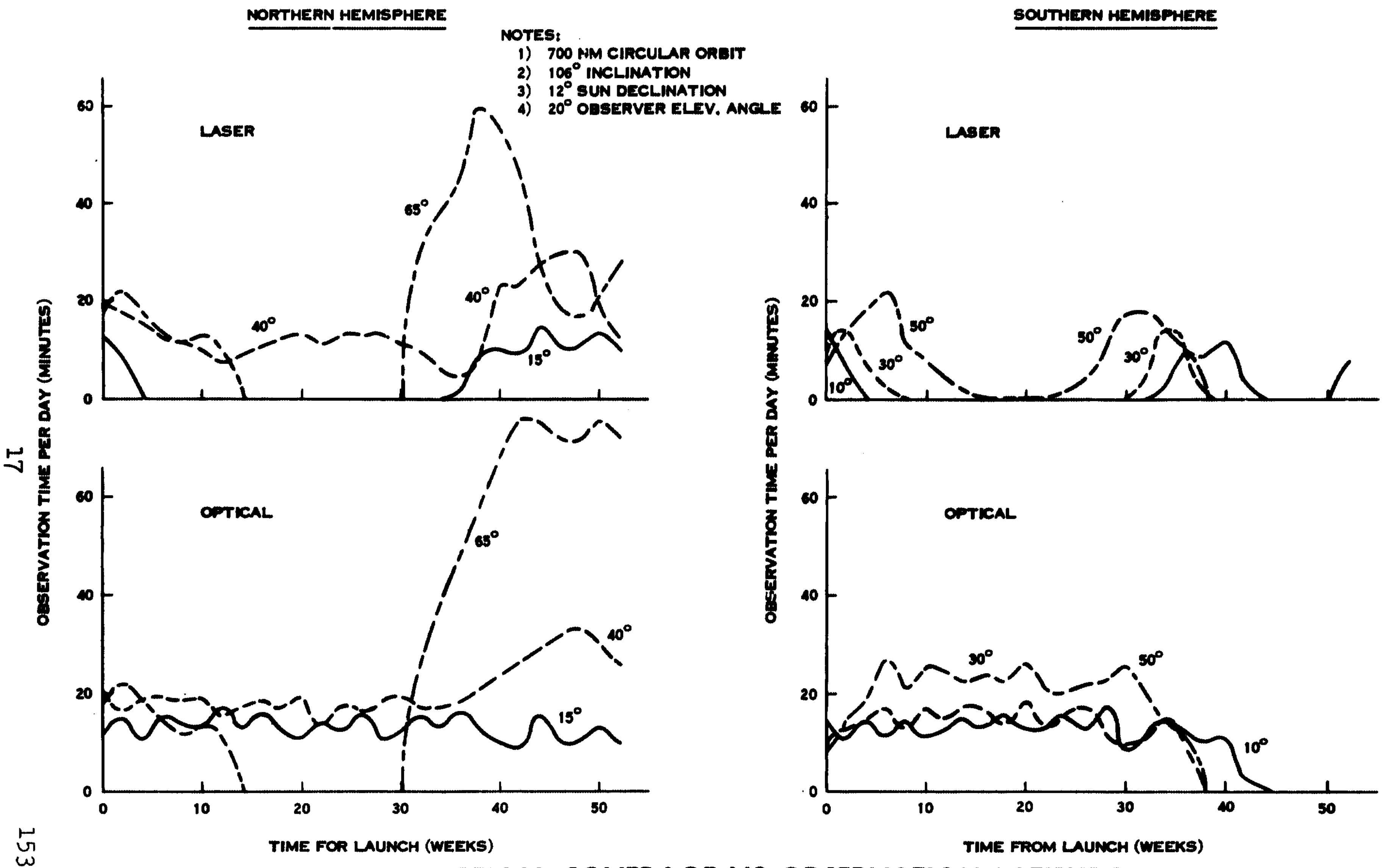


Figure 9. LASER AND OPTICAL COVERAGE VS OBSERVATION LATITUDE AND TIME FOR A 1700 HRS ZULU 17 JAN LAUNCH

NOTES:
1) 700 NM CIRCULAR ORBIT
2) 106° INCLINATION

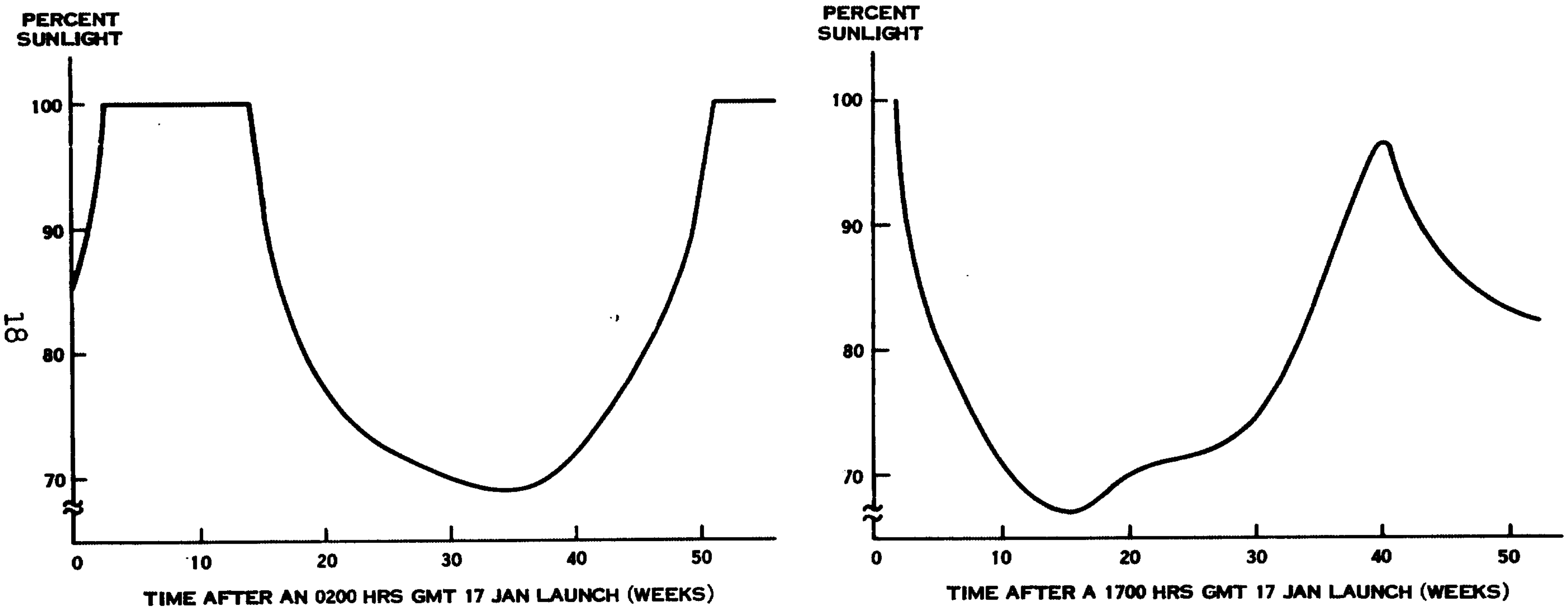


Figure 10. SUNLIGHT CONDITIONS

DOCUMENTATION OF GEODETIC/TRACKING STATION LOCATIONS

Bernard Claveloux

Geonautics, Incorporated

Prepared For

GEOS PROGRAM REVIEW MEETING
12-14 December 1967

NASA HEADQUARTERS
400 Maryland Avenue, SW
Washington, D. C.

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DOCUMENTATION OF GEODETIC/TRACKING STATION LOCATIONS

In order to meet the geometric objectives of NGSP it is necessary that all observation stations, including optical and electronic tracking systems, be positioned on their national datum within a minimum accuracy of one meter. In terms of geodetic survey specifications this should be interpreted as the maximum allowable error in horizontal and vertical position for connecting the observation station to the primary geodetic network. The one-meter specification is, of course, somewhat arbitrary. Actual requirements would vary from site to site, depending upon distance from existing control, quality of primary control, etc. One meter allowable error should meet the requirements at any individual site, and should not be difficult to meet if existing geodetic control stations are considered when selecting the location of observation stations.

All participants in NGSP have agreed to provide detailed information on the location of their tracking stations to the NASA Program Manager so that geodetic surveys at each observation site can be documented and disseminated to interested investigators. The information required for proper documentation of geodetic surveys includes the following ten items:

1) Geodetic latitude and longitude of the observing equipment on the national datum or a preferred major datum, specifying horizontal datum used.

2) Elevation above sea level, specifying vertical datum used.

3) Geodetic azimuths to adjacent geodetic control stations.

4) Definition of precise points on the equipment to which geodetic position, azimuth, and elevation apply. This should be the exact point of reference for the observations.

5) Astronomic latitude, longitude and azimuth, or other information useful in determining deflection of the vertical.

6) Geoidal height, based on astro-geodetic data, if available, listing source from which obtained.

7) A brief description of survey procedures used in connecting position of the observing equipment to existing horizontal and vertical control networks, including instrumentation, observation methods, and survey sketches showing geodetic control stations and monumentation. This should include a definition of the geodetic control stations to which the local survey was connected.

8) Positions and descriptions of survey monuments at the facility.

9) Discussion of results obtained from these surveystoegher with estimates of accuracy.

10) Name of organization which made the surveys, with date of surveys and location of survey records.

Data sheets for recording these items were sent to all participants, and these or similar forms are being used. It is evident that unless these data are made available, the reliability of station coordinates on their local datums will remain in question, which is indeed the case for some tracking facilities which have been in use for a number of years. The importance of adequate, correctly identified monumentation (to aid in future recovery and possible re-use) and of precise relative orientation between monumentation and tracking instruments (particularly where more than one tracking instrument is involved) cannot be over-emphasized.

Geonautics is assisting NASA in collecting the information mentioned above, and will compile geodetic data sheets received from various participants into a directory which will be published by NASA by the middle of 1968. This directory will be similar to the GoddardDirectory of Tracking Station Locations which was published in 1964 (revised 1966). At present we have received detailed survey data for some 75 stations participating in the program. These include all existing NASA stations, many of the optical and electronic stations used by other U.S. agencies, and some camera stations used by international participants.

It is of interest to comment briefly on some of the errors which have impaired the values of tracking station positions in the past. These errors need to be noted since they could have been avoided if proper documentation of geodetic survey data had been available. They include the following:

1) Failure to identify the point described. This usually occurs when the position of a nearby survey monument has been used instead of the position of the tracking equipment. This is especially true of elevation. Errors up to 60 meters have been attributable to this source, and errors of a few meters are common.

