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NASA CR-66376

ORBITAL OPERATIONS AND ANALYSIS FOR A 15-MICRON HORIZON RADIANCE MEASUREMENT EXPERIMENT

Horizon Definition Study

N67-36690
(ACCESSION NUMBER) (THRU)
(PAGES) (CODE)
(NASA CR OR TMX OR AD NUMBER) (CATEGORY)
FACILITY FORM 602

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GPO PRICE $ _____

CFSTI PRICE(S) $ _____

Hard copy (HC) 3.00

Microfiche (MF) .50

ff 653 July 65

May 1967

Prepared under Contract No. NAS 1-6010 by

HONEYWELL INC.
Systems & Research Division
Minneapolis, Minn.

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA CR-66376

ORBITAL OPERATIONS AND ANALYSIS FOR A 15-MICRON HORIZON RADIANCE MEASUREMENT EXPERIMENT

By William F. Vogelzang
James J. Baltes
David K. Scharmack

HORIZON DEFINITION STUDY

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FOREWORD

This report documents Phase A, Part II of An Analytical and Conceptual Design Study for an Earth Coverage Infrared Horizon Definition Study performed under National Aeronautics and Space Administration Contract NAS 1-6010 for Langley Research Center.

The Horizon Definition Study was performed in two parts. Part I, which was previously documented, provided for delineation of the experimental data required to define the infrared horizon on a global basis for all temporal and spatial periods. Once defined, the capabilities of a number of flight techniques to collect the experimental data were evaluated.

The Part II portion of the study provides a measurement program plan which satisfies the data requirements established in the Part I study. Design requirements and the conceptual design for feasibility of the flight payload and associated subsystems to implement the required data collection task are established and documented within this study effort.

Honeywell Inc. Systems and Research Division performed this study program under the technical direction of Mr. L. G. Larson. The program was conducted from 28 March 1966 to 10 October 1966 (Part I) and from 10 October 1966 to 29 May 1967 (Part II).

Gratitude is extended to NASA Langley Research Center for their technical guidance, under the program technical direction of Messrs. L. S. Keafer and J. A. Dodgen with direct assistance from Messrs. W. C. Dixon, Jr., E. C. Foudriat, H. J. Curfman, Jr., K. Crumbly, and J. Daniel, as well as the many people within their organization.

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ORBITAL OPERATIONS AND ANALYSIS FOR A 15-MICRON HORIZON RADIANCE MEASUREMENT EXPERIMENT

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SUMMARY

The orbital operations and analysis documented in this report consisted of the evaluation of orbit and orbit-related parameters, an evaluation of accuracy of spacecraft position determination, a preliminary tracking and data acquisition plan, and the conceptional design of an attitude determination system. The purpose of these studies was to assure compatibility between the mission requirements, the spacecraft, and the ground stations associated with tracking and data acquisition. The analysis and interpretation of results associated with these studies are presented.

It was determined that a nominally circular, 500-km altitude, sun-synchronous orbit (97.38°) with initial ascending node at 3:00 p.m. local time, and launch date of 28 October meets the experiment and system requirements for the mission. The Western Test Range (WTR) should be used for the launch site and a 2-stage Improved Delta vehicle should be used to achieve adequate injection accuracy. The S-band Range/Range-Rate system should be used to obtain the raw tracking data. The vhf STADAN telemetry command links should be used as primary links since the best telemetry coverage can be obtained by using stations with the vhf capability. The Range and Range-Rate S-band system is recommended as a back-up link. The tone-digital command system is recommended since it can handle the type and quantity of commands required while resulting in minimum spacecraft equipment complexity. A starmapper and attitude determination concept was developed capable of determining the pointing direction of the spacecraft radiometer to an accuracy of 0.25 km in tangent height at the earth's horizon.

INTRODUCTION

The orbital operations studies and analyses documented herein are a portion of the Horizon Definition Study (HDS) conducted for NASA Langley Research Center, Contract NAS 1-6010, Phase A Part II. The purpose of the Horizon Definition Study is to develop a complete horizon radiance profile measurement program to provide data for use by the scientific and engineering communities in the design of instruments and measurement systems which use the earth's horizon as a reference.

Part I of the HDS resulted in the following significant contributions to the definition of the earth's radiance in the infrared spectrum:

- The accumulation of a significant body of meteorlogical data covering a major portion of the Northern Hemisphere.
- Computation of a large body of synthesized horizon radiance profiles from actual temperature profiles obtained by rocket soundings.
- Generation of a very accurate analytical model and computer program for converting the temperature profiles to infrared horizon profiles (as a function of altitude).
- An initial definition of the quantity, quality, and sampling methodology required to define the earth's infrared horizon in the CO_2 absorption band for all temporal and spatial conditions.
- An evaluation of the cost and mission success probabilities of a series of flight techniques which could be used to gather the radiance data. A rolling wheel spacecraft was selected in a nominal 500-km polar orbit.

The Part II study effort was directed toward the development of a conceptually feasible measurement system, which includes a spacecraft to accomplish the measurement program developed in Part I. In the Part II HDS, a number of scientific and engineering disciplines were exercised simultaneously to conceptually design the required system. Accomplishments of Part II of the study are listed below:

- The scientific experimenter refined the sampling methodology used by the measurement system. This portion of the study recommends the accumulation of approximately 380 000 radiance profiles taken with a sampling rate that varies with the spacecraft's latitudinal position.

- A conceptual design was defined for a radiometer capable of resolving the earth's radiance in the 15-micron spectrum to 0.01 watt/meter^2-steradian with an upper level of response of 7.0 watt/meter^2-steradian.

- A starmapper and attitude determination technique were defined capable of determining the pointing direction of the spacecraft radiometer to an accuracy of 0.25 km in tangent height at the earth's horizon. The combination of the radiometer and starmapper instruments is defined as the mission experiment package.

- A solar cell-battery electrical power subsystem conceptual design was defined which is completely compatible with the orbital and experiment constraints. This system is capable of delivering 70 watts of continuous electrical power for one year in the sun-synchronous, 3 o'clock nodal crossing, 500-km orbit.

- A data handling subsystem conceptual design was defined which is capable of processing in digital form all cientific and status data from the spacecraft. This subsystem is completely solid state and is designed to store the 515 455 bits of digital information obtained in one orbit of the earth. This subsystem also includes command verification and execute logic.

- A communications subsystem conceptual design was defined to interface between the data handling system of the spacecraft and the STADAN network. The 136 MHz band is used for primary data transmission and S band is used for the range and range-rate transponder.

- A spacecraft structural concept was evolved to contain, align, and protect the spaceborne subsystems within their prescribed environmental constraints. The spacecraft is compatible with the Thor-Delta launch vehicle.

- An open loop, ground-commanded attitude control subsystem conceptual design was defined utilizing primarily magnetic torquing which interacts with the earth's field as the force for correcting attitude and spin rates.

- The Thor-Delta booster, which provides low cost and adequate capability, was selected from the 1972 NASA "stable".

- Western Test Range was selected as the launch site due to polar orbit requirements. This site has adequate facilities except for minor modifications to handle the program and is compatible with the polar orbital requirements.

This report contains documentation of the areas of study not directly related to the conceptual design of the vehicle but are directly related to orbit characteristics and orbit operations. The studies documented herein are:

- Mission Profile
- Vehicle Position Determination
- Data Acquisition
- Attitude Determination

The objectives of these studies are as follows:

- To identify the characteristics and environmental factors associated with the orbits of interest and to select that orbit which best meets the mission goals.
- To establish positional accuracy requirements and to evaluate on a preliminary basis the accuracy with which the geocentric position of the spacecraft can be determined.
- To define, from systems requirements and feasible subsystem concepts, a data acquisition concept which utilizes with little or no modification the Goddard space tracking and data acquisition network.
- To establish spacecraft attitude accuracy requirements and to evolve a preliminary design concept which will meet the accuracy, operational, and environmental requirements of the spacecraft.

The detailed studies performed to meet these objectives are presented in the four major sections of this report corresponding to the four areas of study listed above.

MISSION PROFILE

INTRODUCTION AND OBJECTIVES

The mission profile study was concerned with the evaluation of orbit and orbit-related parameters pertinent to the experiment effectiveness, system design, or mission operations planning. This study is actually an extension of the Phase A, Part I flight techniques analysis. Computerized mathematical modeling was used to a great extent in performing this analysis. This automation enabled a more precise analysis to be made, greatly extended the number of parameters and range of parameter variations possible, and made generalized models available for rapid study of new orbits and/or parameters which were needed as the system study progressed. Highly accurate trajectory simulations were not required in this study; rather the emphasis was on parametric evaluation of the variables pertinent to the mission planning and systems design. Although there was considerable overlap and reiteration, the mission profile study was essentially conducted in three phases:

- Parametric investigations. In this phase, the objective was to examine the orbits feasible from an experiment point-of-view in order to assess the effects on the system and mission. During this phase, no attempt was made to narrow the selection of possible orbits.

- Orbit selection. In this phase, those orbits which appeared to best meet the mission goals and yield possible solutions to system design problems were examined in more detail. Analysis of deviations from nominal orbits and their effects were made. In this phase, the 3 o'clock, sun-synchronous, 500-km orbit was selected as the nominal HDS orbit.

- Detailed analysis of selected orbit. In this phase, exhaustive evaluations of sun-angle geometry, tracking/telemetry coverage, drag decay, etc., were conducted.

These phases of the study will be covered in the following sections.

MISSION PROFILE REQUIREMENTS

The mission profile investigation was initially guided by the basic requirements imposed on the study, primarily the following:

- Orbit altitude will be above 150 km
- Orbit will be chosen with consideration of Space Tracking and Data Acquisition Network (STADAN) system coverage
- Orbit will be compatible with launch site and launch vehicle
- Orbit will be near polar
- Orbit duration will be at least a year

Although the orbit altitude is explicit in the study requirements, in reality, the orbit altitude is primarily determined by the one-year duration requirement as will be seen later.

STADAN utilization is imposed on the mission profile analysis as a general requirement. Since the extent of STADAN coverage is not spelled out, it is really a requirement on the study approach, not on the system or mission. Because of other considerations, the orbit cannot be optimized with respect to STADAN coverage alone. Coverage with the STADAN system, assuming circular orbits, is primarily a function of orbit altitude and inclination.

The launch site and launch vehicle requirement relates to launch site and booster limitations. In conjunction with requirement for a near-polar orbit, the launch site requirement dictates a choice of Vandenberg Western Test Range (WTR) for the launch site if heavy payload penalties are to be avoided. Launch facilities at WTR are available for all launch vehicles under consideration such as Scout, the Delta series, Thor-Agena, and Atlas-Agena. Compatibility of the orbit with the launch vehicle consists primarily of payload-weight/orbit-parameter constraints and orbital injection error tolerances which are suitable.

The near-polar requirement stems from the need for global coverage. The term "near-polar" is used since the polar regions can be seen by a satellite in orbits which are "near enough" to polar.

The orbit duration requirement reflects the need for data coverage over a complete range of seasons. Primarily, this requirement affects the orbit altitude choice, since orbit altitude determines the orbital decay rate.

In addition to these basic requirements, the need for consideration of diurnal variation data was imposed on the study. This aspect has influenced the

selection of alternate orbits and was a prime factor in selection of the orbit discussed later.

PARAMETRIC INVESTIGATIONS

With the mission requirements as a guide, an analysis of several areas, including atmospheric effects, launch site and booster constraints, solar illumination, and telemetry/tracking coverage, was undertaken.

Atmospheric Effects on Missions

In spite of the extremely low atmospheric densities encountered at orbital altitudes, the effects of the atmosphere are still measurable and possibly significant below 600-km altitude. The two primary effects are reflected in orbit lifetime and orbit determination accuracy. This section will be concerned only with orbital lifetime effects. Orbit determination effects are considered in the vehicle position section of this report.

The problem of determining orbit lifetime for elliptic orbits is somewhat involved and has received considerable treatment in the past. For conceptual design purposes, a circular orbit was assumed. Derivation of the basic orbital altitude decay equation is straightforward, starting with the differential equations (in polar form) for a body in a central gravity field and initially in a circular orbit. Neglecting periodic effects, the result is

$$dh/dt = \frac{(\mu r)^{1/2}\rho}{(M/C_D A)} \tag{1}$$

where

h	=	orbit altitude
r	=	h + (earth radius)
t	=	time
μ	=	earth gravitational parameter
ρ	=	atmospheric density
M	=	spacecraft mass
C_D	=	effective drag coefficient
A	=	effective frontal area

This equation was numerically integrated "in reverse" from an initial altitude of 100 km to a final altitude of 700 km. A piecewise exponential fit to the I. C. A. O. 1962 standard atmosphere was used. Figure 1 shows the resulting decay profile. It should be remembered that the result is based on a M/C_DA of 100 kg/m^2 (about 20 lb per square foot) which is the current estimated value for the HDS spacecraft. For a different M/C_DA, multiply all time values on the graph by 0.01 times M/C_DA in kg/m^2. The amount of orbital decay in a given time can be estimated by entering at the left at initial altitude, going horizontal to the curve, then dropping to the bottom scale. Shift to the left by the given time (corrected for any difference in M/C_DA from 100 kg/m^2), go vertically up to the curve, then horizontal to the left scale where the final altitude can be read off.

Orbit lifetime can be read from Figure 1 directly (from altitude at left to curve, down to lifetime in days). Note that, for $M/C_DA = 100\ kg/m^2$, a one-year life means a minimum altitude of 440 km. Because of injection errors, atmospheric variations, and orbit determination requirements, this minimum altitude would not be adequate. For present purposes, a 500-km altitude has been selected. Allowing for an extreme injection error of 60 km in semi-major axis (440 km altitude) then, still allows a one-year life, assuming $M/C_DA = 100\ kg/m^2$. Figure 2 shows the rate of orbital altitude decay as a function of altitude for $M/C_DA = 100\ kg/m^2$.

Launch Site, Booster Constraints

For near-polar orbits, the WTR is clearly the most advantageous site for launching. Severe range-safety constraints in the form of ascent trajectory "dog-legging" or plane-changing would be emposed on an Eastern Test Range (ETR) launch. Thus, for all foreseeable HDS orbital launches, the WTR is recommended as the one to be used.

Detailed analysis of launch vehicle performance (payload weight as a function of orbit parameters) is being carried out in the vehicle operations area of this study. A nominally polar, 500-km circular orbit will be assumed for this study. The approximate payload capability of some feasible launch vehicles from WTR for this orbit are as follows:

- Scout (1966) — 260 lb
- Scout (study) — 390 lb
- DSV-3G Delta (2-stage, direct injection) — 420 lb
- DSV-3G Delta (2-stage, Hohmann Transfer) — 670 lb

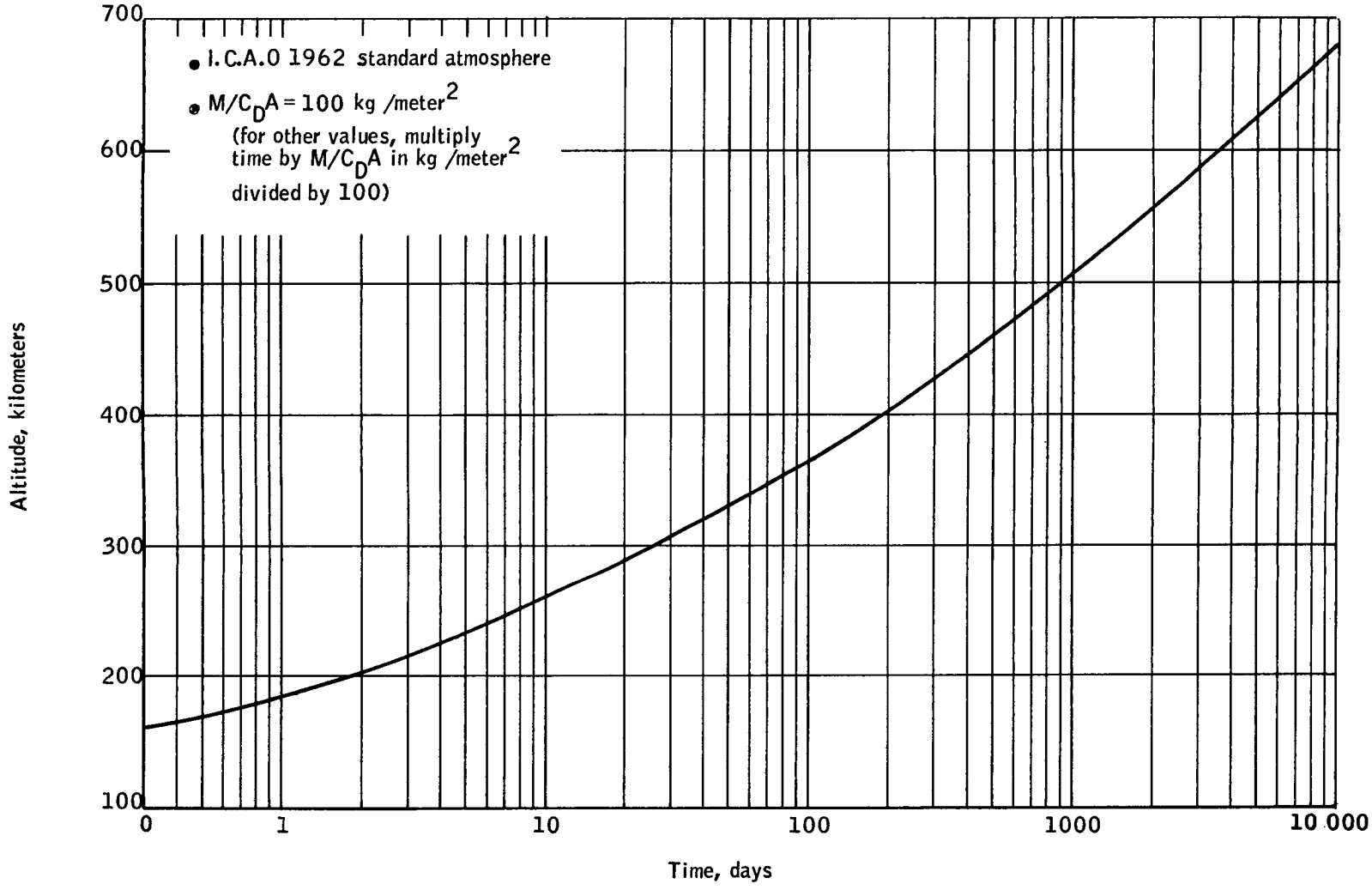


Figure 1. Circular Orbit Decay Profile

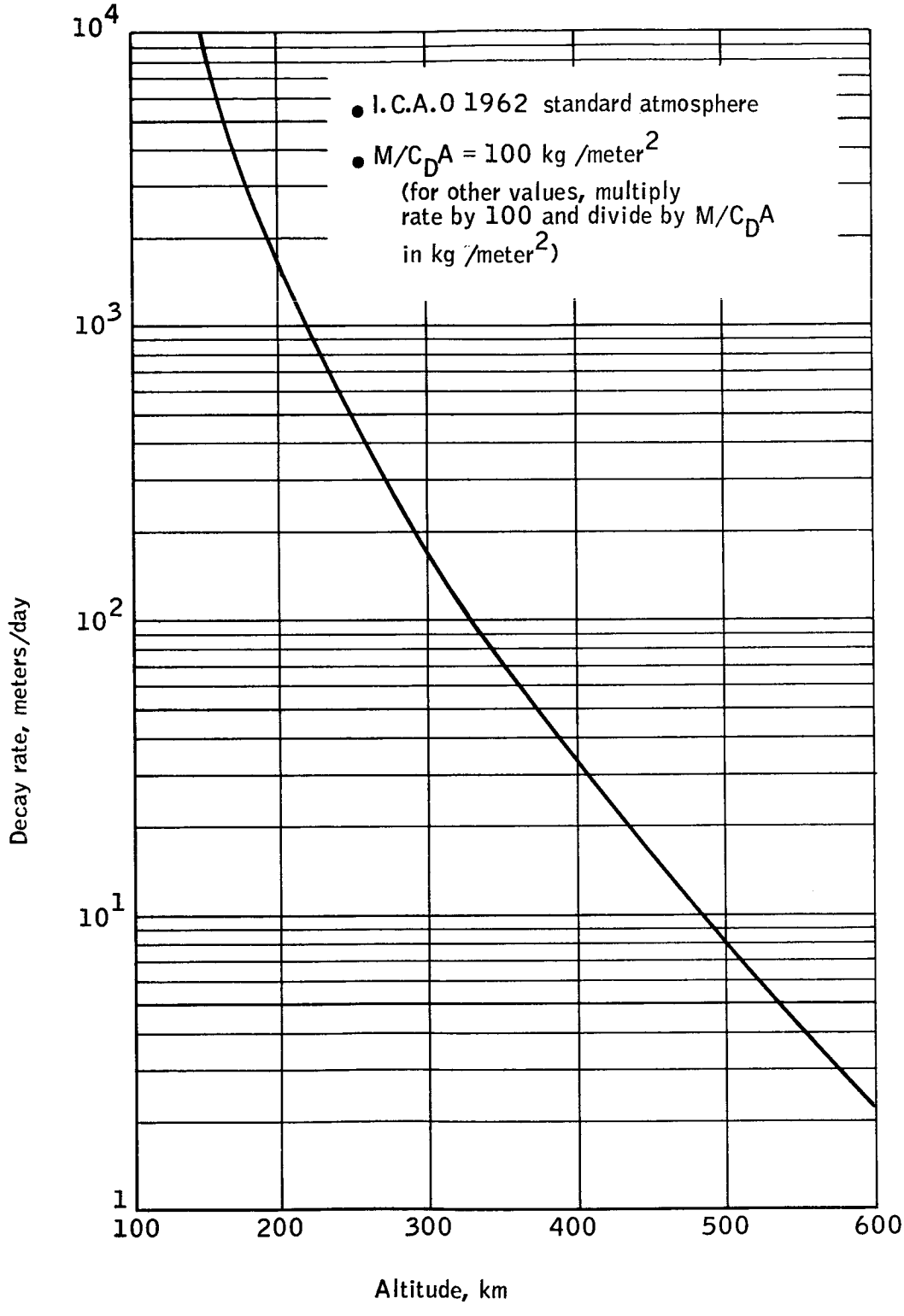


Figure 2. Circular Orbit Decay Rate

- DSV-3L Delta (2-stage, direct injection) 790 lb
- DSV-3E/X-258 Delta 1050 lb
- DSV-3L Delta (2-stage, Hohmann Transfer) 1210 lb
- DSV-3L/FW-4 Delta 1970 lb

The use of 2-stage versions of the Delta poses a particular advantage -- increased injection accuracy. While this is not extremely important for all missions, it is crucial to attainment of sun-synchronous orbits such as the selected orbit. Based on available data, an initial recommendation of the DSV-3G or DSV-3L (two stage) Delta vehicle for the HDS mission is indicated. The estimated injection errors for the 2-stage Delta (ref. 1) are approximately:

Δi (inclination)	0.06°, 1 sigma
Δa (semi-major axis)	10 n. mi. = 18.5 km, 1 sigma

Converting this to an equivalent total 3-sigma error in inclination (in terms of effect on nodal precession rate) for a 500 km, sun-synchronous orbit gives

$$\Delta i_{3\delta} = 0.266°$$

This value was used in predicting possible drift of the sun-synchronous orbit relative to the sun. A more complete error evaluation of injection dispersions was performed by Douglas, and will be covered later.

Solar Illumination Profiles

Evaluation of solar-illumination and sun-angle profiles has been carried out using a computer. A description of the program (SHASTA) is given in Appendix A. With inputs consisting primarily of orbit altitude, inclination, initial node location, and date of launch, and assuming circular orbits, the program yields a time history of 1) fraction of orbit in earth's shadow, 2) angle from sun-line to orbit-perpendicular, and 3) local sun-time at ascending node. The program takes into account the orbital motion of the earth, including first- and second-order eccentricity terms. It also takes into account the first-order nodal precession of the spacecraft orbit itself.

Figures 3 through 7 are sample plots showing the shadow fraction and sun-angle for three sun-synchronous and two polar orbits. Figures 3 through 5 are for identical orbit altitudes, inclinations, and launch dates, with only the launch time (corresponding to nodal location) being different. These three orbits are sun-synchronous, and the resulting difference in profiles illustrates the strong effect of initial nodal location on this type of orbit.

Figures 6 and 7 are for identical polar orbits, one for a noon launch, the other for a 6 p.m. launch, both on the same day. Although the difference

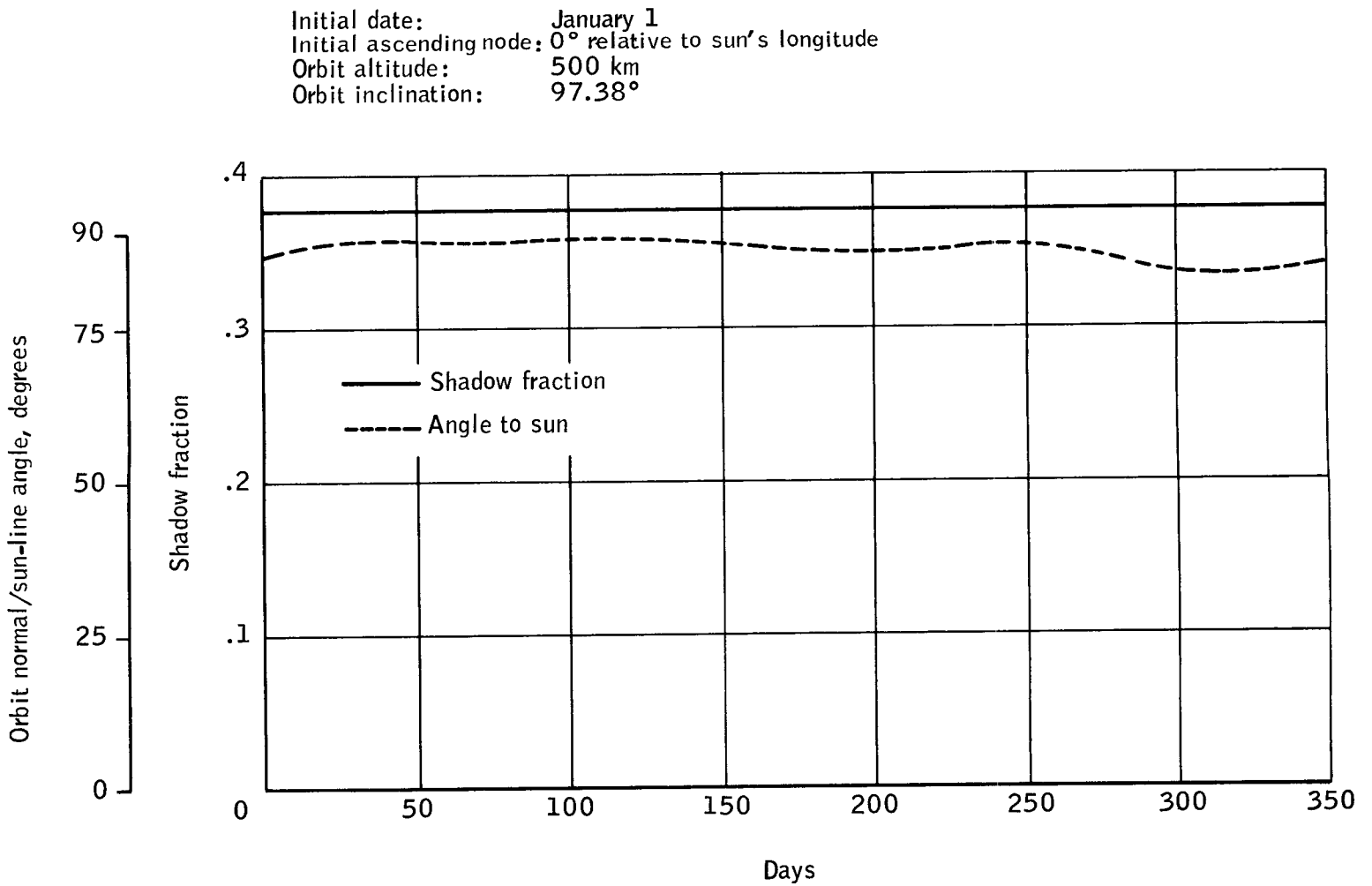


Figure 3. Shadow Fraction and Sun Angle, 500 km, Sun-Synchronous Orbit, Noon Launch

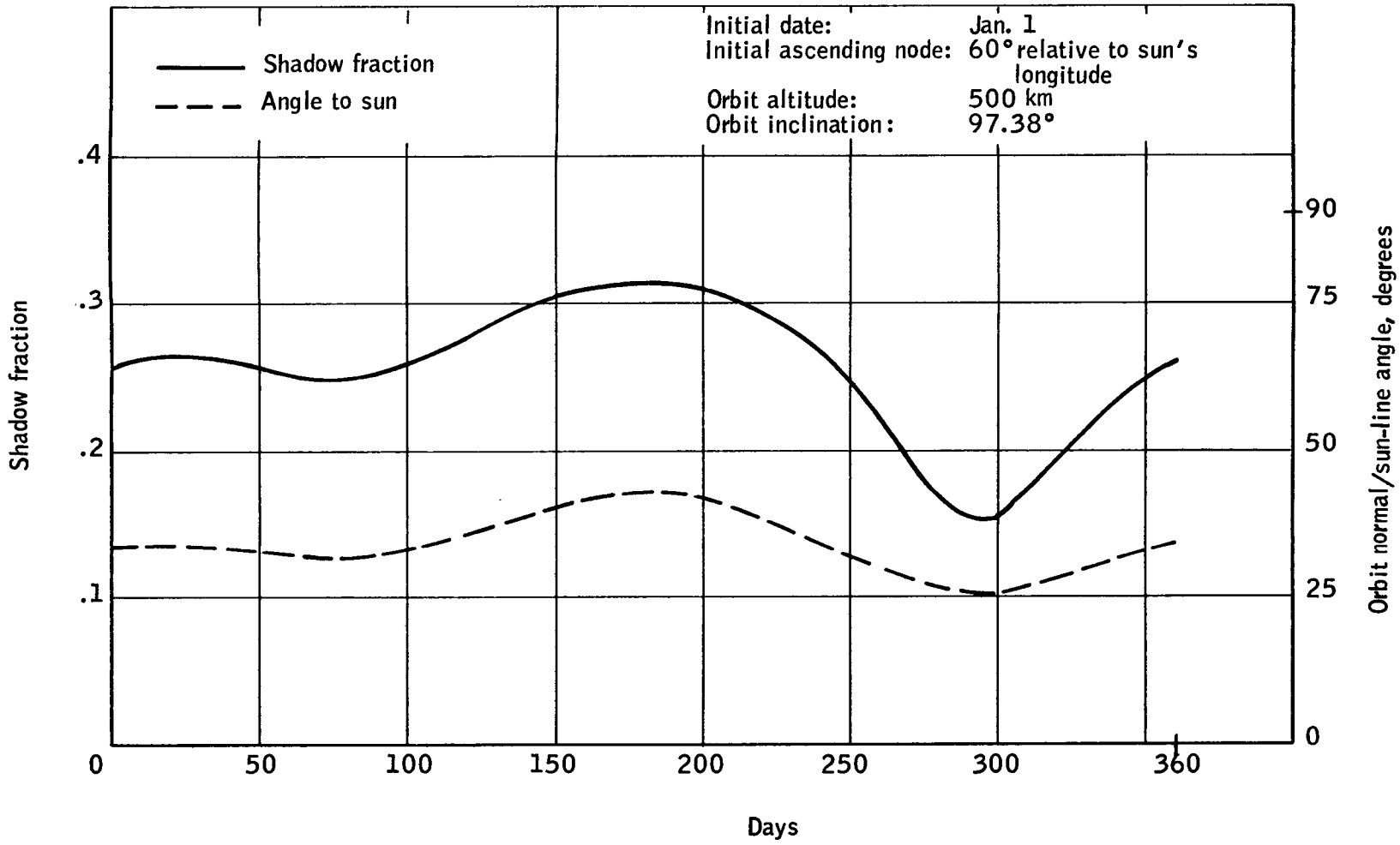


Figure 4. Shadow Fraction and Sun Angle, 500 km, Sun-Synchronous Orbit, 4 p.m. Launch