2) Failure to specify clearly the geodetic datum on which the position is given. Use of the spheroid name (as "Bessel") instead of the datum can permit false assumptions with errors up to 300 meters. The date of adjustment of the datum must also be specified, since successive adjustments of many datums can make significant changes in published positions. For stations in Europe the preferred datum in the European 1950 Datum. For points lying outside an adjusted datum (like islands) the date and method of the tie to the mainland must be specified. Several errors of about 30 meters have been attributed to neglect of this clarification.

3) Failure to give the type and date of the local survey. Often more than one position has been listed for the same station as a result of progressively better resurveys. If the source of this information is not available, the data are unreliable. The survey should be described, or the agency by which it was made should be given. Evidence of reliability is necessary if the information is to be used; and this requires documentation of when, how, and by whom the survey was made. The name and quality of the stations on which the survey was based should be included. In some cases it may be necessary to give the coordinates of the control stations used, since differing values for the same geodetic monuments are sometimes published.

4) Failure to give elevation references. As mentioned earlier the difference of elevation between the point of observation and the survey monument is frequently not noted.

By providing uniform documentation of the items of information previously mentioned for each NGSP observing station, we will be able to avoid these types of errors and provide reliable positional data for NGSP investigators.

Plan for Wallops Station C-Band Radar Participation Using GEOS-B

by

H. Ray Stanley
GEOS-B C-Band Project Manager
NASA Wallops Station
Wallops Island, Virginia

and

N. A. Roy
S. J. Moss
Applied Sciences Department
Wolf Research and Development Corporation
College Park, Maryland

Presented at GEOS Program Review Meeting
NASA Headquarters, Washington, D.C.
December 15, 1967

1.0 INTRODUCTION

The decision to evaluate the potential of the C-Band radar systems as tracking tools capable of performing first-order satellite geodesy poses some challenging problems to the tracking scientist. The C-Band beacon and passive array aboard GEOS-B afford us the opportunity to evaluate our calibration procedures while obtaining meaningful geodetic information.

The primary objectives of the C-Band systems project are:

A. To provide geodetic scale for the interim NASA unified network.

B. To better determine the accuracy of radar systems, develop refined methods for calibrating these systems, and improve the techniques employed in processing their data.

C. To better determine the geodetic location of the C-Band radar sites and their intersite distances

D. To compare C-Band results with those obtained from other GEOS-B systems.

E. To make available to qualified users the results of both the C-Band system calibration and geodetic investigations.

Arrangements have been made to include a significant number of the eighty-five American made C-Band radar systems. The agencies presently planning to participate in this effort are:

1. U.S.A.F. Eastern Test Range
2. U.S.A.F. Western Test Range
3. U.S.A.F. Flight Test Center
4. The Pacific Missile Range
5. White Sands Missile Range
6. The GSFC Manned Space Flight Network
7. The NASA Flight Research Center
8. NASA Wallops Station

Initially, each of these agencies will evaluate their own data for the purposes of calibration and standardization of procedure. At an appropriate time, procedures will be compared and evaluated and a standard C-Band calibration method defined.

The Wallops Island Station has developed a plan and a set of objectives which we believe will allow us to contribute to the successful accomplishment of the overall project goals. This plan emphasizes the self-calibration of the C-Band system since we believe that this is a prerequisite to the geodetic investigations. We believe that an efficient and effective calibration procedure can be developed through analysis of both the C-Band hardware and software systems taking into consideration the geodetic objectives of the project. Once we are satisfied that our system is <u>consistently</u> delivering quality data, we can begin to satisfy the geodetic requirements such as station positioning, intersite distance measurements etc. I would like to emphasize that when we speak of system in this context we mean both the instrumentation and the methods used to reduce the data.

2.0 WALLOPS STATION PLAN

A prerequisite to any successful calibration, evaluation and data reduction effort is the establishment of sound standard operating procedures in pre- and post-flight calibration techniques and data taking operation of the instruments. Wallops Station is presently critically evaluating existing procedures in an effort to establish effective standards for GEOS-B operations. We anticipate changes in these procedures as our calibration effort progresses; however, our intention is to incorporate any changes in a carefully controlled fashion.

A concurrent effort is a detailed hardware analysis of the Wallops AN/FPQ-6 system, including the on-board transponder. This study will help us to postulate an error model for the AN/FPQ-6 system, including the pulsed doppler system which has recently been added. Included in this is a review of the current Wallops AN/FPQ-6 calibration procedures to determine whether the present pre-mission procedures are suitable or even necessary in the geodetic effort. By this we mean that certain pre-mission calibration procedures may be obviated by the availability of a calibration source such as GEOS-B.

During the course of the hardware analysis, information will be generated which will allow us to modify, verify, and expand, if necessary, the error models currently available in our data reduction programs.

When we have postulated a set of comprehensive error models we will then perform a series of error analyses to validate these models. We start with the assumption that the calibration can be accomplished by the estimation of coefficients of error models which describe the systematic errors in the measurement data. Initially, we will use our computer programs in the orbital GDOP mode, to investigate the recoverability of the various error model coefficients under varying geometries. Basically, these analyses will tell us which error model coefficients can be recovered and the degree of accuracy with which we can recover them. These analyses will be performed using simulated data for single and multiple station configurations and a variety of passes ranging from zenith to low elevation, side-looking passes. As GEOS-B data becomes available, our effort will turn to actual evaluation of our models.

During the course of the above efforts similar analyses will also be performed to evaluate the contribution of C-Band data used in conjunction with data from the other GEOS-B instrumentation systems. We plan to evaluate the use of co-located instrumentation sites compared with existing network locations where the various sites provide a wide geographic distribution.

We realize that the mathematical error models developed cannot reflect all of the systematic errors affecting the system. The sensitivity of the system performance to uncorrectable and/or unrecoverable error model parameters (such as refraction errors, geopotential coefficient uncertainties etc.) must be known in order to ascertain the validity of the variance estimates from the data reduction and to point out the most important directions for improving system accuracy.

In order to estimate the effects of those systematic errors which may be present, typical satellite passes will be used to compute the systematic error effects on reduced data. We will simulate the effects of unit errors in the more important error model parameters on radar measurement residuals. This will thus provide us with a set of curves demonstrating the patterns which systematic errors will exhibit in actual data reduction. Associated with the curves showing residual effects, will be tables showing effects on recovered parameters. This study will also show what combinations of satellite passes and instrumentation coverage will provide the most accurate determination of instrumentation error model parameters, station locations, and geopotential coefficients. This will also help us in the scheduling of the satellite.

Another phase of our planned effort is the development and documentation of a "pre-processing" system. We will perform a series of studies to determine the most accurate and efficient methods to edit, smooth, filter and otherwise process the raw data as obtained by the tracker prior to the data reduction or its submission to the National Space Sciences Data Center. As you are well aware, if we were to submit or use data at the maximum sampling rate of the AN/FPQ-6 two immediate problems would arise. The first would be simply the mass of data to be handled by the data center and other users. They would soon be inundated in raw data. In addition the data is likely to be inherently corrupted by the serial correlation which occurs at such high sampling rates. Since geodesists are interested in using data which is not highly correlated, we believe that it is our responsibility to provide them with data which most closely meets these requirements. However, care in smoothing and filtering will be taken to avoid the loss of significant information contained in the data.

We intend to perform serial correlation studies on the raw data, standardize our editing procedures, implement a standard smoothing technique, and provide a standard data format for input into our data reduction programs.

In addition, we will evaluate our data correction procedures to insure that they are adequate for the geodetic effort. By correction procedures, I mean those corrections which we can apply to the data before we submit it to the data center or use it ourselves in the data reduction process. These corrections include atmospheric refraction corrections to the range, range rate and elevation data; ionospheric retardation; and timing corrections to reduce the data to a Universal Time (UT) system at the satellite.

To develop an optimal smoothing or filtering technique for the received signals, we plan to analyze the frequency content of the noise on the signals. This can be done by using the techniques of spectral analysis.

For an optimal filter, the noise on the output signal should have the characteristics of white noise (i.e., have a constant spectral density over the range of frequencies that can be measured). To establish the characteristics of the noise on the output signal for various filters, it is necessary to estimate the spectral density function of the noise on the input signal. When this function has been estimated, various frequency response functions can be tried to determine which filter has the most desirable characteristics.

Some special analysis techniques will have to be developed since the measurements will not be at equal time intervals. There may also be problems with the time series not being stationary over a complete pass. The series may only be stationary within a particular range of elevations for instance.

When all of these studies have been completed, the results will be documented and a "pre-processing report" prepared giving the details concerning all phases of the data pre-processing performed by Wallops. This report will contain information concerning:

The nature of the measurements made

The nature of the system and its hardware calibration

The source and best estimate of magnitude and statistical properties of the errors in the data

The processing procedures used on the raw data with regard to:

1. Editing
2. Filtering and Smoothing
3. Corrections
4. Models used in data reduction

During the course of the investigations just outlined, we will be performing reductions of live data and we feel that we will be able to furnish the geodetic community with meaningful geodetic information. We plan to improve the position of the Wallops and Bermuda FPQ-6 radars relative to the Earth's center of mass during the course of our calibration investigations. In the initial phases, we will probably concentrate on short-arc one and two station pass configurations, and then increase both the length of the arcs and the number of stations used in the reductions. Our intention is to emphasize the calibration effort initially and, as the results of this effort increase our confidence in the geodetic capabilities of the system, to gradually shift the emphasis to geodetic investigations. As we stated previously, when we are satisfied that our system can consistently deliver data of geodetic quality and we are satisfied that our calibration procedures are correct, we can then place full emphasis on the geodetic investigations outlined in the C-Band systems project plan.

These studies are presently underway at Wallops Station. The availability of orbital tracking data from the FPQ-6 is presently quite limited; however, I would like to give you a brief look at some results we have obtained from skin tracking of ECHO-II. We have computed short arc single station orbits from the Wallops Station FPQ-6. The residuals from the short arcs show runs fits of:

Range	∿	5 m
Azimuth	∿	40 arc-seconds
Elevation	∿	30 arc-seconds

These residuals were subjected to a test for non-randomness and found to be not significantly non-random at the 99% confidence level. These data, taken on a relatively poor radar target, are very promising. We are, however, fully aware of the shortcomings of short arc data reduction i.e., we know that many of the most common systematic errors are masked in such solutions. Except for serial correlations, constant bias,rate and time biases are generally absorbed; it is our experience that fairly accurate noise estimates can be determined from such studies and so what we have found so far, we find very encouraging.