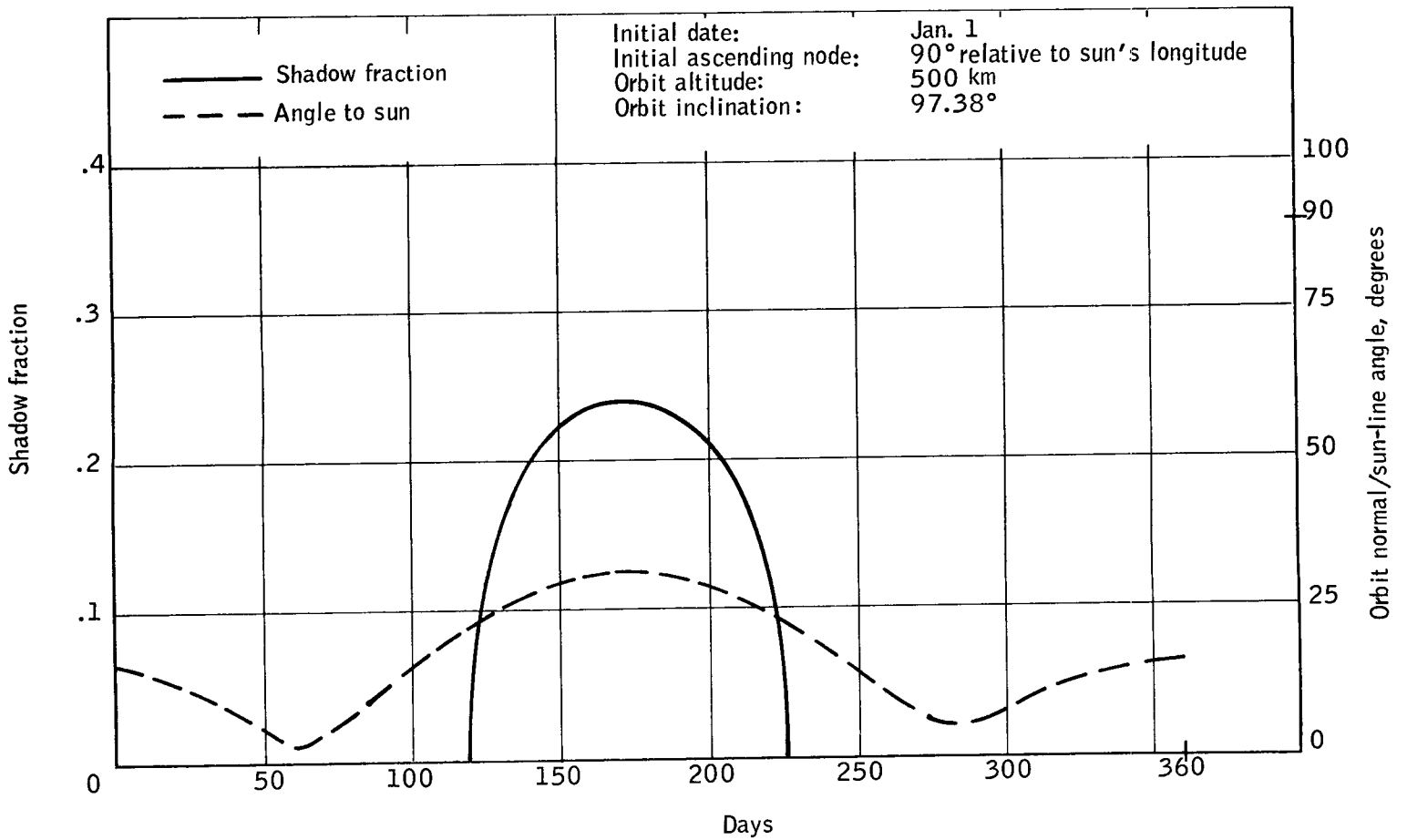


Figure 5. Shadow Fraction and Sun Angle, 500 km, Sun-Synchronous Orbit, 6 p.m. Launch

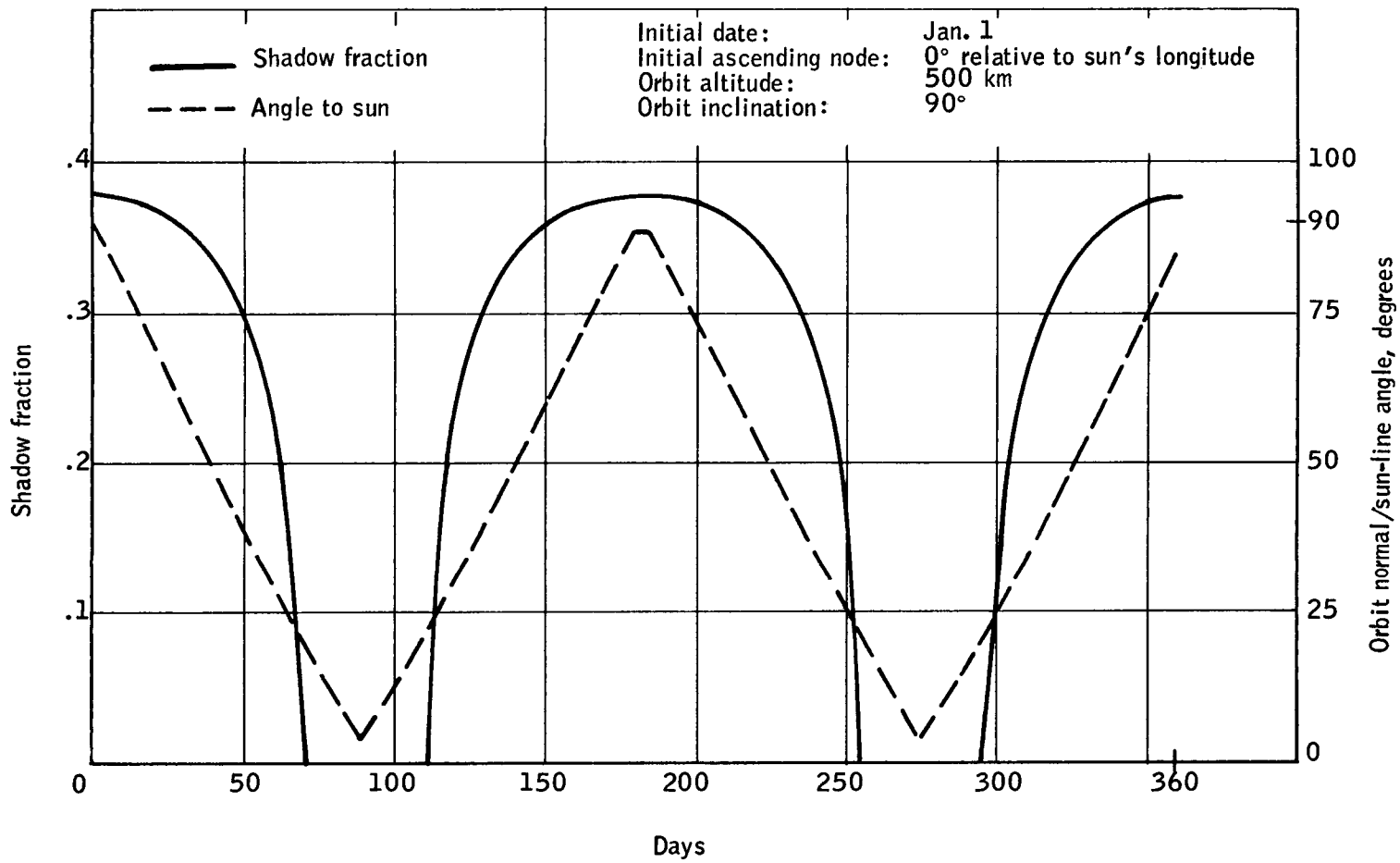


Figure 6. Shadow Fraction and Sun Angle, 500 km, Polar Orbit, Noon Launch

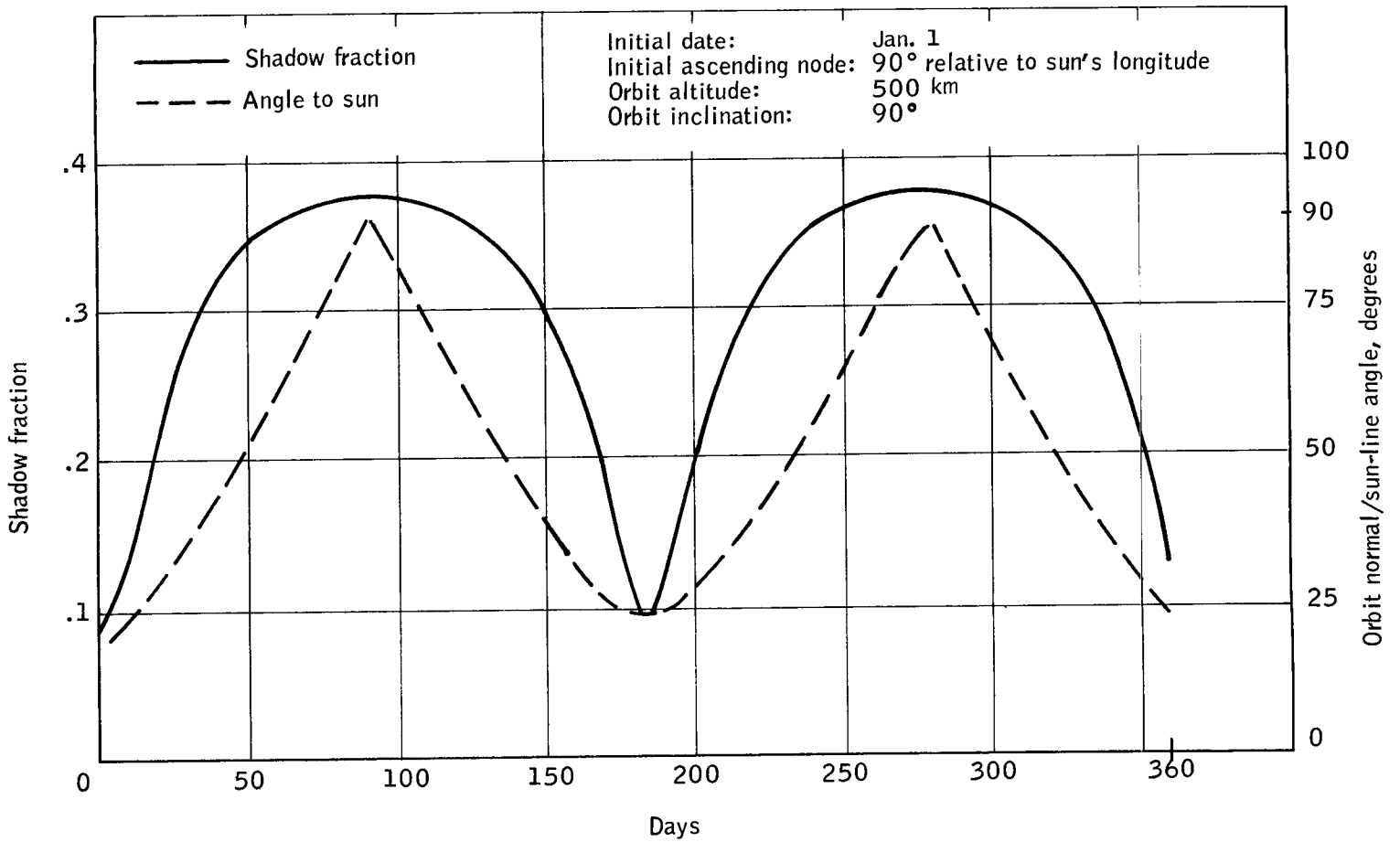


Figure 7. Shadow Fraction and Sun Angle, 500 km, Polar Orbit, 6 p.m. Launch

in profiles is significant, the effect on spacecraft design is not significant because of the basic cyclic character in either case.

It should be mentioned that the angles plotted in Figures 3 through 7 are restricted to the range 0° to 90°. For the polar orbits, it should be pointed out that, in reality, the sun moves from one side of the orbit plane to the other. This would be obvious if the sun-line and orbit-normal were taken as vectors rather than merely lines, in which case the angles would be from 0° to 180°. Later plots will show this effect.

Dozens of parameter combinations were tested, and certain generalizations became obvious as the data was evaluated. The polar orbit always exhibits a sun-shadow profile and sun-angle profile which places severe demands on a "no-moving-parts" spacecraft, regardless of launch date or initial nodal location. The sun-synchronous orbit, on the other hand, possesses clear-cut advantages from the same viewpoint. In this case, however, launch date and initial nodal location are both relatively significant parameters.

Telemetry-Tracking Coverage

Evaluation of the telemetry and tracking coverage using the STADAN network was carried out using three computer programs (TECO, SICO, and PICO). The primary inputs to these programs are orbit altitude and inclination, minimum elevation, minimum visibility time (SICO) and (PICO) and a nodal longitude step size. All programs assume circular orbits. TECO outputs the visibility times for each station (maximum 15 stations) on each orbit (ascending-node to ascending-node) for ascending node longitudes from zero to 360° with a step size given by the input nodal longitude step. The sequence of coverage which would occur in an actual flight cannot be easily obtained from TECO output. SICO, on the other hand, generates the time sequence which would occur on "typical orbiting days." Each "day" corresponds to a particular initial ascending node, starting with zero longitude. New "days" are generated for increasing initial-node longitudes, incremented by the input nodal longitude step, until the "cycle" begins to repeat. The total output then represents a fairly comprehensive sampling of all possible "orbiting days" which will occur in practice. PICO is used to generate a time sequence similar to SICO, except that the sequence starts at injection and runs continuously from that point. Such output is useful only for a reasonably short time (days) after launch.

Study of near-polar orbits using the STADAN system does not show any drastic variations in coverage with the various orbits. Figures 8 and 9 show TECO output for two 500-km orbits, one sun-synchronous and the other at 70° inclination. The stations used are the STADAN sites equipped for range/range-rate tracking (Alaska, Carnarvon, Rosman, Santiago, and Tananarive). Note that the total coverage (per orbit) and maximum single-station time (per orbit) are both plotted. The minimum elevation is 10°. Coverage of these two orbits changes when the set of station changes, of course, and use of the entire STADAN system tends to reduce the differences in coverage. Since the differences between coverage on the orbits under

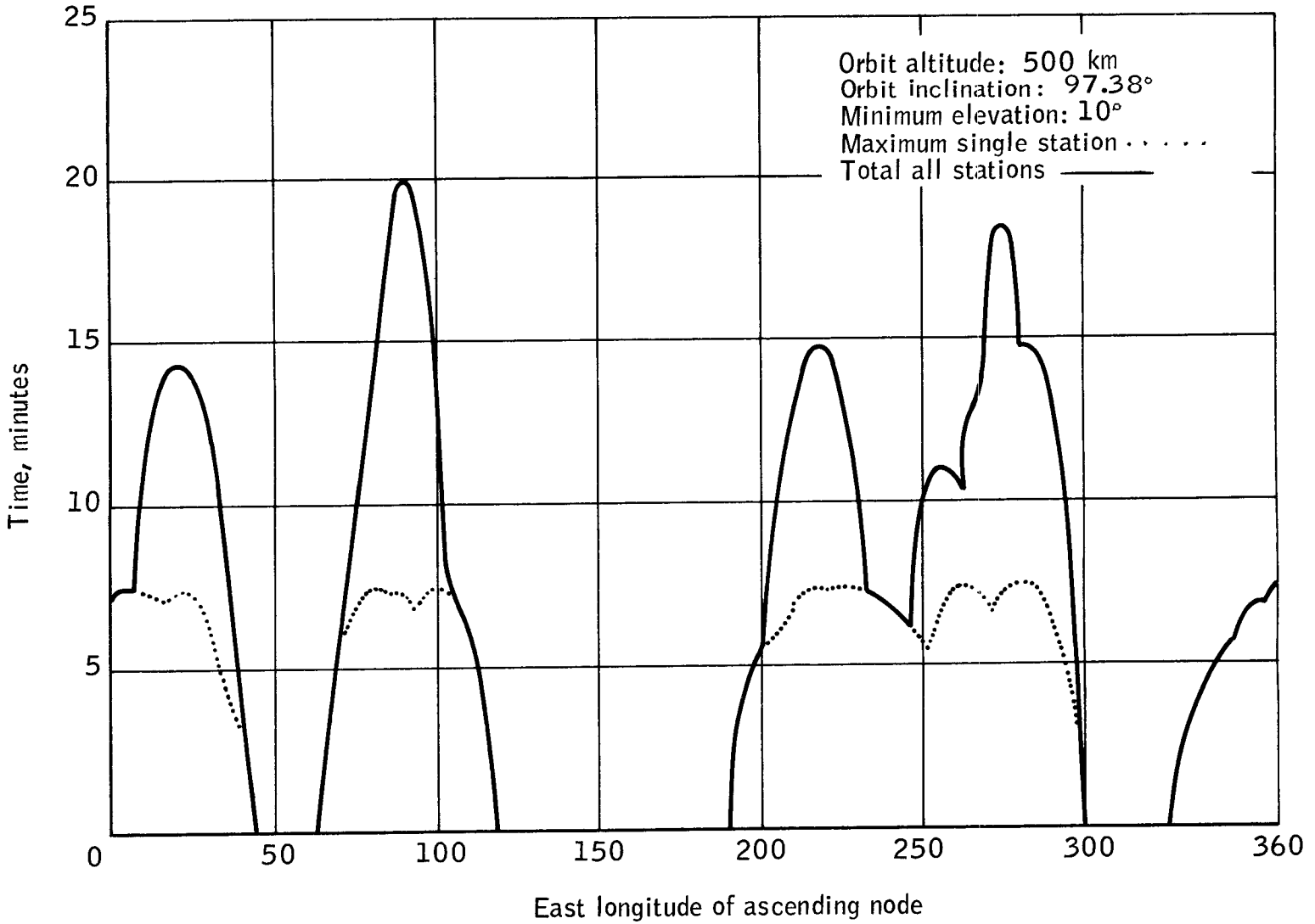


Figure 8. STADAN System Coverage: Time Above Minimum Elevation, Sun-Synchronous Orbit, 500 km