This describes, in capsule form, the investigations we plan to undertake and what we have done in support of the C-Band project. I would now like to briefly discuss the computational tools we plan to use to perform these investigations.

We have two data reduction programs currently operational at Wallops on our GE-625 computer. They are the Simultaneous Least Squares Adjustment of Parameters program (SLAP) and the Recursive Estimation Technique for Instrumentation Calibration program (RETFINC).

The SLAP program is a batch process, Bayesian Least Squares program written in FORTRAN IV with program linkage suitable for use in a 32^K memory machine. The program consists essentially of two parts. The first is an orbit generator that uses a Cowell special perturbation technique to generate a nominal ephemeris. The force model has provisions to account for the geopotential perturbations due to the zonal harmonics J_2 through J_5 and atmospheric drag using the ARDC standard atmosphere. The second part of the program is the estimator portion that uses the minimum variance technique to estimate position and velocity of the satellite, compute the observational residuals, evaluate the numerical partial derivatives and yield improved estimates of geodetic survey and error model parameters. The program will accept the following observational data:

- Range
- Range Rate
- Azimuth and Elevation
- Direction Cosines
- Rates of all of the above

In its present form on the GE-625 computer, the program can combine up to 40 different measurements at any one time and simultaneously solve for a total of 50 tracker error model and survey parameters in any combination. The program can be operated in a GDOP mode providing error analysis capability. The program also accepts a priori information on the orbital elements, error model parameters, and survey.

The RETFINC program is a recursive program written in FORTRAN IV with suitable linkage for use on a 32^K memory machine. This program also consists essentially of two parts. The first is the orbit generator routine which uses a variation of parameters technique to generate nominal ephemeris. The force model has provision for geopotential perturbations through 20, 20; lunar and solar gravitational effects, solar radiation pressure and drag using the U.S. Standard Atmosphere. This portion of the program also computes observational residuals and evaluates the analytic partial derivatives. The second portion of the program uses the formalism of Kalman to update the state vector. The Kalman technique allows one to see the improvement in the estimates of the parameters with each additional measurement.

The program accepts the following observational data:

- Range
- Range Rate
- Azimuth and Elevation
- Topocentric right ascension and declination
- Direction Cosines
- Frequency shift

The program will estimate the following parameters:

- Six orbital elements
- Station positions
- All coefficients of the geopotential up to 8, 8 or selected coefficients through 20, 20
- Error model coefficients

The program will accept up to five different orbital arcs simultaneously in the estimation procedure. In its current form on the GE-625 the program can estimate up to 115 parameters. Finally an editing program called (DAPPER) (data preprocessor and error recovery program) is presently being put on the GE-625.

DAPPER is a form of recursive, minimum variance estimator which is designed to provide efficient estimates of both true trajectory and total radar systematic errors from radar observations of an arbitrarily moving target. Since target motion dynamics are assumed to be completely unknown, accurate recovery of errors is predicated on the use of several radars tracking simultaneously and with favorable geometry. By utilizing relaxation methods for the solution of the normal equations, the trajectory is solved for directly, without resort to conventional linearization techniques. Solutions for radar systematic errors in function space (rather than parameter space) are obtained, thus permitting DAPPER to respond to an extremely wide class of errors, even those whose mathematical form may be unknown prior to data processing. Finally, DAPPER incorporates a form of adaptive measurement noise variance estimation, thus insuring that near-optimum data weighting can be obtained at all times.

3.0 CONCLUDING STATEMENT

In conclusion, we believe that the plan outlined here, while ambitious, can be accomplished to provide timely support to the C-Band systems project. We realize that many of the problems we encounter during this effort will not be resolved to our complete satisfaction, but we think that the overall endeavor will provide answers to many questions which have remained unresolved for too long.

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ANTICIPATED CONTRIBUTIONS OF GEOS-B TO INVESTIGATIONS AT THE SMITHSONIAN ASTROPHYSICAL OBSERVATORY

Charles A. Lundquist

Presented at the GEOS Program Review Meeting
NASA, Washington, D. C.
December 12-14, 1967

Smithsonian Institution
Astrophysical Observatory
Cambridge. Massachusetts 02138

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ANTICIPATED CONTRIBUTIONS OF GEOS-B TO INVESTIGATIONS AT THE SMITHSONIAN ASTROPHYSICAL OBSERVATORY[1]

Charles A. Lundquist

Smithsonian Astrophysical Observatory

The anticipated contributions of GEOS-B to geodetic and geophysical research must be viewed in the same broad framework discussed for GEOS-I (Lundquist, 1967). Again, the role of GEOS-B is incremental in that observations of it supplement a bulk of previous data and the augmented observations allow improvements of geodetic results.

Within the broad framework of the continuing program at the Smithsonian Astrophysical Observatory (SAO), four specific areas of activity and investigation deserve recognition for GEOS-B: (1) regional datum ties to a geocentric coordinate system, (2) scale refinement for the coordinate system, (3) secular and long-period dynamical effects on the orbit, and (4) improved knowledge of the tesseral harmonics in the geopotential.

REGIONAL DATUM TIES

The SAO Baker-Nunn sites and the tracking instruments of the other global networks provide tracking data sufficient to determine a geocentric coordinate system with well-defined axes. Regional or continental geodetic datums can be related to the geocentric coordinate system if coordinates of a statistically significant number of instrument sites covering the datum are also accurately determined in the geocentric system by satellite techniques.

As the operator of a major international network, SAO recognizes an obligation to participate actively in observing programs

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[1] This work was supported in part by grants NsG 87-60 and NSR 09-015-018 from the National Aeronautics and Space Administration.

to tie instrument sites and datums to the geocentric system defined by analyses of Baker-Nunn and other data. Substantial progress along this line was made with GEOS-I observations, and GEOS-B offers a valuable opportunity to continue this effort.

In the North American datum, a considerable number of stations have coordinates known to an accuracy approaching 10 meters. Thus, the principal promise from GEOS-B is improved accuracy rather than more sites.

The number of accurately located sites in the European datum is still small. The list of points for which some accurate data exist was lengthened through the use of GEOS-I (see, e.g., Lapuschka, 1967; Muller, 1967; Gaposchkin and Veis, 1967), but many of these await further refinement from GEOS-B data before their coordinates reach the desired 10-meter accuracy. Thus, cooperative procedures and arrangements established for GEOS-I will be continued and expanded during the life of GEOS-B. SAO now has in both Spain and Greece Baker-Nunn sites that can co-observe with other European instruments. Incidentially, since both of these sites are in southern Europe, they likewise can serve as tie points to instruments in northern Africa.

Argentina has specific plans to activate additional camera stations within its territory during the anticipated operational life of the GEOS-B flash system. The Baker-Nunn instrument in Comodoro Rivadavia and to some extent those in Natal and Arequipa will provide the link between the local Argentinian results and a global system.

India likewise has plans to activate a local network of small cameras within its territory. When this is accomplished, the SAO-associated stations will again provide a global link.

Still other local and regional plans are under consideration and discussion. For example, a cooperative activity may evolve among Japan, the USSR, and the USA in the northern Pacific.

SCALE REFINEMENT

Laser range measurements, particularly in connection with photographic direction observations, facilitate a determination of scale for a geocentric coordinate system. The results of this determination can be compared with those of other techniques for fixing the scale (Veis, 1967).

French, Greek, Spanish and USA facilities will be combined in a coordinated observing program, one consequence of which should be a scale determination. In France, French teams will operate a station with both camera and laser instrumentation. In Greece, a laser system assembled by the Technical University of Athens will be located at the Baker-Nunn site. In Spain, a French team will collocate a laser system with the Baker-Nunn site. These three sites will be programmed to obtain simultaneous observations. Other sites, for example, Prague, may join this program when their instrumentation is operational.

SECULAR AND LONG-PERIOD ORBITAL EFFECTS

The unique retrograde orbit of GEOS-B and the plans for extensive tracking over many months provide a valuable opportunity to further diversify the data base used for determining zonal harmonic coefficients and for investigating other long-period effects. Earth tides and polar motion are examples of the latter.

For these objectives, SAO plans to produce "normal" orbits for a number of successive months. Because of photoreduction limitations, these orbits may rely more heavily on electronic tracking data than have previous efforts at SAO. The evolution of a reasonably extensive laser network, with its possibility of rapid data processing and with its promise of superb accuracy, may also be exploited in these investigations. The laser data may be particularly valuable when used in studies of small effects such as earth tides.

TESSERAL HARMONICS

For determination and refinement of tesseral harmonic coefficients, the most accurate orbits attainable are necessary. This requirement implies that careful attention be given to the density and distribution of the tracking data. Hence, SAO intends to nominate two intervals of about one month each for "saturation" tracking. The intervals will be chosen by SAO on the basis of visibility patterns for photographic and laser tracking. Final selection of times for saturation tracking must also reflect discussions with other tracking and scientific groups.

Baken-Nunn data collected during these intervals of saturation tracking will be reduced in the "multiple-frame" mode when possible. About 1200 photographic frames will be reduced for each month. These will be combined with other data to produce "select" orbits for these intervals. The select orbits, in turn, will be combined with similar select orbits for other satellites with differing orbital elements in the determination of tesseral harmonic coefficients.

Because laser tracking offers a significant advantage in accuracy over other systems, the operational status of the laser instrumentation operated by SAO and other participating groups will weigh heavily in the choice of saturation periods.

REFERENCES

GAPOSCHKIN, E. G., AND VEIS, G.
1967. Comparison of and results obtained from observing stations. Presented at COSPAR meeting, London, July 24-29, 1967.

LAPUSHKA, K.
1967. Results of tracking the GEOS-A satellite at the Riga station (USSR). Presented at COSPAR meeting, London, July 24-29, 1967.

LUNDQUIST, C. A.
1967. Contributions of GEOS-I to geodetic objectives. Presented at GEOS Program Review Meeting, NASA, Washington, D. C., December 12-14, 1967.

MULLER, P.
1967. Participation Francaise au Programme GEOS. Presented at COSPAR meeting, London, July 24-29, 1967.

VEIS, G.
1967. The determination of the radius of the earth and other geodetic parameters as derived from optical satellite data. Presented at the XIV General Assembly, International Union of Geodesy and Geophysics, International Association of Geodesy, Lucerne, Switzerland, September 25-October 7, 1967.

PLANS FOR GEOS-B INVESTIGATIONS

Prof. William M. Kaula

Institute of Geophysics and Planetary Physics

University of California, Los Angeles

Prepared For

GEOS PROGRAM REVIEW MEETING
12-14 December 1967

NASA HEADQUARTERS
400 Maryland Avenue, SW
Washington, D. C.

PLANS FOR GEOS-B INVESTIGATIONS

Prof. William M. Kaula
Institute of Geophysics and Planetary Physics
University of California, Los Angeles

Of the work at UCLA, there are four aspects which can be regarded as logical extensions of the satellite orbit analysis described yesterday: 1) A continuation of the analysis of the satellite orbits to determine geodetic parameters; 2), the adaptation of the techniques used in earth satellites to lunar satellites; 3), the application of the results of satellite geodesy (the coefficient of the gravity field to geophysical problems); and 4), the use of the improved results to get improved variations of the orbit in the long term, and the application of this to things of geophysical interest. Of these, I think all except 2) -- the application of lunar satellites -- essentially pertain to the geodetic satellite program.

The first item -- continuation of earth satellite orbit analysis -- I have come to feel is not something which is appropriately done in the University. It is better done in a government center or industry, since the amount of technical detail involved in these computer programs is getting to be such that it is impossible to ask any graduate student to pick up the work as a research problem. However, I do have definite ideas about what direction the analysis described yesterday would go after it achieves its objective: from approximately seven camera satellites and six doppler track satellites to determine on the order of about eighty-five coefficients the test of validity being a mean square discrepancy from terrestrial gravimetry on the order of 160 milligals square. The obvious next step is to increase the capacity of the program compatible with a computer on the scale of an IBM 360-75, which should not be too difficult to reach 150 or 200 unknowns. There are desirable in the program as it stands some refinements in analytical theory but I still think they're not too important or too difficult.

Next, of course, continued progress requires addition of more satellites of differing inclination; we again emphasize the desirability of a 15 degree inclination satellite.

And, finally, we also hope to use the more accurate tracking such as the laser systems. But, as I say, I do not feel that a university is an appropriate place to continue on these elaborations.

Item 3) on the list, (skipping over 2)), was the application of the gravitational field to geophysical problems. This is something we are very much concerned about in that it still is true that what we've gotten from the geodetic satellites gives a very handsome looking geoid -- lots of suggestive ups and downs, but that the progress in apply this to understanding the interior of the earth is still fairly slow. I won't take very much time to talk about this because a review paper on the subject will shortly appear in the Space Science Reviews. But, we can enumerate some of the benefits obtained from improvements in the gravity field -- obtained say, as of 1966, and since. The fact that the gravity coefficients do get smaller at a marked rate is clearly established. The dimunition is perhaps best shown by Anderle and Smith in USNWL Technical Report Number 2106: the normalized coefficients $\overline{C}_{LM}$, S_{LM} fit extremely closely a law that they drop off proportionate to $10^{-5}/l^2$. The second feature which is clearly established now is that originally pointed out by Jeffrey years ago: the correlation of the gravity field with topography for broad variations up to about degree 5 (half wave lengths more than 36 degrees) -- is virturally zero: the big obvious variations of the geoid do not correlate with the surface features of the earth. However, the increased accuracy of the high degree coefficients has shown that for shorter wave length variations -- less than continental in extent -- the correlation is definitely positive: where the topography goes up, the geoid goes up and vice versa. There are other correlations which have been showing up with other types of geophysical data. A negative correlation with heat flow is still tentative on the scale of satellite data, but is well established on the local scale.

Recently, Science published an article by Toksoz of MIT which shows that on a global scale there is a strong negative correlation of the gravity field with seismic velocities. Both the heat flow and seismic correlations suggest the simple fact that heated rocks are less dense and less rigid.

To explain these correlations and to get a better notion as to what's going on in the mantle, particularly the upper mantle, to which the satellite gravity contributes, there have been some improvements in two areas. Firstly, in the area of rheology -- the behavior of materials under stress -- both laboratory experiment and inferences drawn from geophysical data (such as the crustal uplifts and the lag in the shape of the earth in response to the slowing down of the rotation) as well as solid state theory about how defects travel through materials under stress, suggest that there's more to Newtonian viscosity than just simple mathematical convenience. It now appears that the law of Newtonian viscosity -- stress proportionate to deformation rate -- does apply largely to most of the mantle. However, these same considerations indicate that this viscosity is strongly temperature and pressure dependent and that there is a change by order of magnitude from a maximum viscosity in the crust to a minimum at a depth on the order of say, 160 kilometers, and back up to a higher value again. There's also the likelihood that in this weak layer in the upper mantle the viscosity is strongly stress-dependent. Secondly, an improved understanding of the mantle is dependent upon better analytical theory of how systems such as this behave. It's quite clear that the mantle is not an efficient system to transfer heat and that it breaks down into a system of several cells. The next question is whether these cells are persistent: Do they keep going on for a long time geologically, or are they turbulent? In other words, does the system break down fairly often on a geological time scale and build up again elsewhere? The definition of long time in this case is still somewhat vague, but it does seem we have reached the stage now where appropriate to talk about model calculations of steady systems. This is essentially because the ratio of the viscosity of the mantle to the thermal emissivity is high, the same as saying that the system is moving because it's forced to in order to transfer heat and that it moves in such a sluggish way that it's kept at it and prevented from breaking down and do something else.

So, at UCLA, we firstly are going further into these theoretical considerations of what is an appropriate model to do and then we have proposed to adapt some numerical models relating the stress field in the mantle, using the gravity field, and the boundary conditions to adapt these numerical calculations to a viscous model using these sort of considerations.

The final aspect of work at UCLA which is related to the geodetic satellite program is one which we think is the new area of endeavor of scientific interest in satellite geodesy. With the improvement in the tesseral harmonics and in the station positions and in the tracking and everything else we now can talk about much more accurate determination of long-term variations of the orbit -- variations caused by the fixed xonal harmonics but also those caused by tidal variations of the earth and shifts of mass in the earth's atmosphere, in our knowledge and understanding of the earth. Some work on this problem has already been done by Kozai and by Newton. They essentially determined two parameters -- one is the amplitude factor, called the Love number, which is the ratio of the response of the earth to the effect of the sun and the moon; the other is the phase lag. The most accurate of these analyses is that of Newton, who got an interesting result phase lag, one smaller than that obtained by other means. However, he used only polar satellites, which meant that some of the complications of the effect of the ocean tide are averaged out. For non-polar satellites there might be some interesting variations in the apparent phase lag detected by satellites due to the interaction of the ocean tide with the topography. So, this was an aspect in which we got interested because the oceanographers are still in doubt as to what is the height of the tide in the middle of the oceans. The satellites offer a potential way of detecting some of this, but we need a mathematical model to which to compare the data. But no one has ever calculated the tide in a form useful to use it as an input disturbing function for satellite orbit perturbations: i.e., in terms of spherical harmonic coefficients. The reason was that there is a fairly complicated calculation which requires a computer to carry out: in the time of theoretical enthusian about tides, they didn't have the computers to do it this way. But since computers, oceanographers also have been more concerned about getting results that match coastal tide measurements, which are strongly affected by local conditions. Hence, they use a numerical mesh rather than the harmonic coefficients. However, we have been able to set up a set of equations for the spherical harmonic coefficients of the ocean tide which contain as inputs disturbing function from the sun and moon, the rate of that disturbing function, and the spherical harmonic coefficients of the ocean shape, which is the critical thing which makes the problem complicated: the tide is prevented from following the sun and moon around and hence sloshes back and forth between the coasts. One other good thing about this way of solving the problem that makes it very easy to take into account the effect of the elastic yielding of the earth by using the Love number, something which in the past has only been done approximately. Nobody else is doing it this way, and I think this will be an interesting potential application of satellites. It will become definitely a good application if we get some new instrumentation on satellites such as a radar altimeter to measure the height of the tide and a drag-free device so we can separate out these tidal effects and other long-term effects of the orbit.

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DOD OBSERVATION PLANS FOR GEOS-B

Col. J. O'Donnell

Department of Defense

Prepared For

GEOS PROGRAM REVIEW MEETING
12-14 December 1967

NASA HEADQUARTERS
400 Maryland Avenue, SW
Washington, D. C.

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DOD OBSERVATION PLANS FOR GEOS-B

Col. J. O'Donnell

Department of Defense

GEOS B UTILIZATION-DOPPLER

As was the case with GEOS A, the GEOS B doppler subsystem will be observed by the TRANET. The seventy-four (74°) degree retrograde orbit was selected to provide data at an inclination which is important for the earth gravity model analysis. GEOS B will also provide an additional transponder to aid in positioning the remaining primary network stations.

Also the doppler will participate with the laser systems and SECOR in a GEOS B systems co-observation experiment. The system will observe GEOS B simultaneously from a common location. This should provide valuable information concerning the effect of the ionosphere on the electronic signals.

Another point worth mentioning here is the development of a miniaturized doppler receiver or geoceiver, shown in Figure 1, which weighs less than 80 pounds. The prototype version is scheduled for delivery in January, with 10 operational units scheduled for delivery in late 1968.

SECOR - GEOS-B

Immediately following the launch of GEOS B, now scheduled for mid January 1968, a SECOR station will be deployed to Wallops Island to participate in an intercomparison test with NASA laser. The tests are presently scheduled for April 1968. Army, however, will occupy the test site earlier in order to eliminate any problems that may develop prior to observation.

Army and NASA representatives are working out the details for the intercomparison tests. It is believed that this test will furnish very valuable information concerning ray path and calibration data. As agreed upon, Army will expedite the reduction and publishing of test data.