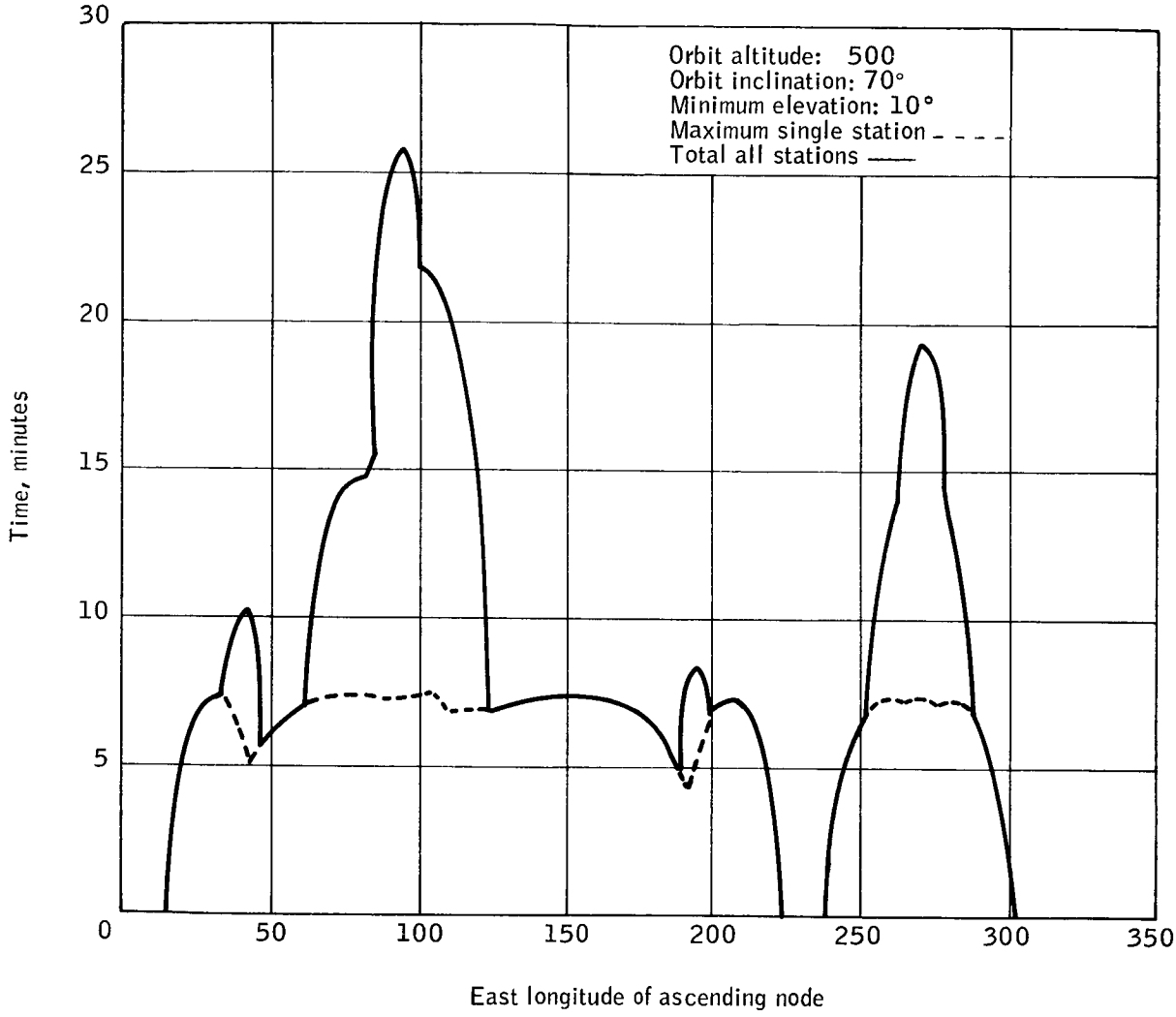


Figure 9. STADAN System Coverage: Time Above Minimum Elevation, 70° Orbit, 500 km

serious consideration were not great, tracking/telemetry coverage was not a significant orbit-choice tradeoff parameter. A slight advantage in coverage is obtained by using a polar orbit rather than a sun-synchronous one, but this is overweighed by sun-angle considerations. The tracking/telemetry coverage analysis was carried out in detail in the position determination and data acquisition studies and is covered in those sections.

ORBIT SELECTION

Based on the parametric data and subsequent evaluation, an initial baseline orbit was selected. The parameters of this orbit are as follows:

- Altitude — 500 km
- Inclination — 97.38° (sun-synchronous)
- Launch — South from WTR (near 6 a.m. about 28 October)

This orbit is sometimes referred to as the "twilight" or "dawn-dusk" orbit. Figures 10 and 11 show the orbital shadow fraction and sun-line/orbit-normal angle for this orbit. The 3-sigma curves shown correspond to the 3-sigma inclination error of 0.266° mentioned earlier. The nominal curves fall between the curves shown. The desire to obtain diurnal variation data led to definition of a first alternate orbit, the parameters being:

- Altitude — 500 km
- Inclination — 70 deg
- Launch — Not important (6 a.m., 28 October assumed)

Figures 12 and 13 compare the shadow fraction and sun-line/orbit-normal angle for the nominal baseline orbit and the first alternate (70° inclination) orbit. The angles plotted in Figure 13 range from 0° to 180°, using the vector representation rather than the line representation. This accentuates the great difference in illumination profiles between these two orbits and consequent differences in the magnitude of power acquisition, thermal, and experiment shielding problems. The main motivation for the 70° orbit is a "fairly" rapid precession of the orbit plane with respect to the sun while still giving polar coverage.

Further study of expected diurnal data variations led to a second alternate orbit which, at present, stands as the selected nominal orbit. Its parameters are:

- Altitude — 500 km
- Inclination — 97.38° (sun-synchronous)

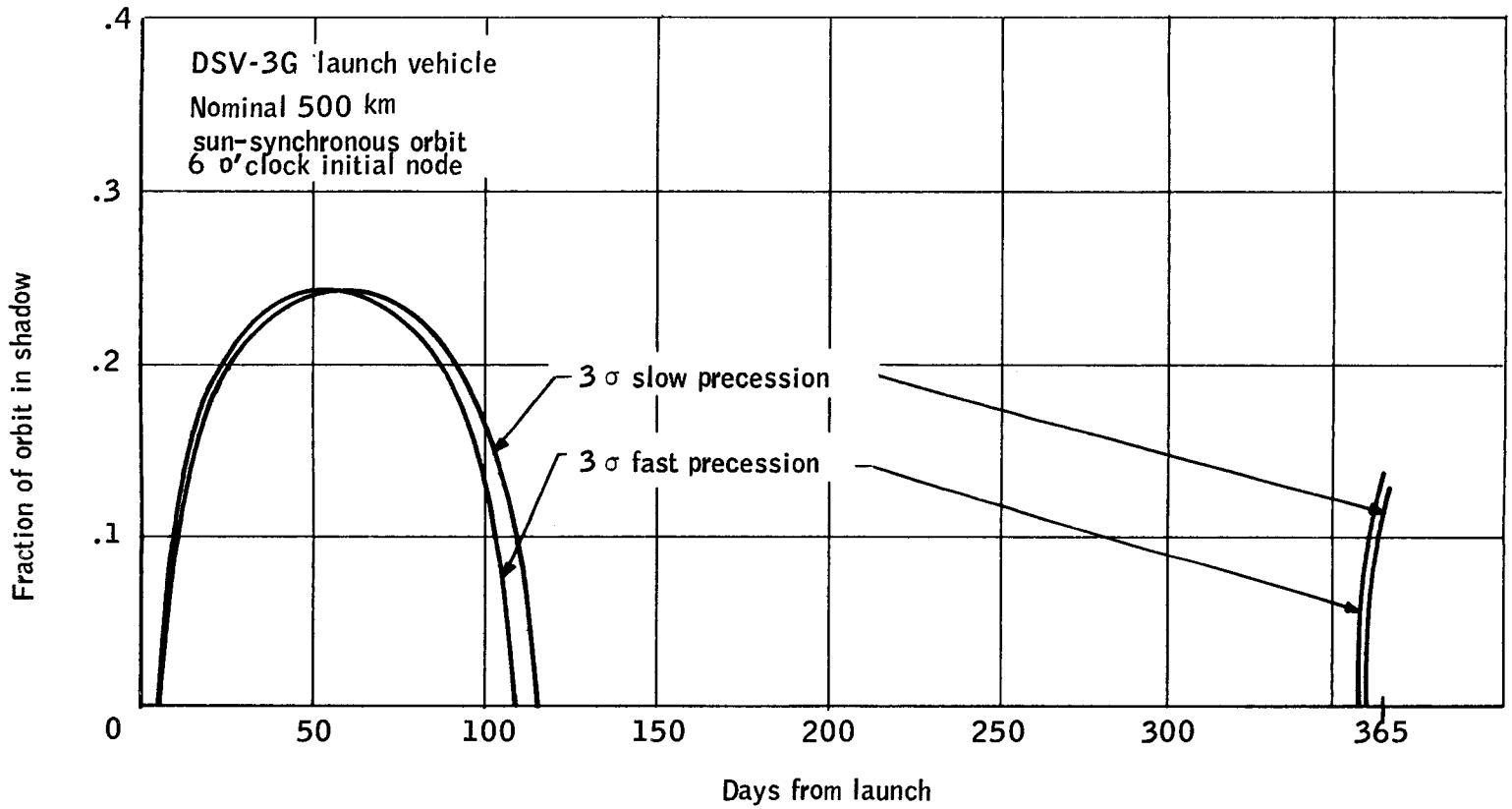


Figure 10. Orbital Shadow Profile Variation Due to Injection Error, DSV -3G

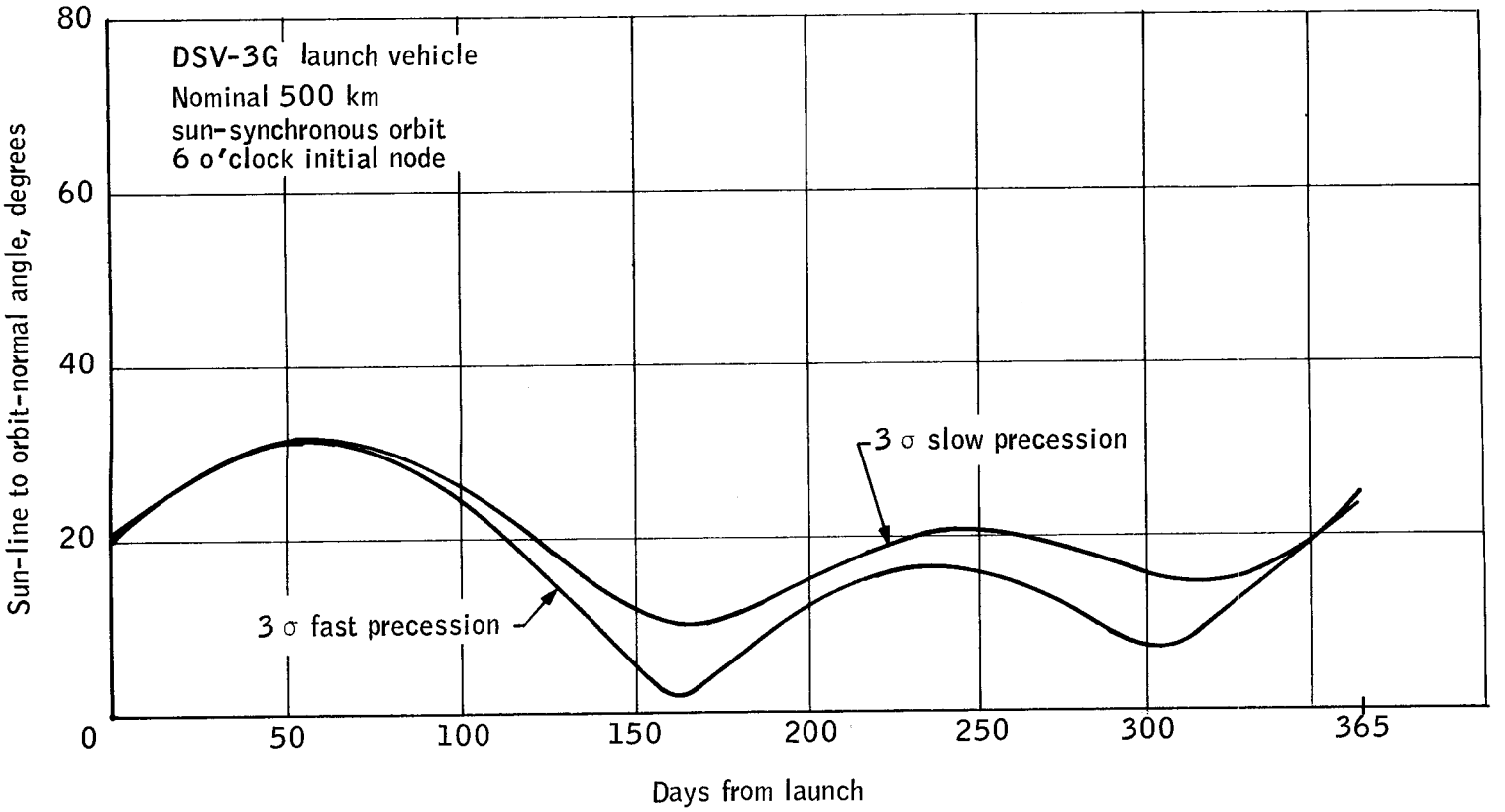


Figure 11. Sun-Line/Orbit - Normal Angle Variation Due to Injection Errors, DSV - 3G

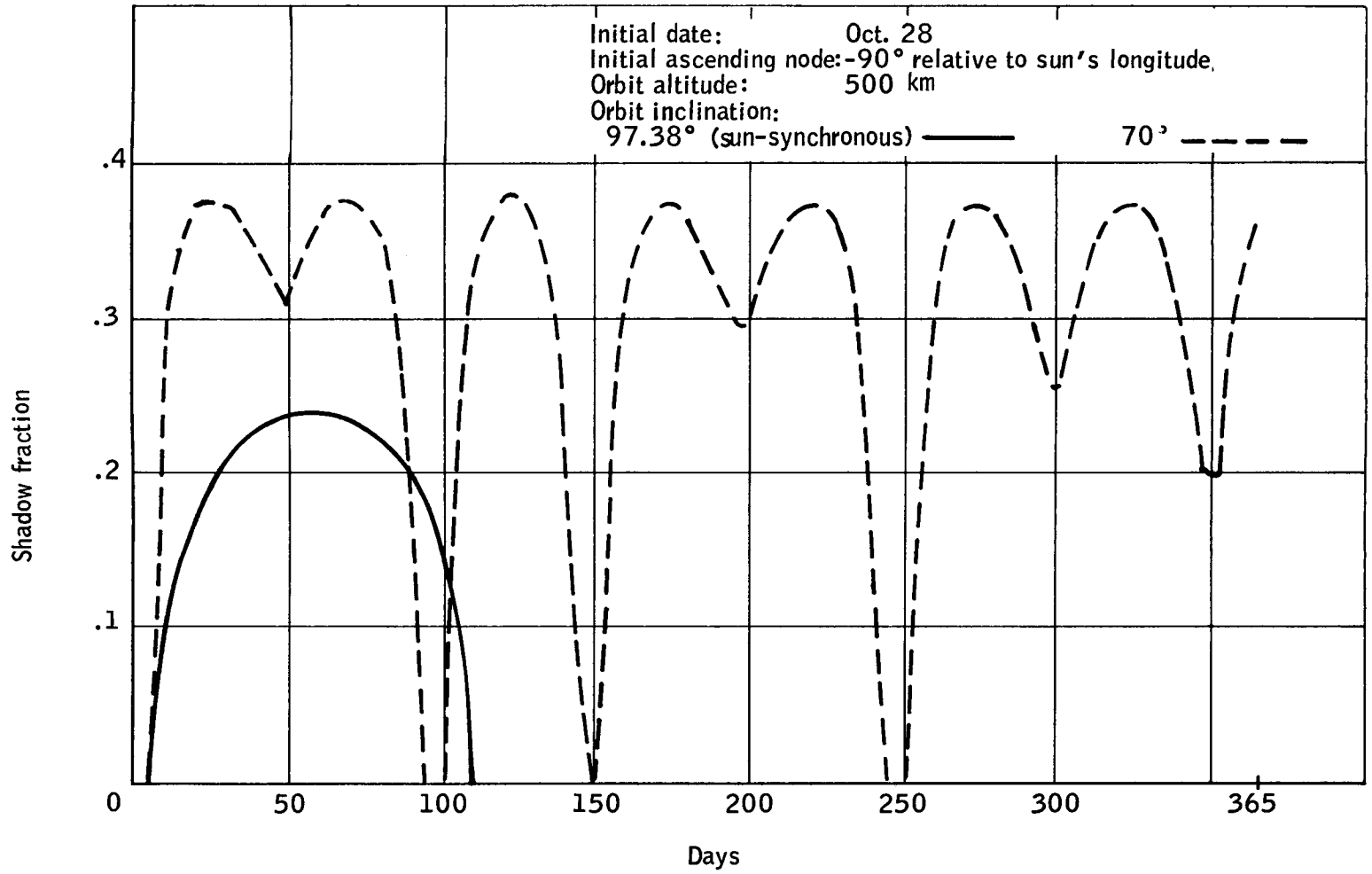


Figure 12. Shadow Fraction, 500 km Orbits

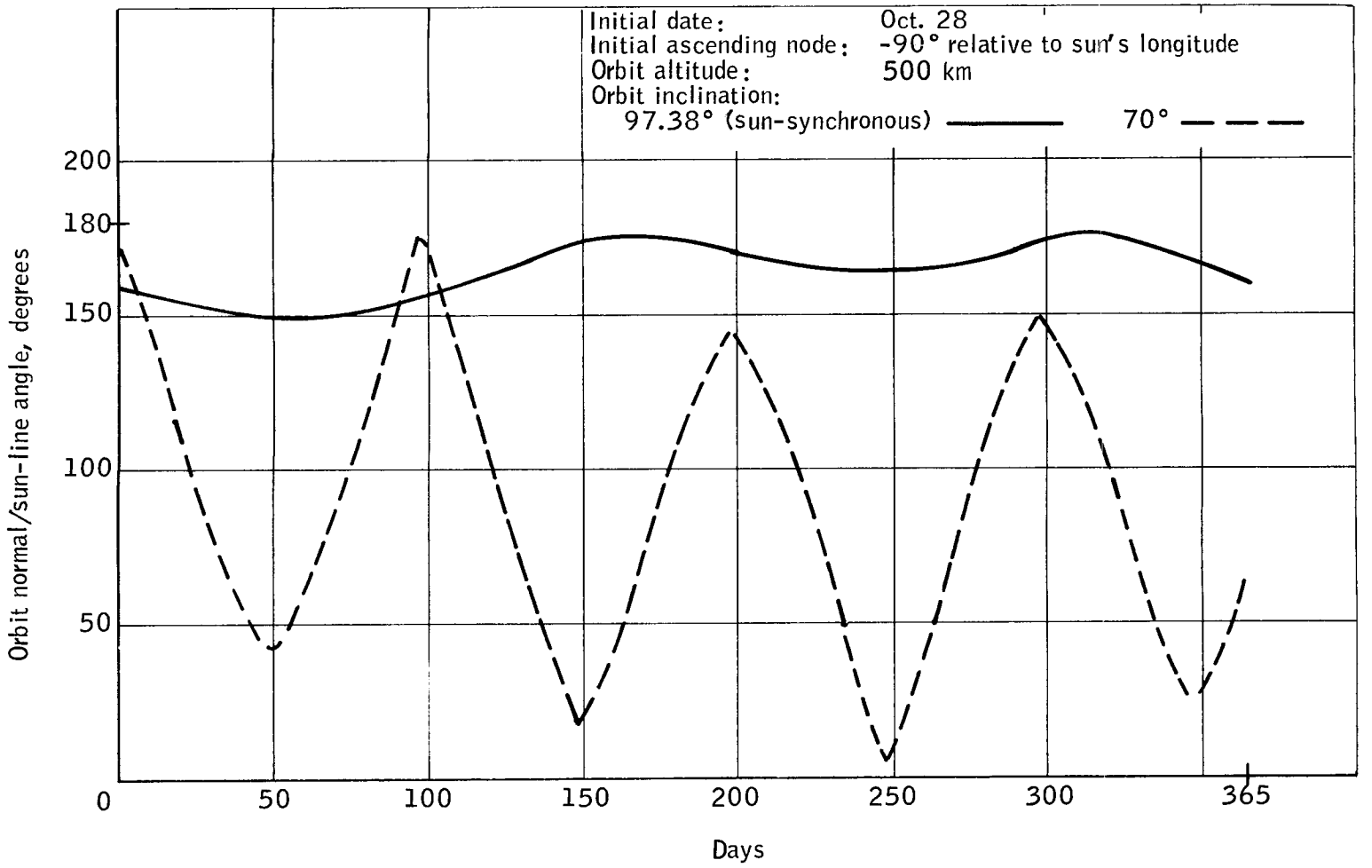


Figure 13. Orbit Normal/Sun-Line in Degrees, 500 km

- Launch — South from WTR
  (near 3 a.m.) 28 October nominal launch date

This orbit, called the "3 o'clock sun-synchronous" orbit, will sample the horizon near the expected diurnal extremes. The characteristics of this orbit will be discussed in the following section.

DETAILED ANALYSIS OF SELECTED ORBIT

The potential orbital profiles were subjected to considerable analysis and comparison. The primary areas affected were 1) solar power acquisition, 2) thermal control, 3) experiment package, and 4) polar and diurnal data coverage. After careful study, the "3 o'clock" sun-synchronous orbit was chosen as the best compromise. In fact, this orbit appears to be the best from the standpoint of polar and diurnal data coverage. From the point of view of the power subsystem, this orbit is satisfactory. Although a nodal time nearer the 6 o'clock would be preferable.

Figures 14 through 16 illustrate the sun-earth-orbit geometry as a function of time for the 3 o'clock orbit. The 28 October launch date is used, although this is not a requisite; effects of other launch dates will be seen later. In each case, curves for 3-sigma fast and 3-sigma slow precession are included with the nominal curve. These 3-sigma curves are based on the 0.266° 3-sigma inclination error, corresponding to use of two-stage Delta launch vehicle. Launch window is assumed negligible in these curves. (A more comprehensive error analysis, including updated injection dispersions and launch window allowance, is given at the end of this section.)

Figure 14 shows the orbital shadow fraction variation. As the curves indicate, almost a constant percentage of sun time is available with this profile.

Figure 15 shows the variation in sun-line/orbit-normal angle. Allowing for 3-sigma variations, angles from 31° to 65° are possible, although the nominal orbit varies only from 44° to 57°. These variations have great impact on the power subsystem problems since the power output is roughly proportional to the cosine of this angle.

Figure 16 shows the local solar time at the ascending node versus time from launch. The nominal orbit holds within 30 min of 3 o'clock, while the 3-sigma curves give variations of up to 50 min from 3 o'clock.

The detailed evaluation of STADAN system coverage of the selected orbit will be given in the position determination and data acquisition sections. As mentioned earlier, this data was produced by the computer programs TECO, SICO, and PICO. These programs utilize a circular orbit model to produce coverage profiles on either a "statistical" (independent of exact orbit parameters) basis (TECO, SICO) or a true time sequence basis (PICO).

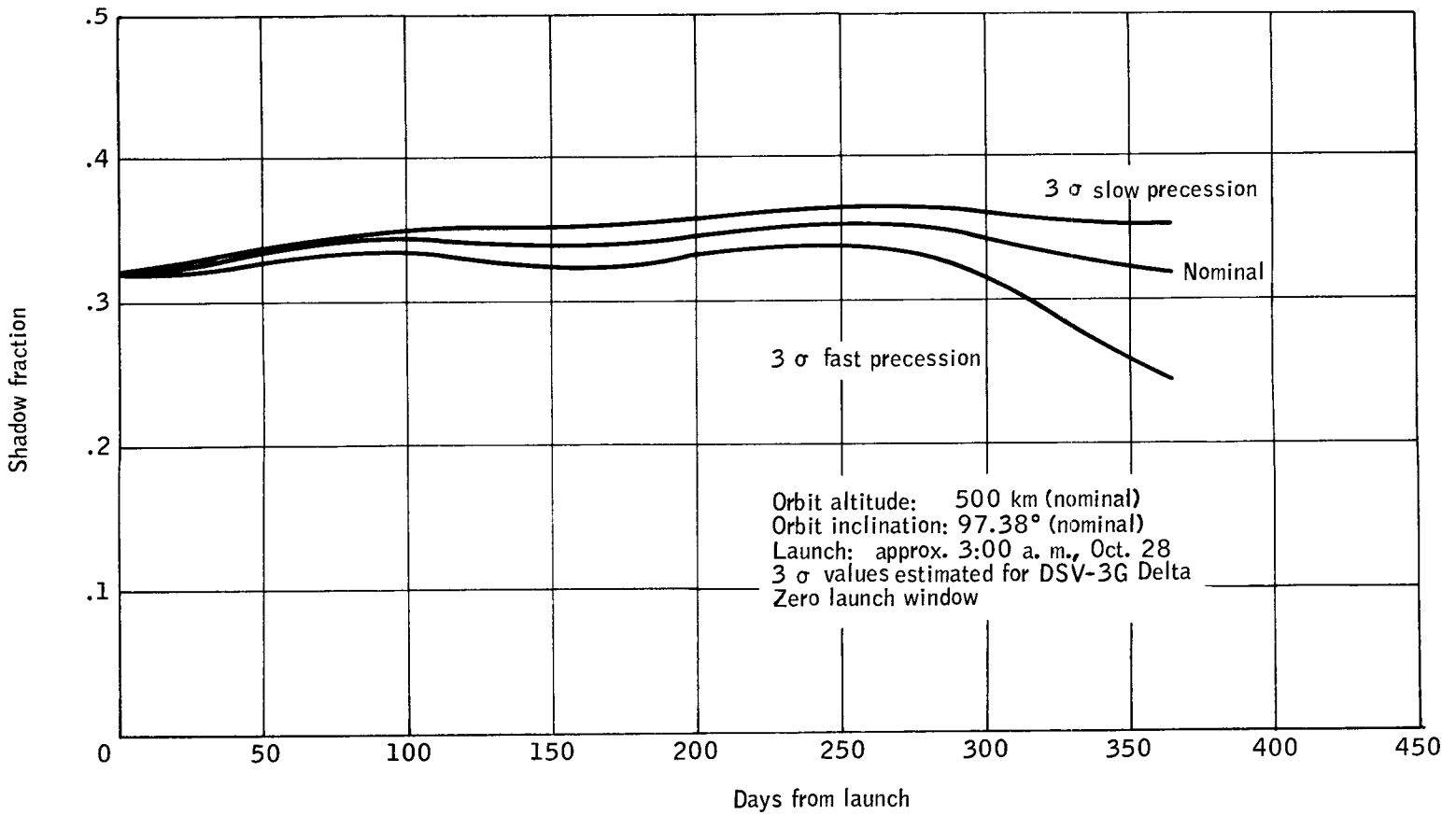


Figure 14. Shadow Fraction Versus Days

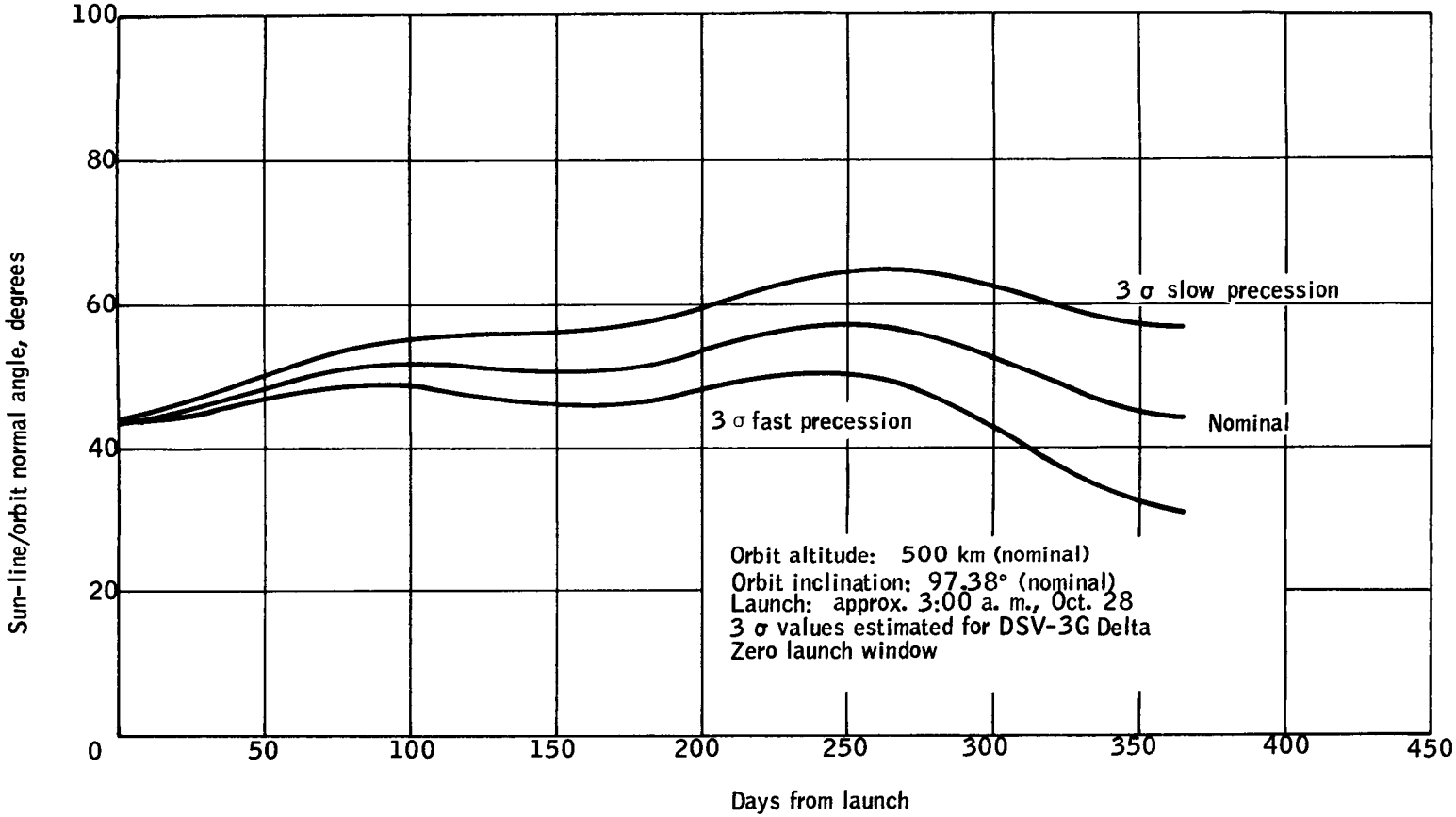


Figure 15. Sun-Line/Orbit Normal Angle Versus Days

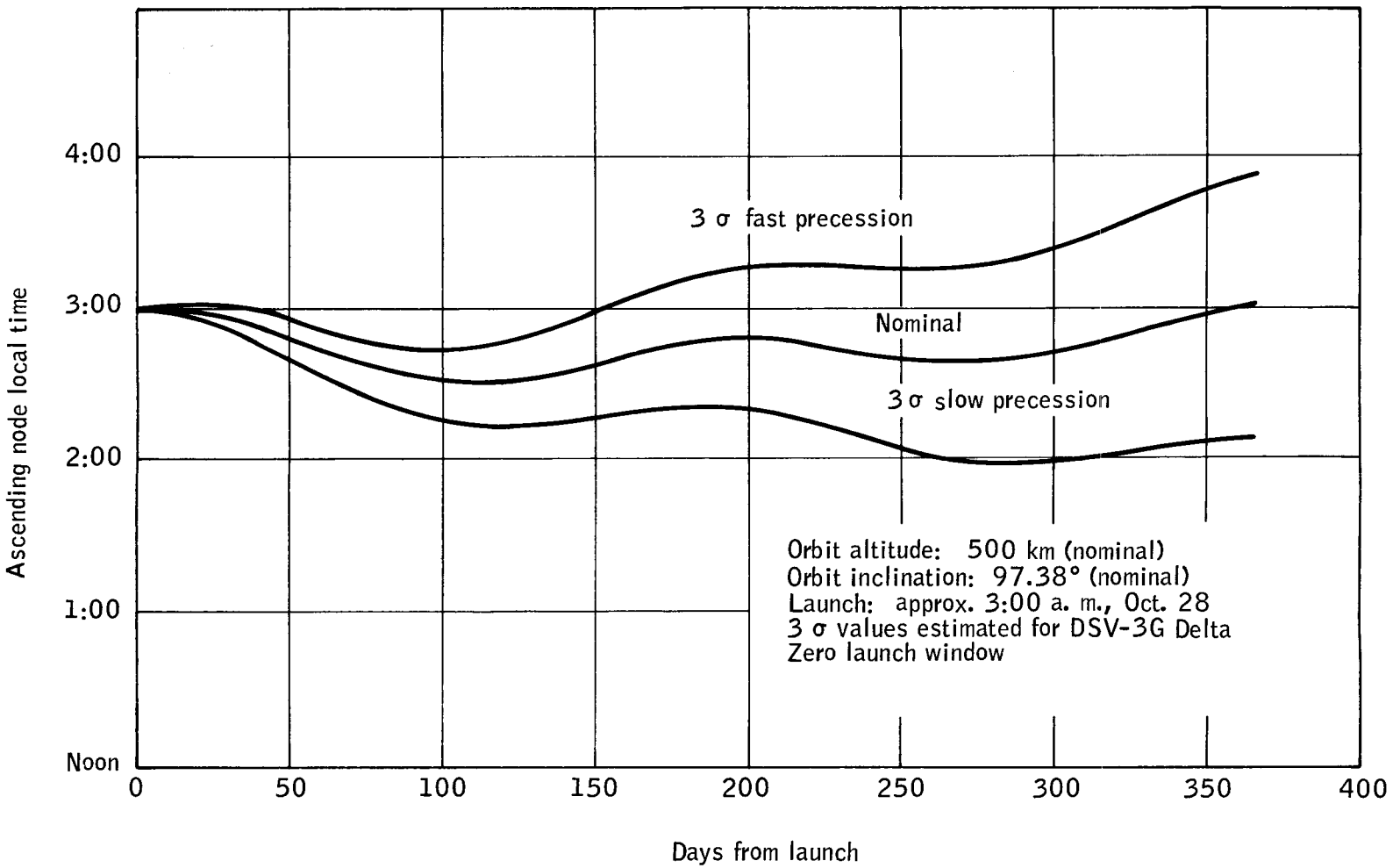


Figure 16. Ascending Node Local Time Versus Days

Recent simulation of the 2-stage Improved Delta launch vehicle trajectory by Douglas Missile and Space Systems Division has resulted in specific injection error values, the pertinent ones being:

Inclination	0.04°, 1-sigma
Altitude	2 n. mi., 1-sigma
Velocity	12 fps, 1-sigma

Assuming the altitude and velocity effects on semi-major axis can be statistically combined by root sum squaring, (this is probably conservative since they are likely negatively correlated), the one-sigma inclination and semi-major axis errors are then

$$\Delta i \text{ (1-sigma)} = 0.04°$$

$$\Delta a \text{ (1-sigma)} = 7.6 \text{ km}$$

The resultant 3-sigma precession relative to the sun for the rss effect of these errors is then about 7.15°/yr. The inclination error which would, itself, cause this total amount of drift is about 0.15°. This value has been used as a single injection dispersion to compute sun-angle variations for the mission.

In addition to the dispersions due to injection errors, launch time will affect the sun-angle profiles. For current purposes, a 30-minute launch window is assumed, centered on the nominal launch time. To give conservative results, a 15-minute early launch will be combined with 3-sigma fast precession (high inclination) error. This accentuates sun-angle dispersion relative to the nominal case.

It should be pointed out that the sun-angle profiles and their associated error "envelopes" can be manipulated to some extent by adjusting launch parameters. For instance, a delay in launch time (past approximately 3:00 a.m.) would normally cause the sun-angle plots to be shifted downward. By slightly decreasing the launch azimuth, however, the sun-angle curves would be biased upward at the right end, tending to at least partially compensate for the launch delay. For small increments in launch time and in launch azimuth, it can be stated that:

(1) later launches cause a downward shift of the whole sun-angle curve and an upward shift in the whole nodal-crossing-time curve; vice versa for early launches

(2) increased launch azimuths cause a downward bias at the right end of the sun-angle curve and an upward bias at the right end of the nodal-crossing-time curve; vice versa for decreased launch azimuths.

Figures 17 through 22 show the resulting sun-angle profiles for six launch dates, the nominal (28 October) in Figure 17.

The complement of the orbit-normal/sun-line angle is the minimum radiometer-scan line/sun-line angle if the radiometer scans in the orbit plane. Figure 23 shows the variation of the forward-scan/sun-line angle (at the time of "scan-intercept-earth") with latitude of the scan point, for the "worst case" 28 October 15-minute early launch, 3-sigma slow precession orbit.

CONCLUSIONS

Based on the analyses conducted in the mission profile study, together with the various system and experiment definition investigations, the following conclusions have been reached:

- A nominally circular, 500-km altitude, sun-synchronous orbit (97.38° inclination) with initial ascending node at 3:00 p.m. local time and launch date of 28 October meets experiment and system requirements for the HDS mission.

- The WTR should be used for the launch site and a 2-stage Improved Delta vehicle should be used to achieve adequate injection accuracy.

- A 30-minute launch window, in conjunction with the latest Douglas estimates of 2-stage Delta 3-sigma injection errors results in possible sun-line/orbit normal angles between 29° and 65° by the end of a one-year mission. The orbital shadow fraction can vary from 0.0221° to 0.364° and the nodal crossing local time can vary from 2:00 p.m. to 4:04 p.m.

- The possibility remains to increase orbit altitude somewhat should this become necessary to increase orbit prediction accuracy or ensure minimal orbit decay during the mission.

- The possibility remains to change or place specific constraints on launch date, to reduce allowable launch window, to bias launch window centering, to compensate for launch delay with appropriate precession-effecting guidance corrections, or to change the nominal launch time. These actions may be desirable or necessary during the development program either a) because of experiment requirements or b) because of sun-angle considerations in the system design.