GEOCEIVER SYSTEM

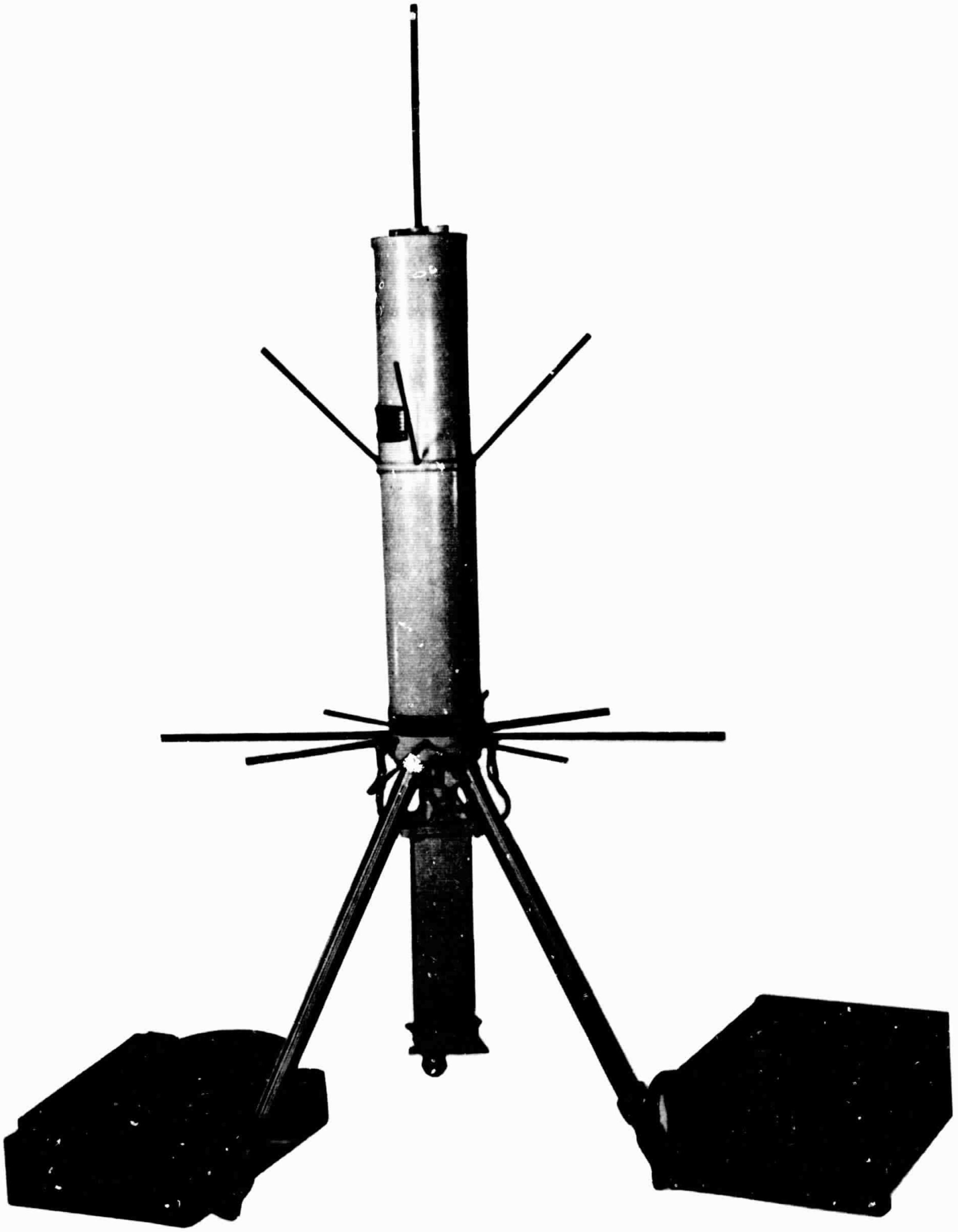

Figure 1

After completion of the current SECOR equatorial network now scheduled for September 1968, plans are to utilize the SECOR systems for accomplishing densification programs (Figure 2) in areas such as Africa to support mapping and charting efforts. At this time, the 800 n. mi. GEOS-B will be used in the Army operational SECOR program. Another satellite scheduled to be launched in this time frame with a SECOR transponder aboard will be the NIMBUS, now planned for late March 1968. GEOS-B and the NIMBUS SECOR satellite will both be used in the densification program.

BC-4 - GEOS-B

The use of GEOS-B in the BC-4 camera program, both by Army and C&GS will be increased as a result of the requirement for co-observation with the Air Force PC-1000 cameras in South America. Also, we expect that the BC-4's will co-observe with the SAO Baker-Nunn and the NASA MOTS cameras to tie these to the basic network. Parenthetically, the demise of ECHO I is predicted for mid-summer of 1968 during the height of the solar storms.

GEOS-B PC-1000 (Figure 3)

The PC-1000 cameras will continue to be used by the USAF to satisfy various DOD requirements. The cameras are now equipped with chopping shutters so that observations of both passive and active satellites are possible. Data obtained by observing GEOS-B in addition to the passive satellites will be used to:

A. Accomplish control densification in such areas as South America to support mapping and charting programs. The densification network(s) will be tied to the Pageos primary network by co-observing with the BC-4 sites. Air Force teams and PC-1000's are presently located in South America at Bogota, Curacao, Trinidad, and Paramaribo. It is our intention to extend the network to complete a control densification of South America.

B. PC-1000 cameras will also observe GEOS-B to improve the accuracy of space tracking sites. Again these will be tied into the primary network by co-observation.

C. Calibration of tracking radars.

WORLDWIDE DENSIFICATION AREAS

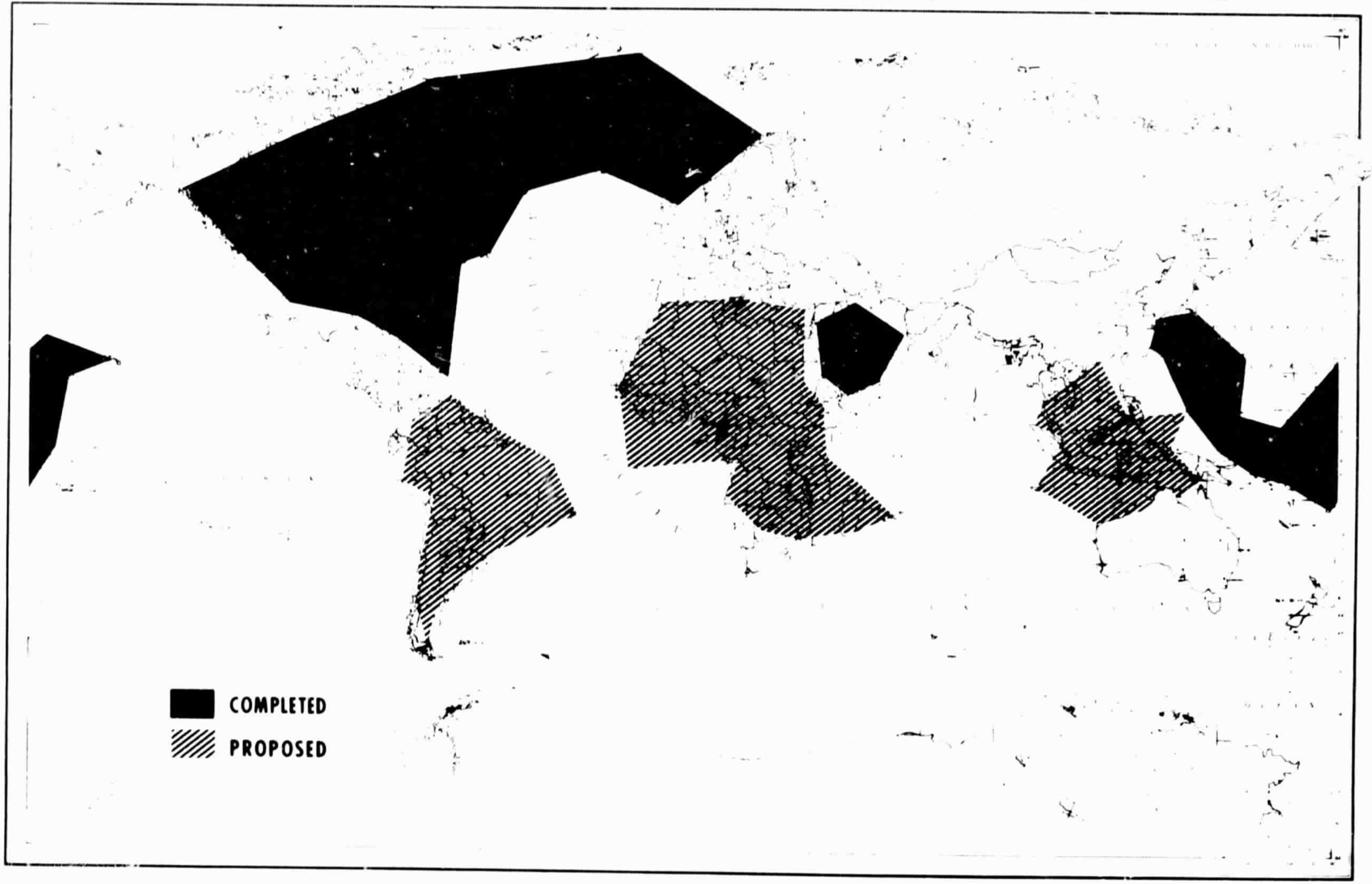

Figure 2

1 Nov. 1967

PROJECT: AF67-27
SOUTH AMERICA DENSIFICATION

Figure 3

GSFC PLANS FOR GEOS-B

John Berbert

Goddard Space Flight Center

Prepared For

GEOS PROGRAM REVIEW MEETING
12-14 December 1967

NASA HEADQUARTERS
400 Maryland Avenue, SW
Washington, D. C.

PLANS FOR GEOS-B

John Berbert

Goddard Space Flight Center

After Professor Kaula's remarks on science versus engineering, I hestitate somewhat to talk about the intercomparison experiment again because to scientists it's really just a lot of engineering. On the other hand, to an engineer, there's an unusual amount of science involved. We should call it perhaps "engineering science" or "scientific engineering". Whatever we call it, what we plan to do is about the same thing we did on GEOS-A. We plan to continue the intercomparison investigations trying to dig a little deeper into just what causes the errors and try to nail them down to within a level that's consistent with the scientific objectives of around 10 meters. In other words, we're trying to get down to around an order of magnitude below that if we can so that the objectives can be met. We plan to observe with the same network as on GEOS-I. We will use the SPEOPT cameras again and just about all the same other systems again. However, the GRARR system, which is going to have a frequency change-over starting the end of 1968, will start being phased out at that time.

The main new thing that we're doing to do is a collocation experiment at Wallops Island with the FPQ6 radar. The GSFC portable laser will be situated there along with the Army Map Service's SECOR system. These three systems will all be located within about 100 meters of each other. I might discuss the layout - just inside the Wallops Island gate the road goes to the right, and the FPQ6 is about one-fourth mile down the road. Right next to it will be the laser and right next to that will be the SECOR. A Goddard camera will be a couple hundred yards back towards the gate. Then there's a small building by the gate where the TRANET doppler system will probably be located. We don't have a definite commitment on this yet. We expect to start this collocation experiment in April 1968. Then if we can extend the experiment long enough we may get the Navy's new geoceiver to also participate. This is their portable doppler system that was described earlier. It is an 80 pound system that is expected to be as accurate or more accurate than the present TRANET type of doppler system. And, possible also, SAO will be able to provide their portable laser, which is under development.

Before the new GSFC portable laser is shipped to Wallops there will be some laser versus laser comparisons at Goddard. The new laser, which is going to Wallops, will be compared against the GSFC prototype laser, which was already discussed in the paper on the Laser/GRARR intercomparison of GEOS-A data at ROSMAN, and also against the doppler laser that Dr. Plotkin will describe next.