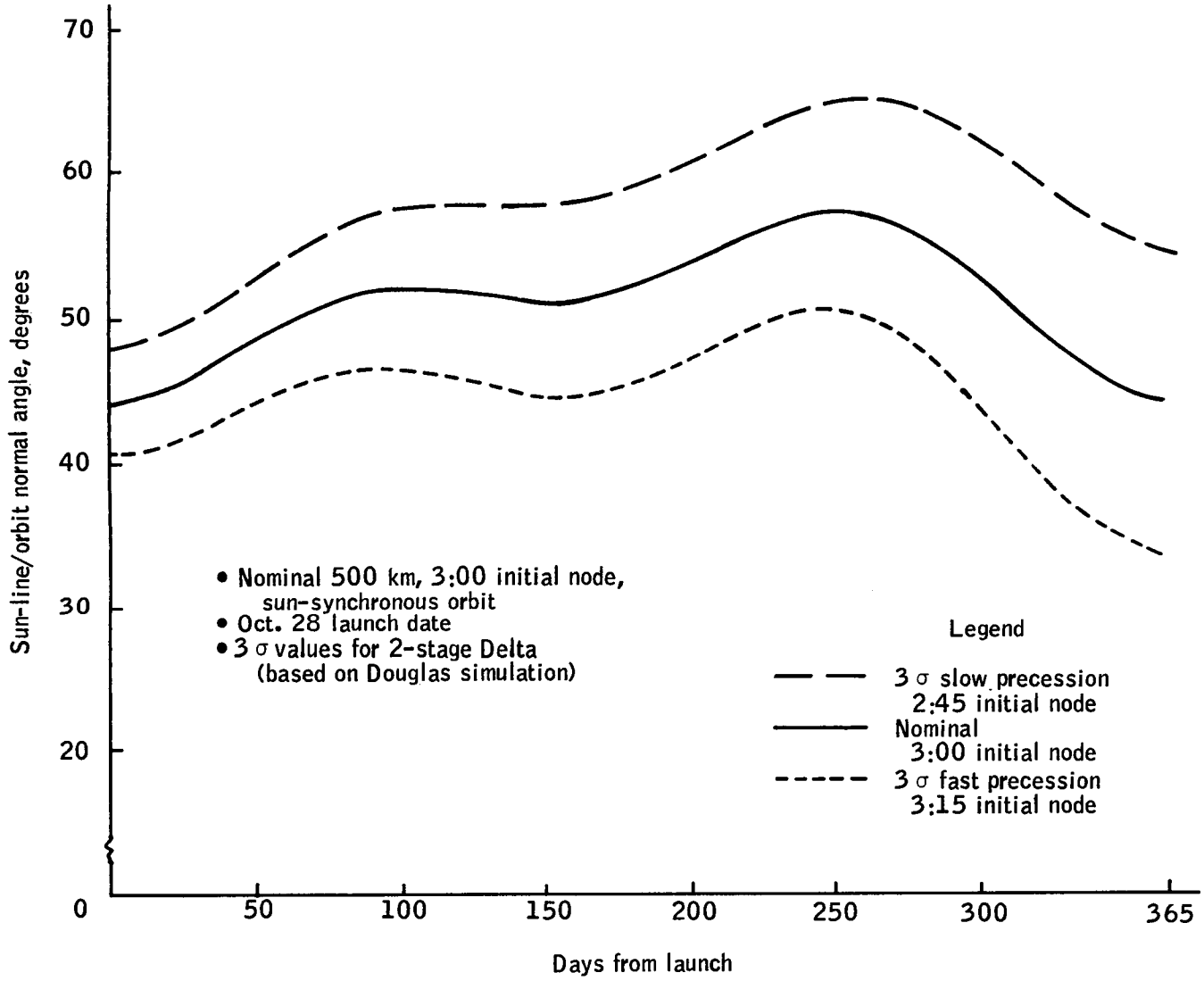


Figure 17. Sun-Line/Orbit Normal Angles, Oct. 28 Launch Date

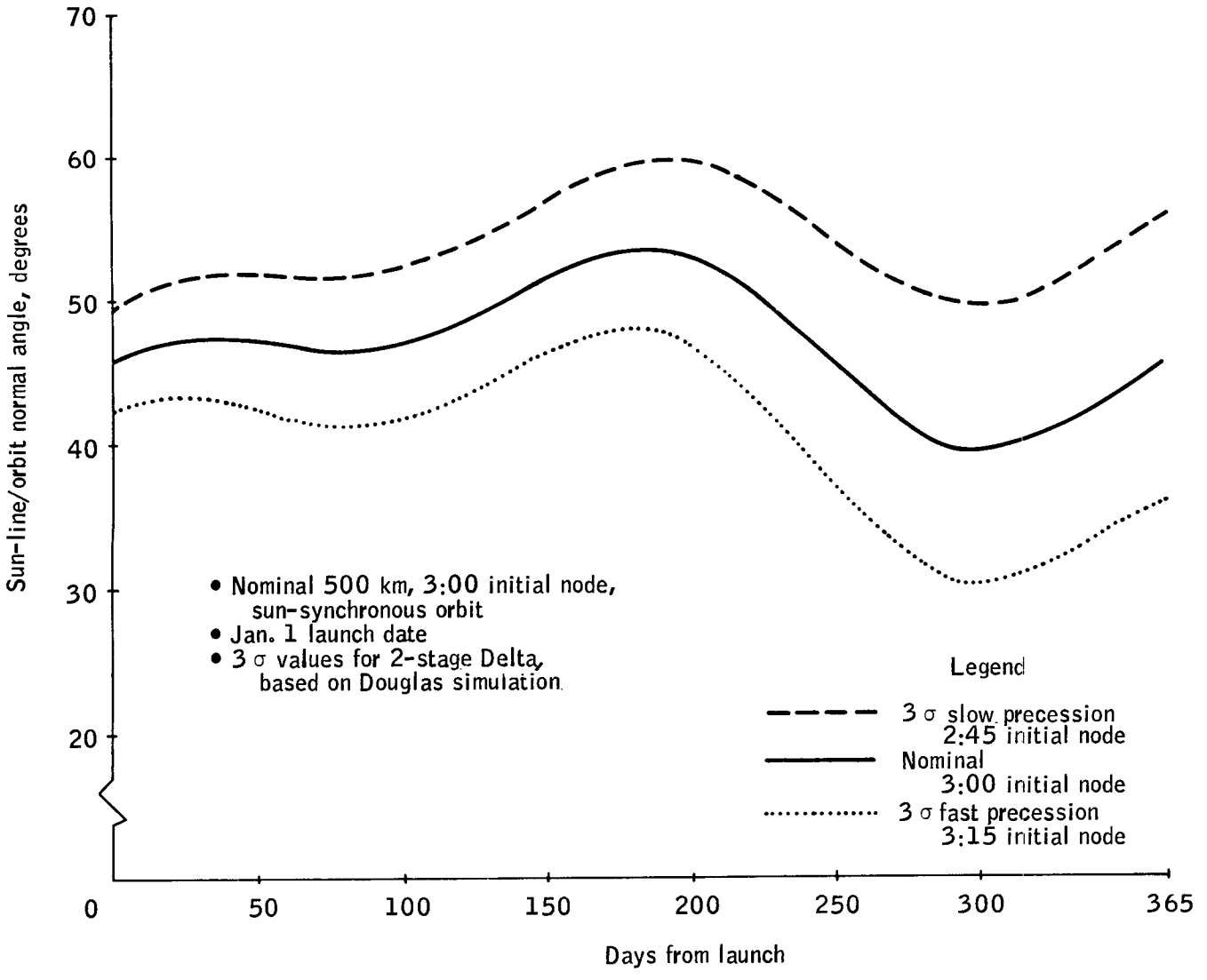


Figure 18. Sun-Line/Orbit Normal Angles, Jan. 1 Launch Date

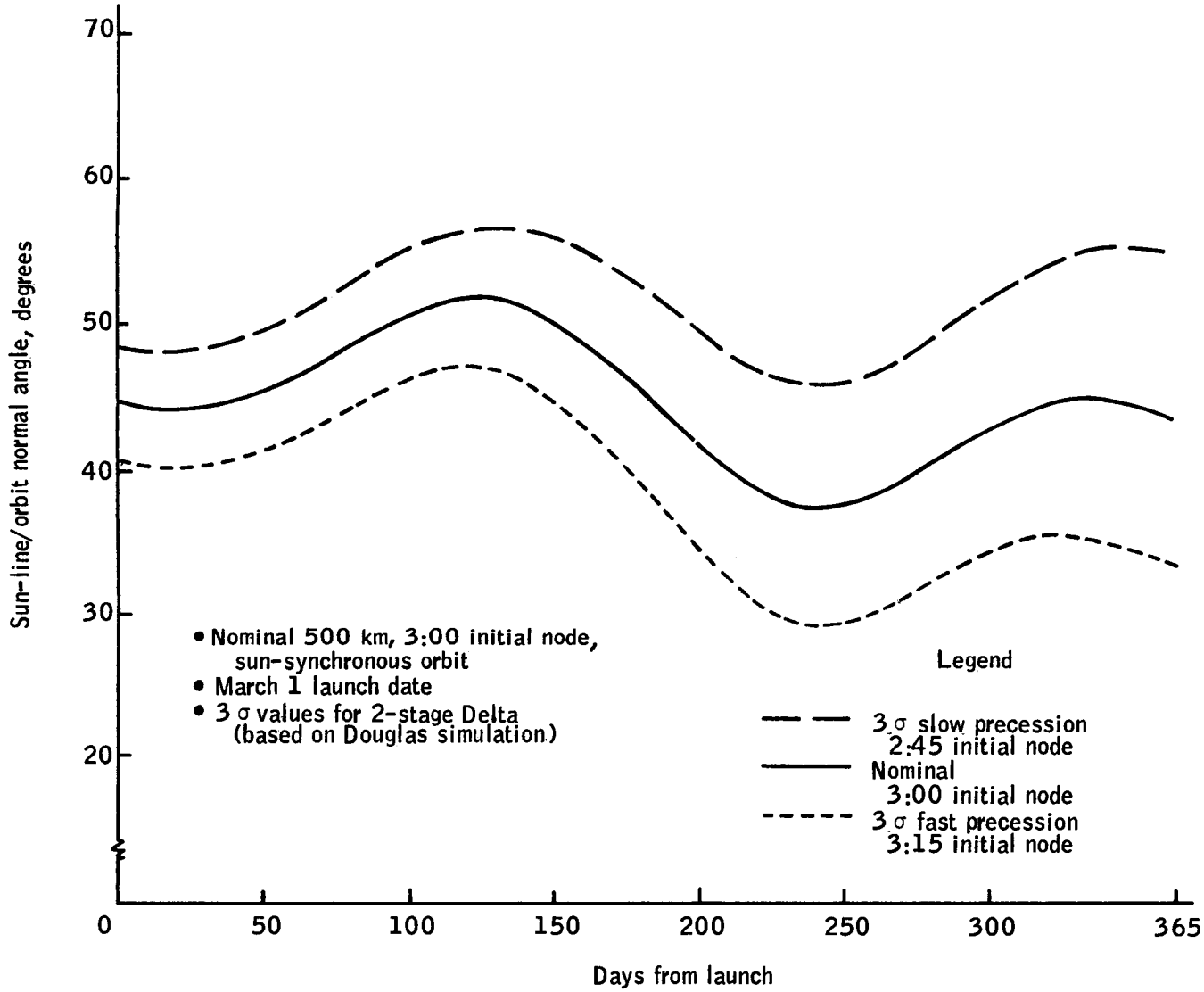


Figure 19. Sun-Line/Orbit Normal Angles, March 1 Launch Date

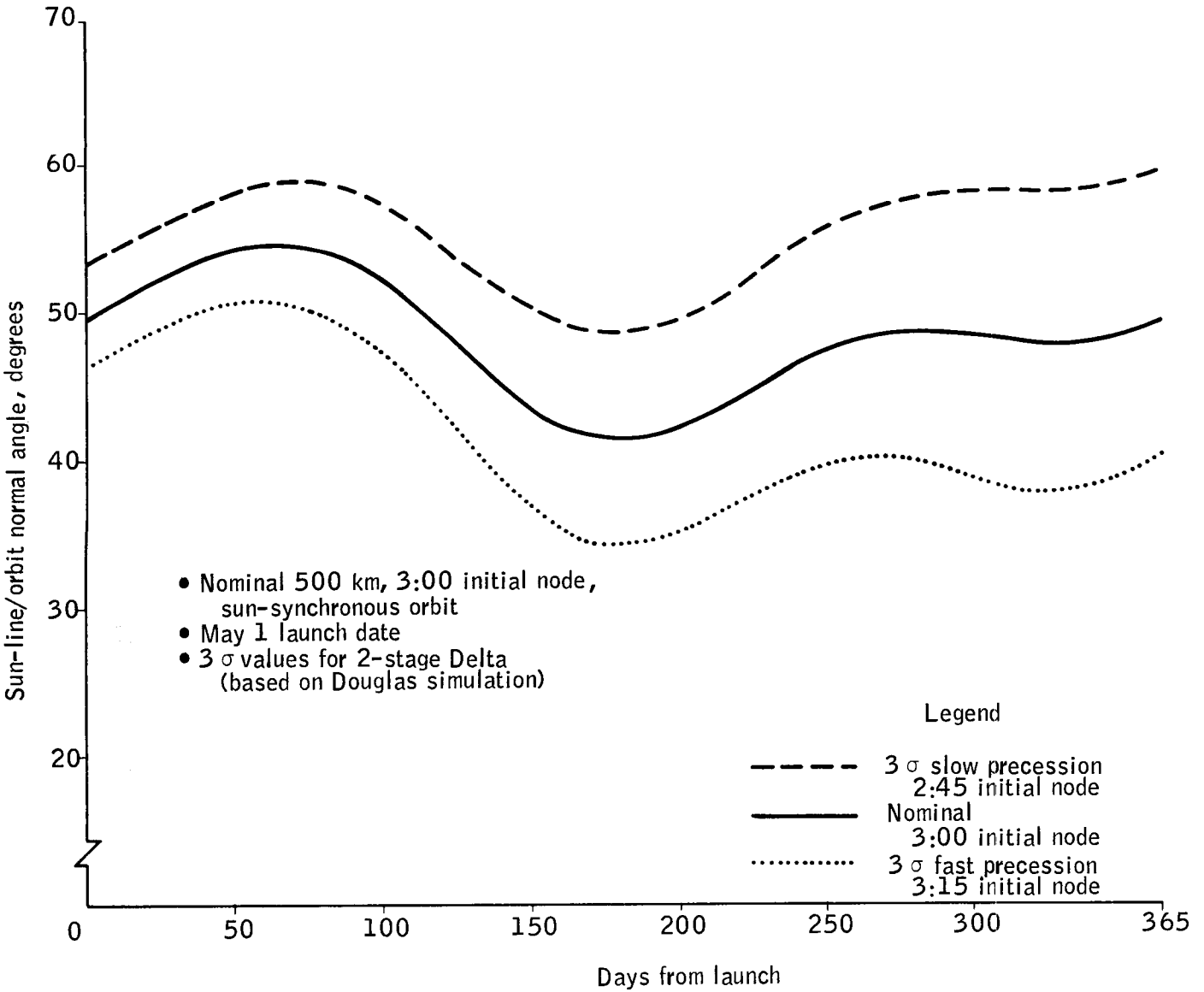


Figure 20. Sun-Line/Orbit Normal Angles, May 1 Launch Date

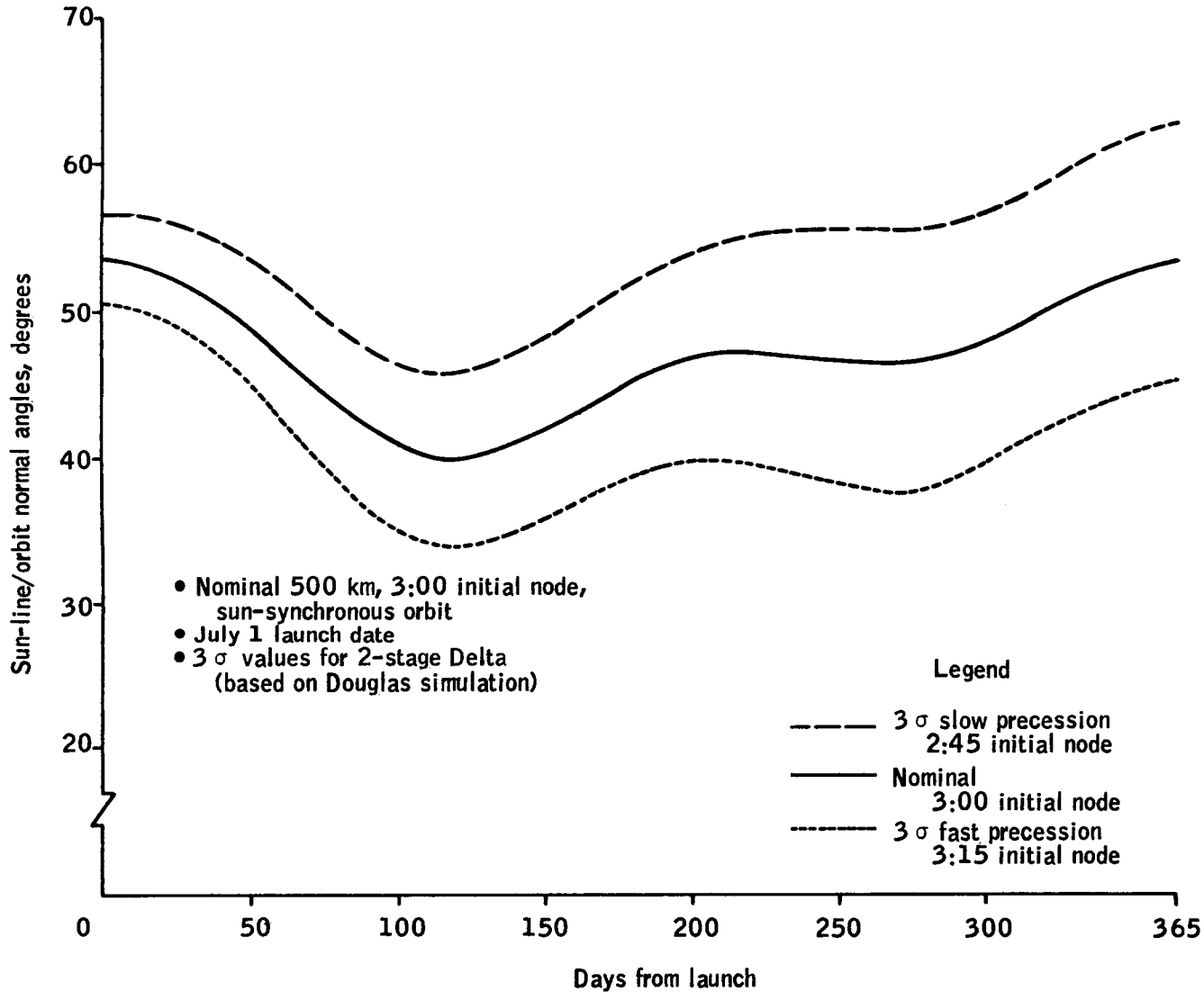


Figure 21. Sun-Line/Orbit Normal Angles, July 1 Launch Date

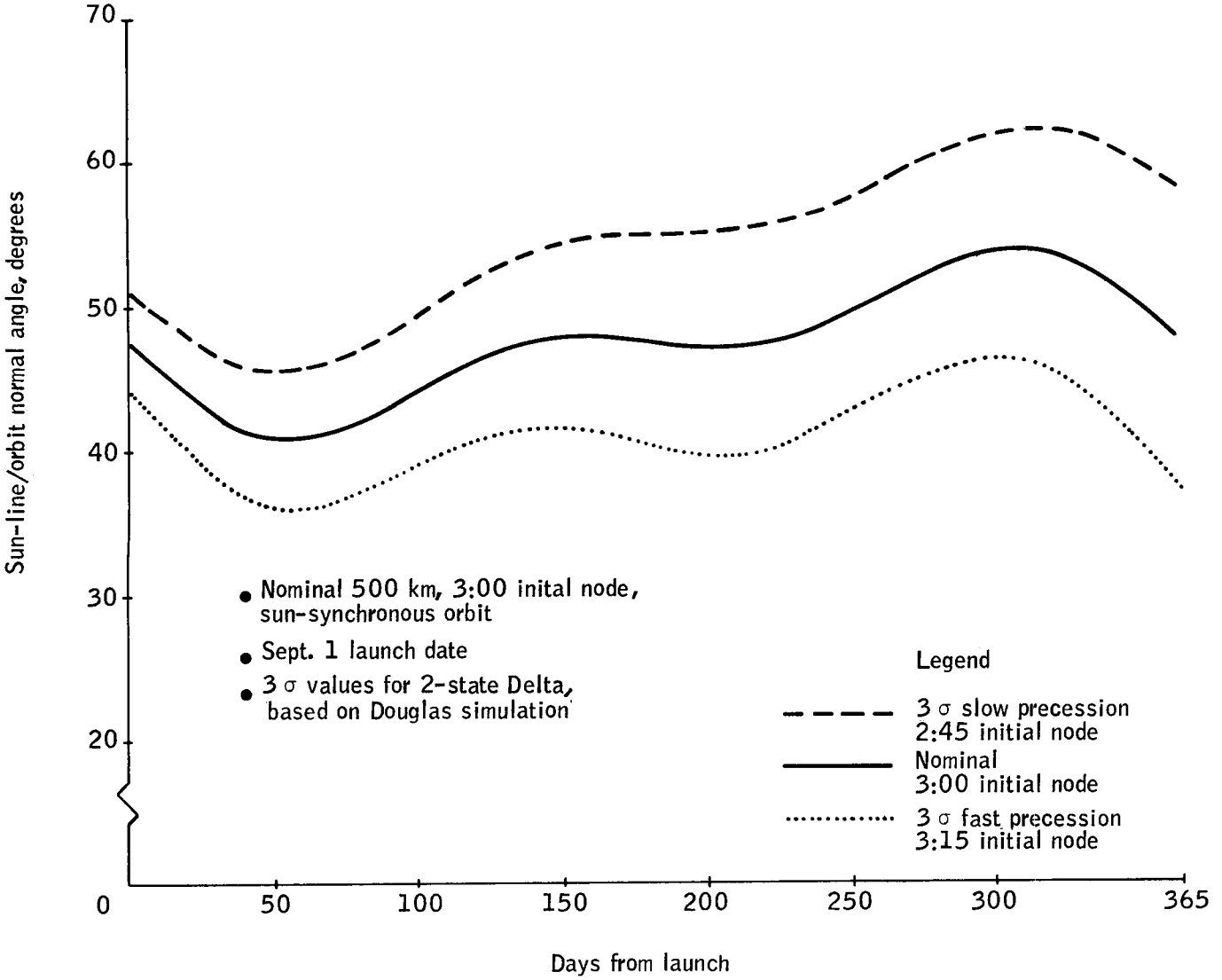


Figure 22. Sun-Line/Orbit Normal Angles, Sept. 1 Launch Date

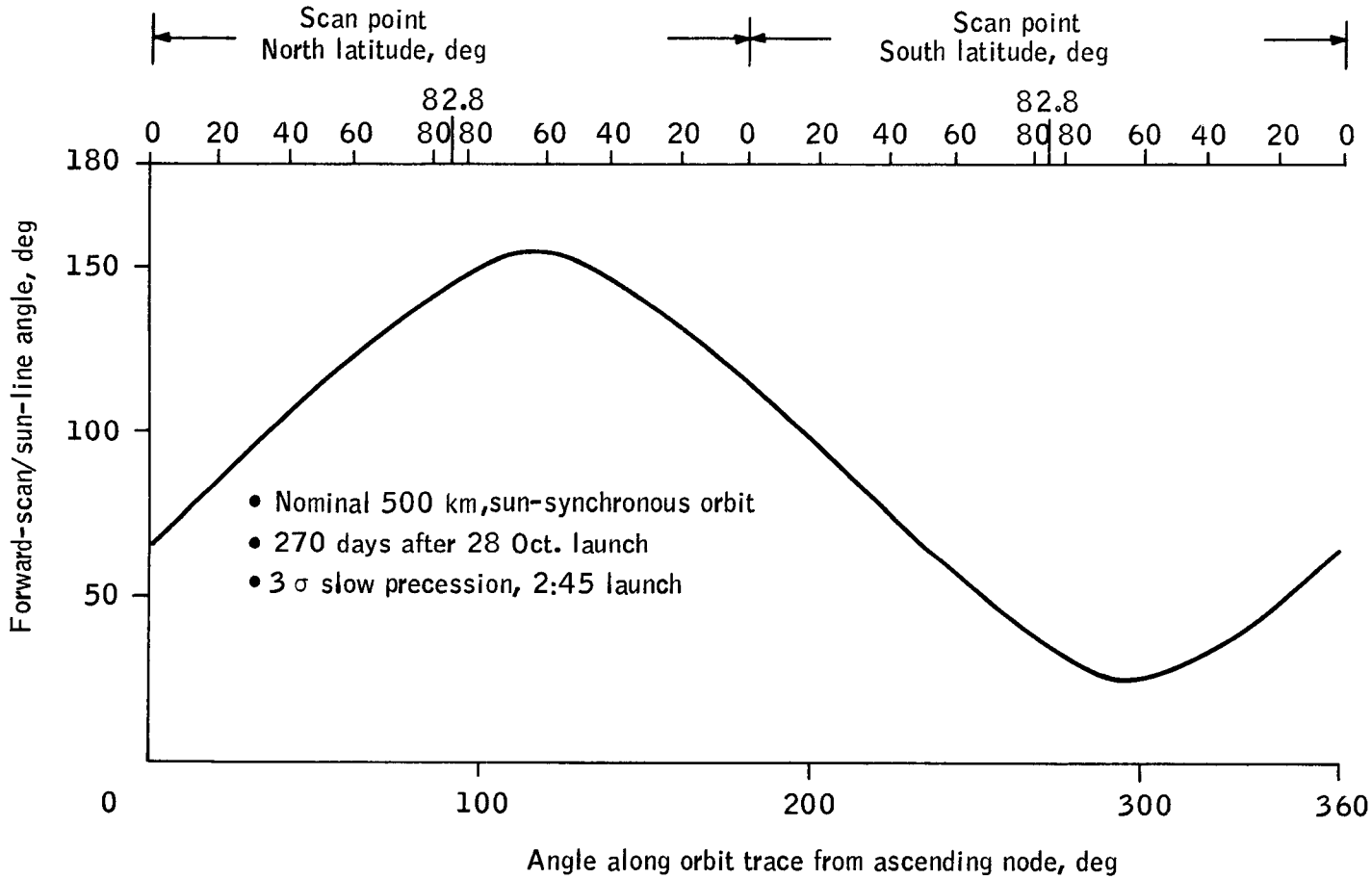


Figure 23. Scan-Line/Sun-Line Angle, "Worst" Case

- Tracking and telemetry coverage obtainable with the 500 km, sun-synchronous orbit and the STADAN system is adequate. Once-per-orbit coverage is available in all but a very small range of the possible orbit nodal conditions. Use of a polar orbit could eliminate the few one-orbit "holes", but at great expense in terms of yearly sun-angle variation and consequent system design problems.

VEHICLE POSITION DETERMINATION

INTRODUCTION AND OBJECTIVES

Purpose of the vehicle position determination study was to evaluate, on a preliminary basis, the accuracy with which the geocentric position of the HDS satellite can be determined. Although tracking and orbit determination for scientific spacecraft are routine operations, the HDS mission imposes a requirement in accuracy well beyond the normal level. This requirement stems from the need to determine tangent height (distance from the radiometer line of sight to the earth's surface) accurately. Part of this determination data comes from on-board celestial sensors (star, sun sensors), but without corresponding data on spacecraft geocentric position, such data would be worthless. The goal for the position determination study was to determine compatibility with and/or additions to, the STADAN tracking network for purposes of generating sufficient raw tracking data. Based on such compatibility, a tracking plan, consistent with HDS mission requirements, was devised. The error analyses, tracking coverage, and the tracking plan are discussed in the following sections.