Charles Lundquist: May I correct one statement. We don't have a portable laser under development. What we do plan to do is after the prototype that's in Arizona is checked out, is order two or three more systems like it which perhaps next fall can go somewhere in the southern hemisphere. And one of those might go perhaps for a little while to Wallops Island but they're not portable systems. It would just be put there for awhile and then moved.

GEOS-B PLANS FOR LASER TRACKING AND EXPERIMENTS BY GSFC

Dr. Henry H. Plotkin

Goddard Space Flight Center

Prepared For

GEOS PROGRAM REVIEW MEETING
12-14 December 1967

NASA . .DQUARTERS
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GEOS-B PLANS FOR LASER TRACKING AND EXPERIMENTS BY GSFC

Dr. Henry H. Plotkin
Goddard Space Flight Center

The laser tracking station already described, which has been used by GSFC to track the five reflecting satellites already in orbit, is primarily an experimental station. We will continue to operate this at Goddard and to supply operational data during a cooperative saturation period. It can be considered as one station in a laser network that may be useful in the future. But the experimental system will be used primarily for further development of techniques. We will study in detail the effects of the atmosphere, we will study velocity aberration (the fact that the return spot is deflected due to the velocity of the satellite), and we will attempt to improve the range resolution. This meeting has shown the geodetic value of tracking accuracies of one or one-and-a-half meters. The resolution seems, so far, to be limited by the instrument. Using very much the same lasers and the same detectors, we believe that we can get an improvement of as much as another order of magnitude in resolution. Geodecists will soon be challenged to fit orbits to tracking data whose resolution and accuracy may be of the order of 15 centimeters.

The second station being developed at the Goddard Space Flight Center is a transportable station. It consists of three trailers-vans: (Figures (1) and (2)) one trailer houses the power-supply for laser, mount, and electronics; one trailer is the control center consisting of an operator's console and a control system which is primarily a small, general-purpose computer; and the third trailer is the transmitter and receiver mount itself. The mount is very similar to that of the experimental laser system except that the laser need not be mounted on the moving portion of the telescope. Instead, the transmitter optical system takes the form of a periscope or Coudé arrangement. The light can come up through the axes while the transmitting laser is kept stationary. It therefore doesn't require cables and water hoses and rigid construction to minimize deflections.

One of our objectives in future development will be to use our own laser ranging data to update the predictions by which the tracking system is directed. Since the mobile station may be operating from a remote site, we would like to become independent of predictions from a central computing agency. Beyond that, with a modest computer, we may soon expect to improve our predictions based on data being obtained in real time, so that, once we have acquired the satellite, we can improve the pointing, making it possible to use narrower beams. These techniques will make it possible to aim the laser beam and illuminate the satellite even when it is not visible. We expect, therefore, to operate in daylight or with the satellite in the earth's shadow, eliminating the previous limitation to periods when the satellite is in sunlight and the station is dark.

The mobile laser tracking station is scheduled to go to Wallops Island for intercomparison tests with other systems on GEOS-B. Thereafter, it would be available to be moved to other stations for intercomparison purposes, or to some spot on the earth from which precise satellite tracking would benefit geodetic coverage.

The next phase of laser development associated with GEOS-B goes beyond the Ruby laser and considers use of continuous lasers. Of these, the most attractive at the moment is the Argon laser. Figure 3 is a picture of the Argon laser to be used for satellite tracking at Goddard. Its light is a brilliant blue-green, consisting of two spectral lines, one at 4880 Angstroms and one at 5140. Operating with both of these lines, using our laser, developed by RCA, we can radiate a continuous power of about 10 watts. Our plans are to operate with only the line at 4880 Angstroms, in which alone the laser will radiate 5 watts. Figure 4 represents our plan for using an Argon laser for satellite tracking. It is shown being used with one of the Beacon explorer satellites but should be even more effective with GEOS-B. In the familiar manner, we illuminate the satellite and receive the reflection. We will impose an intensity modulation on the transmitted beam, and measure the shift in the modulation frequency of the reflected beam due to the Doppler effect to measure the satellite's radial velocity. In the figure, the modulation is shown to be at a frequency of 136 megacycles. It was chosen because it is the familiar minitrack frequency. This is convenient, of course, since after we detect the reflected light and demodulate it, the result is equivalent to the output of a minitrack receiver. Therefore, we can utilize much of the electronic equipment from a minitrack station and realize an appreicable cost saving.

Much of the equipment for this system is already available and checked out. The laser has been tested at output powers as high as 11 watts, and operated in the field. The modulator and basic receiving electronics have also been received and tested. We will employ a narrow band tracking receiver at the 136 megacycle frequency, and measure Doppler shift in the modulation frequency. The receiving telescope that we are using here is a 60 inch aperture telescope (Figure 5) which sounds like a very ambitious telescope, but in reality the telescope is a photon-bucket in the form of a modified anti-aircraft searchlight. We have taken the normal arc-lamp out and replaced it with a hyperbolic secondary, with the detector behind a hole in the primary mirror to form a cassegrain arrangement. The experiment will get underway in the spring, and we hope to have publishable results by summer.

As mentioned in the description of the GEOS-B satellite, it will also carry an on-board detector of laser radiation (Figure 6). Unfortunately, this detector will be sensitive only to argon laser radiation, and not to the ruby laser wavelength. It will monitor the intensity of argon laser light reaching the satellite. The clear aperture of the optics in front of the detector is about 3/4 of an inch. With the detector mounted on the bottom surface of the gravity-gradient oriented satellite, it doesn't look at a particular station, but rather toward the center of the earth. To give ourselves a high probability of reasonably long passes, we have given the detector a fairly wide field of view: about 40 degrees half-angle. To help the detector discriminate against the earth background, we provided an interference filter which picks out the

the 4880 Angstrom spectral line of the laser, and we further chop the transmitted beam at a frequency corresponding to the frequency of a filter on the spacecraft.

After detection by a photomultiplier, a logarithmic amplifier with a dynamic range of one thousand to one provides a signal to the telemetry encoder which then transmits back a measure of laser intensity via the satellite telemetry link. Since there is no storage on board the spacecraft, the telemetry must be monitored continuously, in real time, while it is being illuminated by the laser. Fortunately, Goddard is frequently within sight of the satellite. ROSMAN will therefore command the photodetector "on" and the commutator to stop at the proper read-out channel, while the experiment is performed from Goddard.

The purpose of this, of course, is to study the atmospheric effect of a laser beam transmitted to a distant satellite. A clear understanding of beam scintillation and "wandering" is vital to future development of laser tracking and space communication. Atmospheric theories have been developed which predict the results of such experiments, but this would be the first good test of those theories.

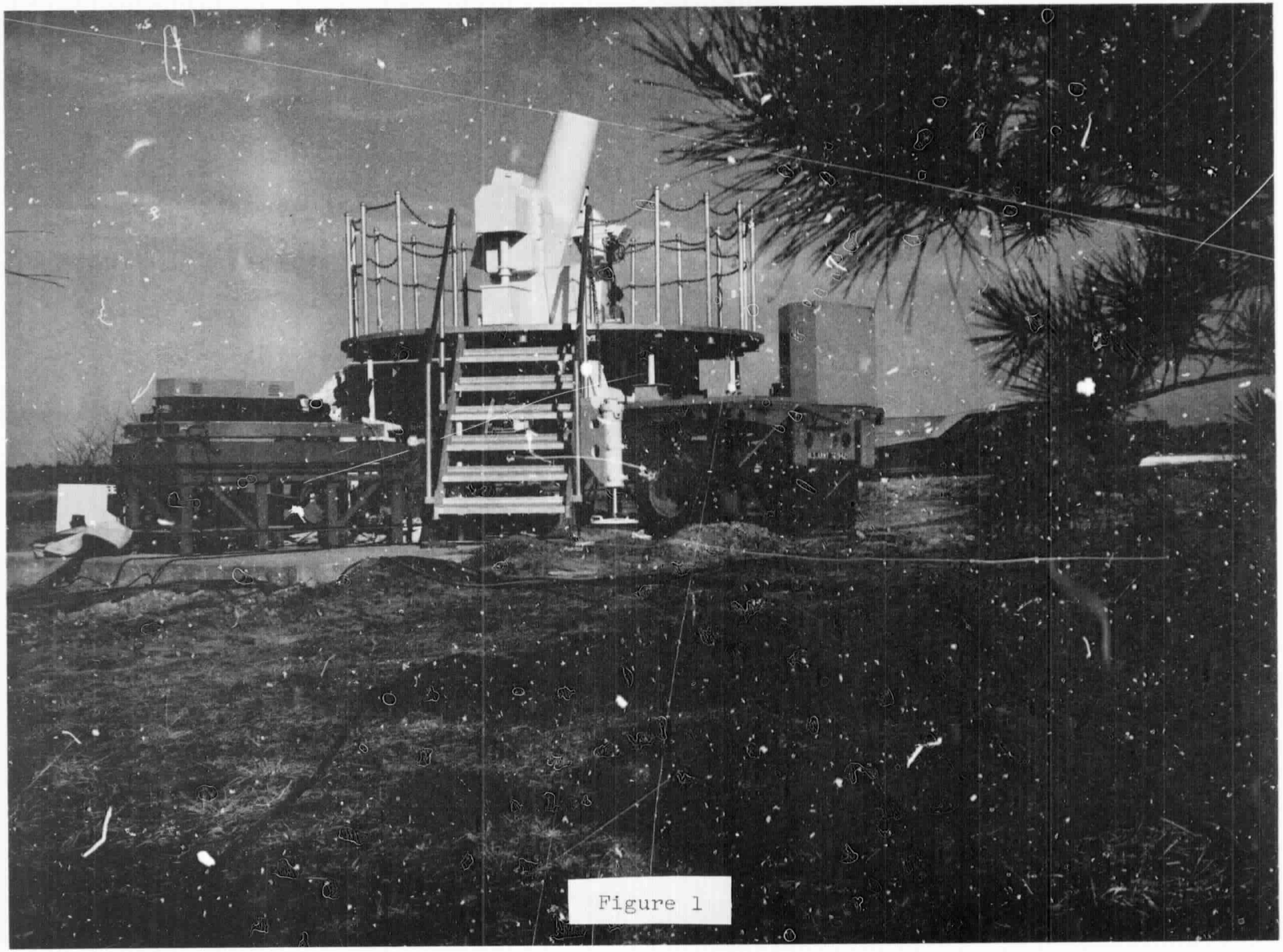

Figure 1

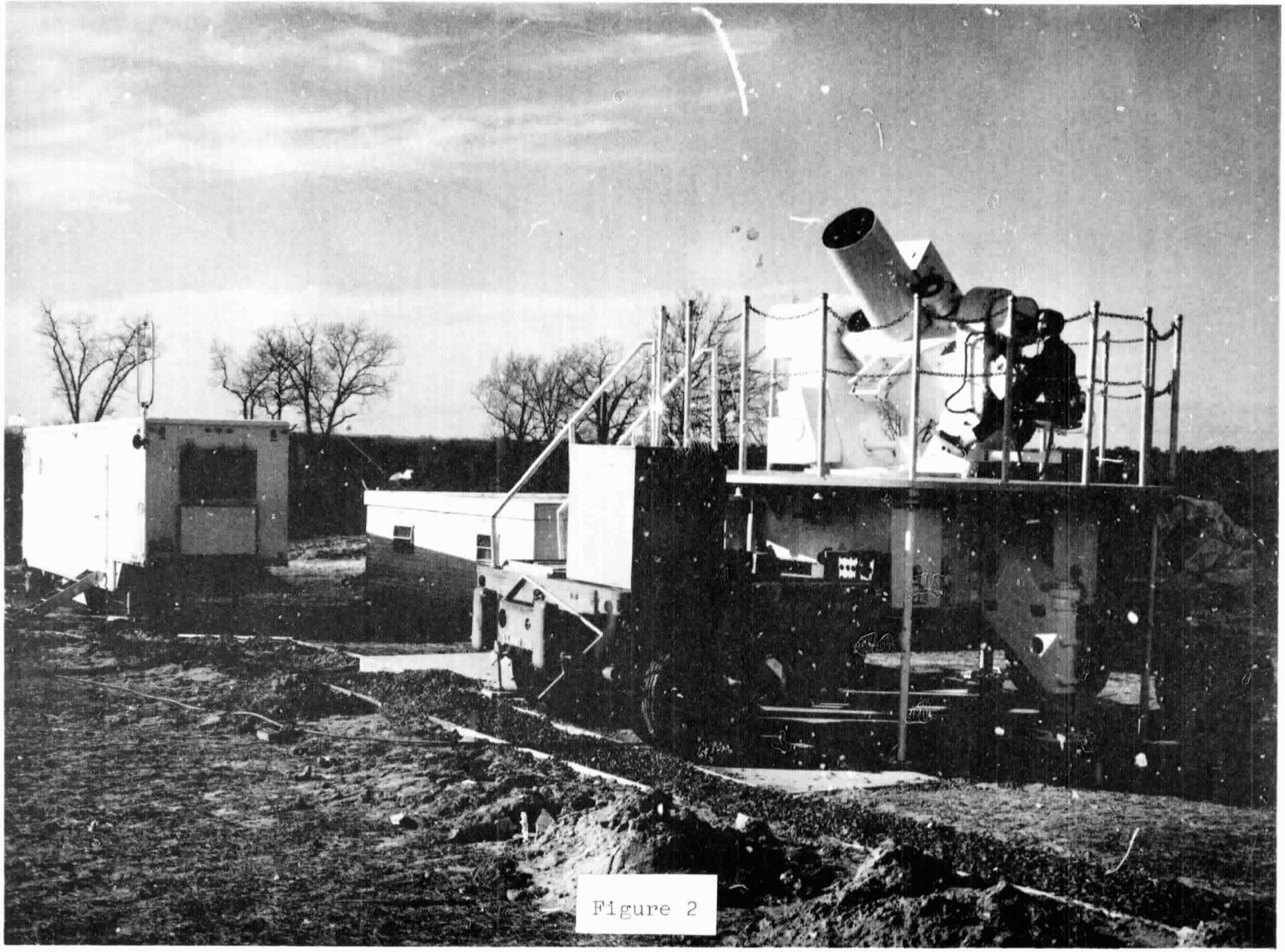

Figure 2

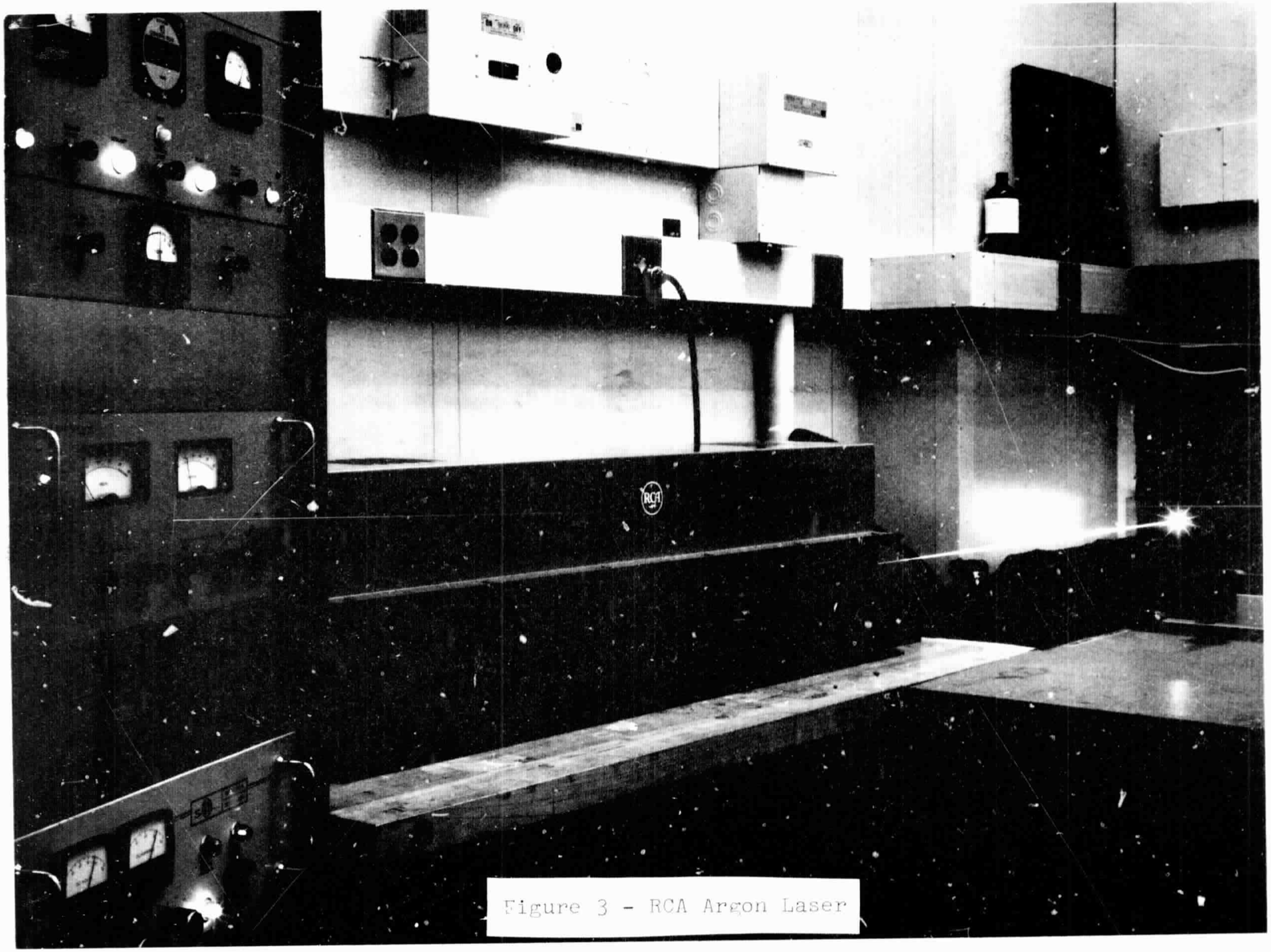

Figure 3 - RCA Argon Laser

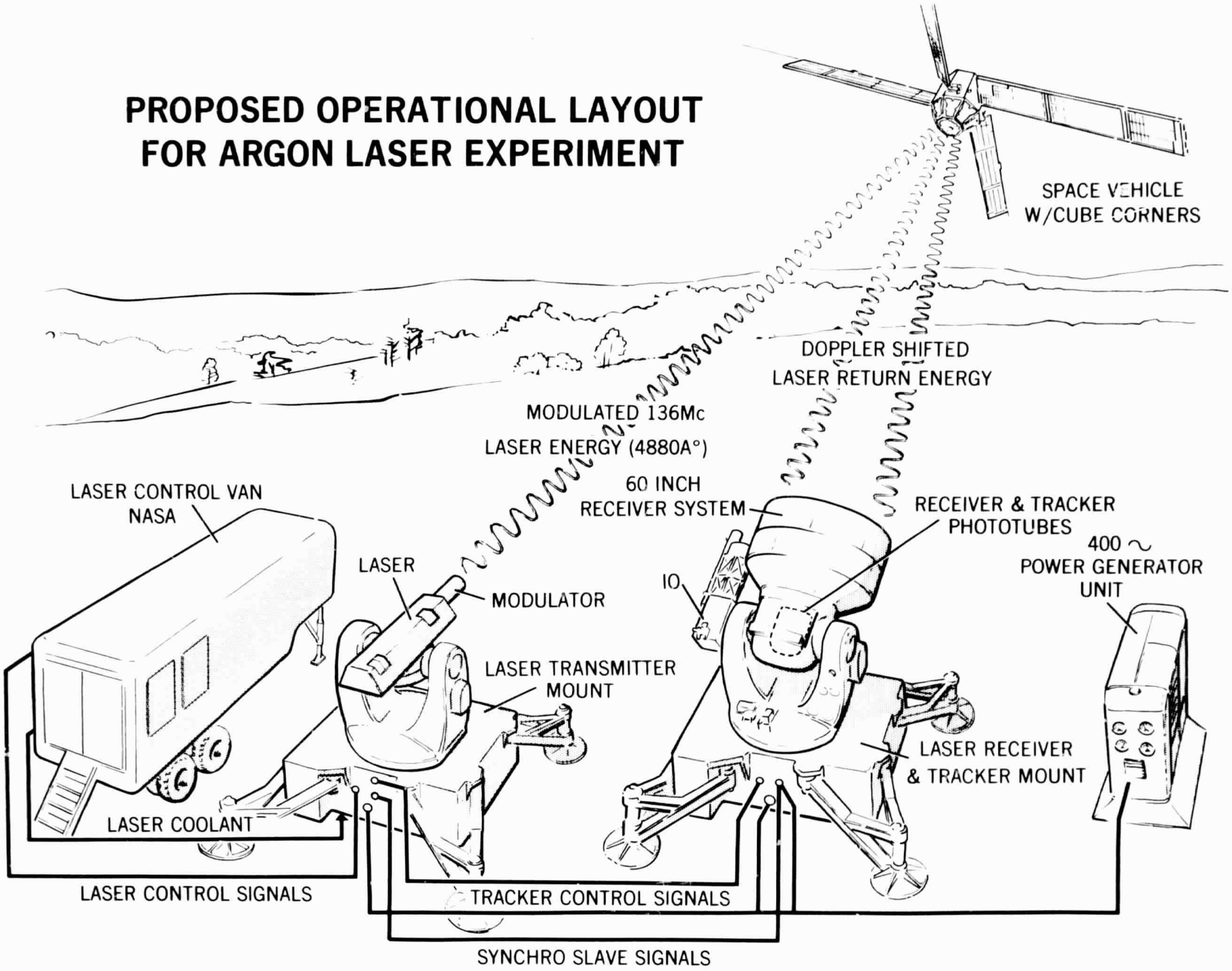

Figure 4 - Plan of Argon Doppler Experiment

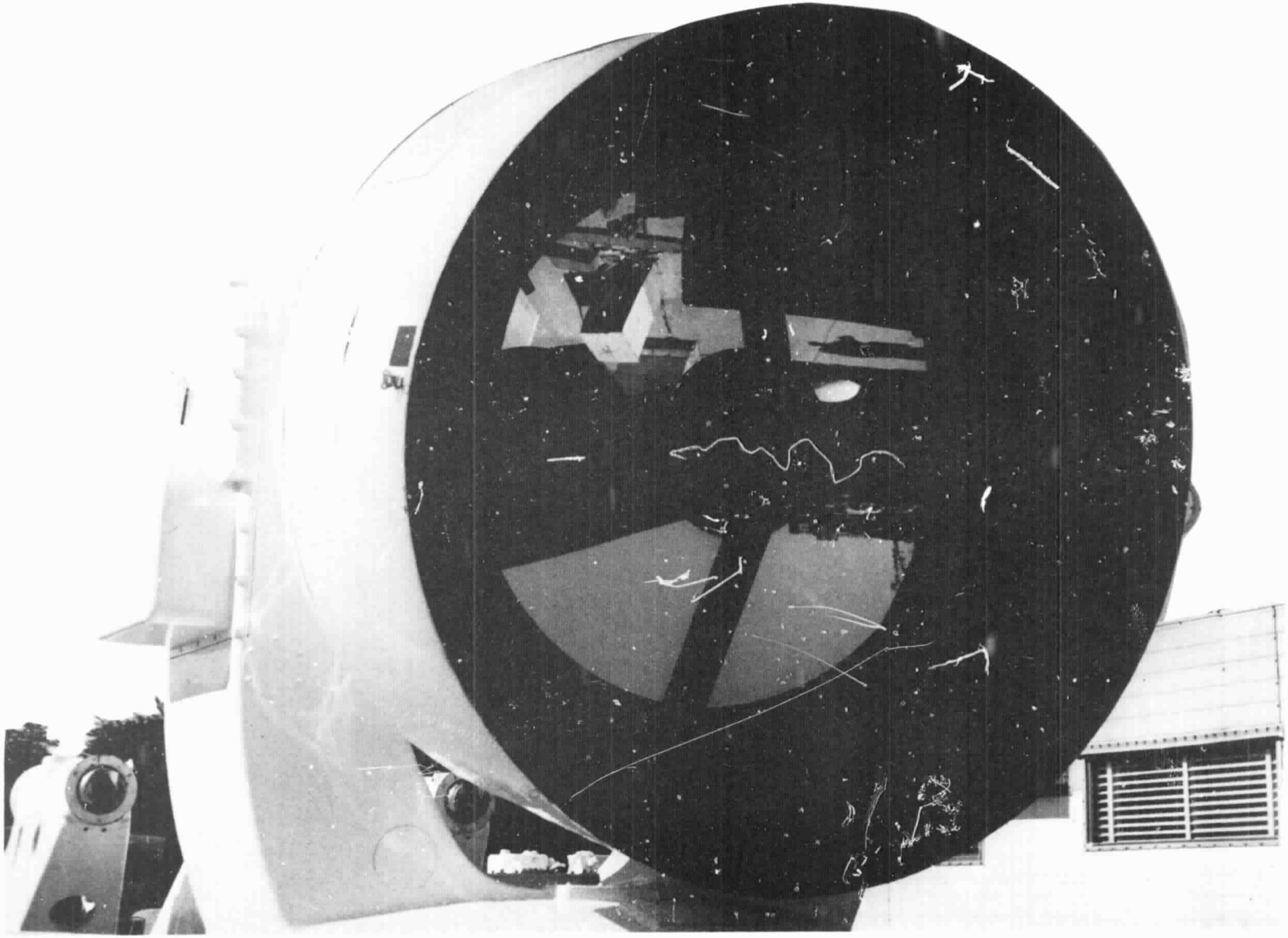

Figure 5 - 60" Optical Receiver

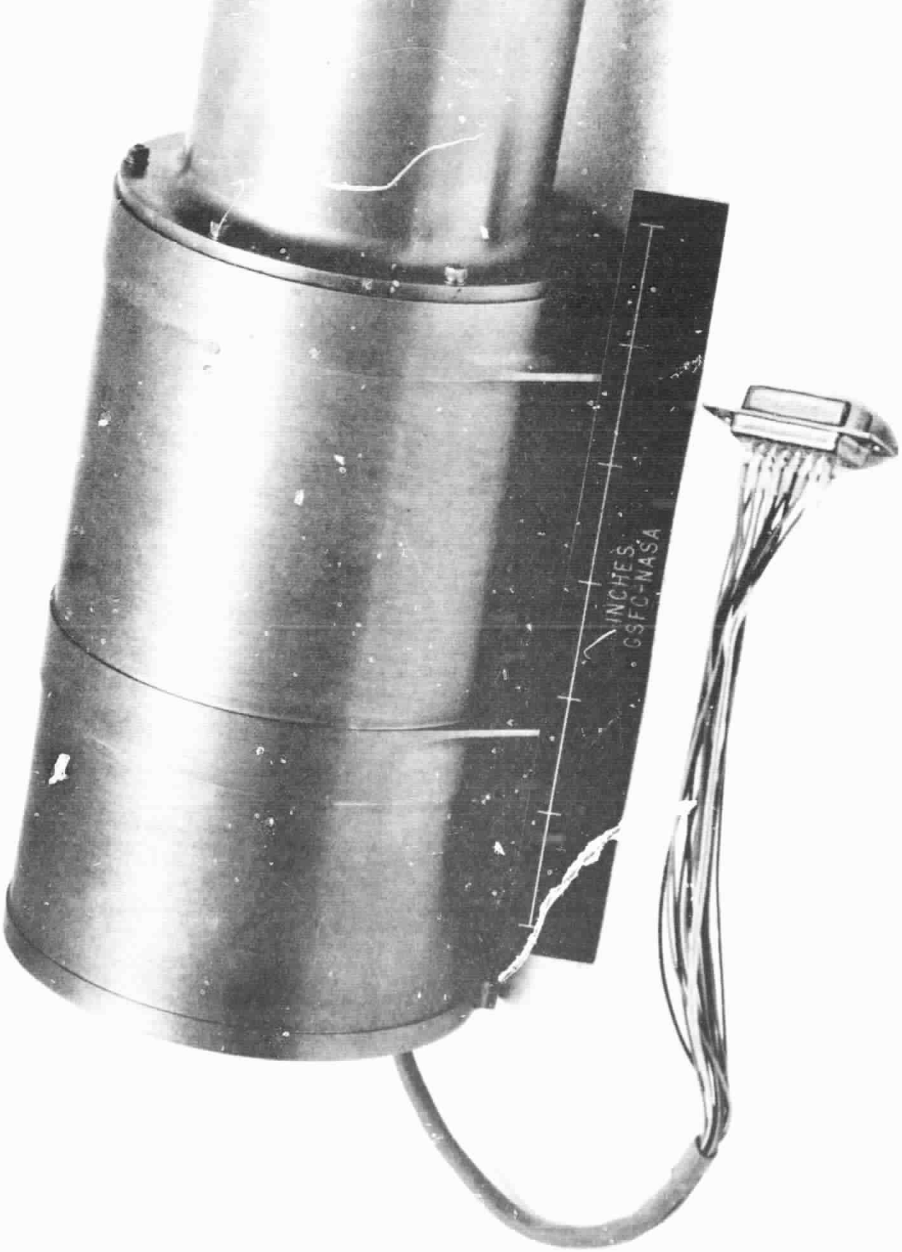

Figure 6 - GEOS-B Detector Package

OSU INVESTIGATIONS IN CONNECTION WITH THE GEOMETRIC ANALYSIS OF GEODETIC SATELLITE DATA

Prof. Ivan I. Mueller

The Ohio State University

Prepared For

GEOS PROGRAM REVIEW MEETING
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OSU INVESTIGATIONS IN CONNECTION WITH THE GEOMETRIC ANALYSIS OF GEODETIC SATELLITE DATA

Prof. Ivan I. Mueller

The Ohio State University

The primary objective of the OSU investigation is the geometric analysis of geodetic satellite data. The analysis is accomplished in three steps:

(1) The establishment of a primary network where station positions are known to an internal consistency of approximately 10 meters or better to serve the following purposes: (a) unify the various geodetic datums in use around the world, (b) connect NASA tracking stations, isolated islands, navigational beacons, and other points of interest to the unified system.

(2) Establishment of a densification network where station positions are known to an internal consistency of approximately 3 meters or better to serve the following purposes: (a) improve the internal quality of existing geodetic systems (triangulation, etc.) by establishing "super" control points in sufficient number, (b) to provide control for mapping to scales as large as 1 : 24,000.

(3) Establishment of a set of scientific reference stations where positions are known to an accuracy of one meter or better with respect to the unified system for advanced applications.

The main objectives of OSU participation in the National Geodetic Satellite Program for the time period 1967-1969 in connection with the fulfillment of the primary objectives listed above are the following:

(1) The extension of the computer programs for range and range rate, Doppler, and laser systems.

(2) The development of data preprocessing systems to handle the data from the above observation methods.

(3) The analysis of observational data for the National Geodetic Satellite Program for the purpose of fulfilling the primary objectives listed above as observational data becomes available.

(4) The development of computer programs for the adjustment of optical, ranging and Doppler data in the short-arc mode.

(5) Theoretical investigations into sequential least squares adjustment of simultaneous satellite observations in combination with terrestrial data.