TRACKING AND POSITION DETERMINATION REQUIREMENTS

Early in the study, an error allocation was formed for the HDS mission, based on a tangent height accuracy of 250 m. The original allocation gave 88 m in tangent height to the vehicle position error. This was later revised to 125 m in tangent height.

For position errors of this magnitude, it is possible to use differential error coefficients to compute the tangent height error due to position errors. The two first-order error coefficients of most interest are those giving sensitivity of tangent height to altitude error and to horizontal position error in the direction of radiometer scan:

$$\frac{\partial h_t}{\partial h} = \frac{R_E + h_t}{R_E + h} \tag{2}$$

$$\frac{h_t}{\partial s} = \frac{\left[h^2 - h_t^{\,2} + 2\,R_E\,(h-h_t)\right]^{1/2}}{R_E + h} \tag{2a}$$

where:

h_t = tangent height

h = spacecraft altitude

R_E = earth radius

s = coordinate in horizontal direction along scan azimuth

For a zero tangent height and 500-km altitude, these coefficients become:

$$\partial h_t/\partial h = 0.93$$

$$\partial h_t/\partial s = 0.38$$

The error coefficients, together with the 125-m budget, form the basic orbit determination requirement.

Since the position of the spacecraft at most times during its flight will be obtained by "interpolation" between tracking passes, any uncertainties involved in the prediction process contribute to the ultimate vehicle position error.

For the HDS vehicle it is likely that the principal sources of prediction error would be station location error, geoid shape error, gravitational model error, timing error, and atmospheric drag error. STADAN stations location errors are expected to be reduced significantly in the near future. All stations are being surveyed to determine their positions more accurately. Studies are also underway to determine more accurately the shape of and the gravitational field of the earth. Of these errors, only the atmospheric drag error can be altered significantly. Atmospheric density variations caused by fluctuations in the solar activity cause drag uncertainities. However, by changing orbital altitude, the effect of the drag uncertainity can be altered. For instance, the mean rate of altitude decay at various altitudes (for M/C_DA = kg/m^2, estimated for the HDS spacecraft) is:

200 km	1500 m/day	400 km	32 m/day
250 km	470 m/day	450 km	16 m/day
300 km	170 m/day	500 km	8 m/day
350 km	69 m/day		

In general, for a nominally circular orbit, the drag perturbations can be expressed as (ref. 2):

$$\Delta h = \frac{-K_3 \rho}{W/C_D A} \left[2\pi N - \sin 2\pi N\right] \text{ (altitude)} \tag{3}$$

$$\Delta s_f = \frac{\rho}{W/C_D A} \left[K_1 N^2 - K_2 (1-\cos 2\pi N)\right] \text{ (in-track)} \tag{3a}$$

where:

K_1	=	$3\pi^2\mu$
K_2	=	2μ
K_3	=	μ
μ	=	earth's gravitational parameter
ρ	=	atmospheric density
$W/C_D A$	=	ballistic parameter of spacecraft
N	=	number of revolutions of earth

The two perturbations represent the altitude (Δh) and forward in-track (Δs_f) position deviations relative to a non-drag affected spacecraft starting from matched position and velocity at N=0.

For values of N greater than a fraction of a revolution, the altitude perturbation is always negative; the forward in-track perturbation is always positive.

Assuming a 125 m tangent height error allocation to orbit determination, an allowance of 100 m will be made for tracking, timing, earth model, and station location errors. The allowable tangent height error for drag model uncertainties is then

$$(\Delta h_t)\text{drag} = (125^2 - 100^2)^{1/2} = 75 \text{ m}$$

assuming this error is uncorrelated with the others.

The tangent height perturbation due to altitude and in-track perturbations is:

$$\Delta h_t = \frac{\partial h_t}{\partial h}\Delta h + \frac{\partial h_t}{\partial s}\Delta s \tag{4}$$

where $\Delta s = s_f$ for forward scans and $\Delta s = -\Delta s_f$ for backward scans. This equation has been evaluated for both forward and backward scans, using the previous expressions for Δh and Δs_f, with nominal altitude (giving ρ, $\partial h_t/\partial h$, and $\partial h_t/\partial s$) as a parameter, and N as the variable. Figure 24 shows the result as a function of N for altitudes of 460, 500, and 540 km. A value of $M/C_DA = 100 \text{ kg/m}^2$ has been used, which is approximately the expected value for the HDS spacecraft. The tangent height perturbation given by figure 24 is inversely proportional to M/C_DA and proportional to the density ρ.

It should be emphasized that Figure 24 represents the entire perturbation on tangent height due to drag. Since drag can be included in the computational model, this perturbation is not, in itself, an error. However, any uncertainty in the drag value propagates to tangent height in value equal to the percentage of uncertainty times the value given by the curve.

Drag parameter excursions as much as a factor of two or three have been observed, although, over a period of weeks. For these analyses, a maximum "effective" uncertainty of 25 percent in the drag parameter between tracking passes was assumed. (By "effective" is meant, for example, that drag increases 25 percent just after a tracking pass, then decreases to 25 percent below the original value halfway to the next tracking pass, so that no detection of the fluctuation is made at the second pass.) Since the maximum position error is reached at the mid-point between tracking passes, the maximum allowable interval between tracking passes is twice the time taken to reach maximum tangent height error (75 m) using Figure 24 and a 25 percent multiplier.

The results for forward scans, in terms of maximum allowable intervals, are

h = 460 km : 10.4 orbits or 975 min

h = 500 km : 11.0 orbits or 1040 min

h = 540 km : 16.6 orbits or 1584 min

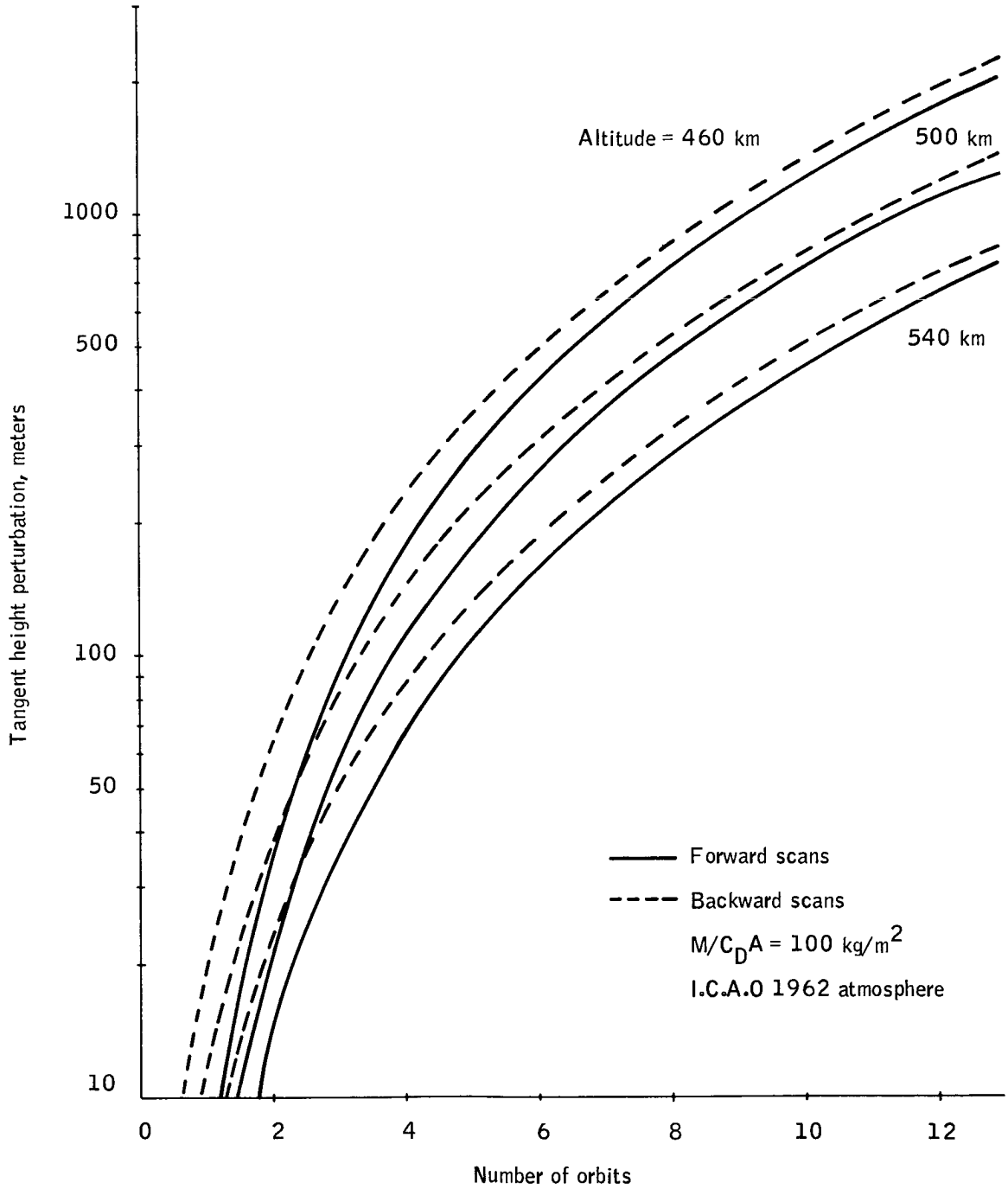


Figure 24. Tangent Height Perturbations Due to Atmosphere Drag

and for backward scans

h = 460 km : 9.2 orbits or 862 min

h = 500 km : 11.8 orbits or 1118 min

h = 540 km : 15.4 orbits or 1470 min

Thus, if allowance for altitudes down to 460 km, is made, and the 25 percent effective uncertainty allocation is adequate, a maximum time interval of 862 minutes between tracking passes will keep the drag parameter uncertainty effect on tangent height error to under 75 m.

STADAN TRACKING SYSTEMS

The STADAN tracking network facilities are discussed in Appendix B. Three basic tracking methods are possible: Minitrack, vhf Range/Range-Rate, and S-band Range/Range-Rate. The R&RR system determines spacecraft range by measuring the travel time of an electromagnetic wave. Knowledge of the propagation velocity therefore gives the distance. The vhf Range/Range-Rate system gives better accuracy than the Minitrack system for very long ranges (highly elliptical orbits). However, due to significant propagation anomalies of vhf frequencies, its accuracy is inadequate for the HDS mission, where a low, circular orbit is used. Therefore, only the Minitrack and S-band Range/Range-Rate system were left as candidates.

Discussions with personnel at NASA-Goddard indicate the following levels of accuracy are attainable:

- Minitrack (fine beam, above 45° elevation) — 300 meters in-track
- S-band Range/Range Rate — 100 meters in-track

The altitude error was estimated to be one fifth or less of the in-track error by personnel at GSFC

The Range/Range-Rate system accuracy given is current; improvement to 40 m in the next few years is estimated by GSFC.

The actual accuracy achievable with the S-band system for near-polar orbits is uncertain at this time due to lack of appropriate experience. However, extremely low orbit determination residuals have been obtained using S-band range/range-rate tracking data from a 24-hour equatorial-orbit spacecraft (ATS-1). Extrapolating these accuracies to the HDS mission gives good indication that, with suitable coverage, orbit determination errors (exclusive of drag parameter uncertainty) can be held to a value giving tangent height errors below 100 m.

TRACKING COVERAGE

Simulations of the tracking coverage available from the STADAN system, using either the Minitrack network or the S-band Range/Range-Rate network, were carried out using the TECO, SICO, and PICO programs. These are described in the mission profile section and, in more detail, in Appendix A. For current purposes, SICO output is the most useful. The basis of this program rests on the nature of orbit nodal distributions in a statistical sense.

When a spacecraft is injected into a circular orbit of given nominal altitude from a given launch site, the ground trace of the orbit can be predicted quite accurately prior to launch for the first few orbits. Each ascending node will be a certain distance west of the previous ascending node, corresponding to the orbit altitude and, to a small degree, to the inclination. This distance can be written as

$$n_r = P\omega_c$$

where P = nodal period of satellite orbit

$\omega_c = \omega_E - \dot{\Omega}$

ω_E = earth rotation rate

$\dot{\Omega}$ = eastward precession or orbit node due to earth oblateness

A typical value for n_r might be 23° for a near 500-km orbit. Although this prediction will be quite good for the first few orbits, note that for any error in this nodel "shift" distance, Δn_r, after N orbits, the error in prediction of the nodal location is $N \cdot n_r$. By differentiation of the equation for n_r, sensitivity coefficients can be generated

$$\frac{dn_r}{da} = \frac{dP}{da}\omega_c + \frac{d\omega_c}{da}P$$

$$\frac{dn_r}{dt} = \frac{dn_r}{da}\frac{da}{dt}$$

where a = orbit semi-major axis. These two coefficients will give the sensitivity of n_r to errors in altitude and the rate of change of n_r with a decaying altitude. Neglecting the $d\omega_c/da$ term which is very small, these equations can be evaluated for a nominally circular, 500-km orbit

$$\frac{dn_r}{da} = 0.0052°/\text{km}$$

$$\frac{dn_r}{dt} = 0.0052\ \frac{(da)}{(dt)}\ \frac{\text{deg}}{\text{unit time}} \quad \text{(for "a" in km)}$$

Thus, for an error of 10 km in orbit semi-major axis, the cumulative error in nodal location after 100 orbits (about one week) is (0.052) (100) = 5.2°. It thus becomes clear that, after a reasonably short time, the ground trace of the orbit becomes unpredictable in pre-flight analysis. On the other hand, it should be evident that traces on successive days will most likely differ. During the course of a one-year mission, any nodal longitude can be expected to be about equally likely, and that the actual distribution of nodal longitudes during a year should approach a uniform distribution. Yet, it is advantageous to know what kind of "coverage days" will occur during the mission. This can be evaluated; the SICO (SImulated COverage) program model utilizes the uniform distribution of nodal longitudes to produce what is, in essence, a Monte Carlo analysis of coverage.

The basis of the SICO model is as follows. Suppose a nominal orbit is started at an ascending node of 0° longitude and run through a complete day of simulated tracking coverage. The second node would occur at, for example, 23° W, the third at 46° W, etc. Start again, but at 1° longitude. This time, the second node is at 22° W, the third at 45° W, etc. Starting again at 2° longitude, and continuing this procedure until the starting node is at 23°, the second node is at 0°, the third at 23° W, which is essentially identical to the first simulated day. This procedure thus generates all of the possible "coverage days" to a resolution of 1° in nodel longitude. The output consists of 23 tables, each corresponding to the sequence of station contacts in a "typical" day.

The PICO model differs from SICO in that it is based on a continuous sequence, starting at injection. As the previous analysis demonstrates, PICO data is valid for only a period of several days after launch (using 2-stage Delta injection accuracies as a guide).

The early orbit tracking coverage PICO output with the S-band Range/Range-Rate system is given in Appendix C. A 10° minimum elevation at each station is assumed.

The long-term coverage profiles generated by SICO for the S-band Range/Range-Rate system are given in Appendix D. Minimum elevation is 10°; only in-sight times in excess of 1 minute are printed. Although some differences in "typical" days occur, the maximum interval between available passes is always less than the 862 minutes mentioned in Appendix D.

Approximate coverage profiles for the Minitrack system can be obtained from Appendices E and F. These tables were generated for purposes of telemetry, not tracking, coverage. However, Minitrack fine-beam coverage (elevations above 45°) can be ascertained by striking out all passes of less than about 8.2 minutes.

TRACKING PLAN

Based on the estimated capabilities of STADAN S-band range/range-rate tracking, and estimated drag uncertainties in orbit prediction as discussed in the previous section, a basic tracking plan has been devised. The elements of this plan are as follows:

- The S-band Range/Range-Rate system should be used as the primary tracking system.

- Alaska and Rosman should be used as the prime tracking stations, giving coverage every 500 minutes or less.

- This plan should result in a total tangent height error due to orbit determination of under 125 m, particularly with proper correction for propogation anomalies and improvement of station location values during the next few years.

- The Carnarvon, Santiago, and Tananarive stations can be used for early orbit tracking, selected tracking at different orbit locations, and as backups to Alaska and Rosman.

- If the error budget remains essentially the same, definite provision for use of the back-up stations is necessary to allow for priorities and/or operation problems.

CONCLUSIONS

The following conclusions regarding the vehicle position determination problem have been determined as a result of the analyses:

- The S-band Range/Range-Rate system should be used to provide raw tracking data.

- Propagation errors and basic tracking measurement errors make the Minitrack system and vhf Range/Range-Rate tracking system inadequate to meet the HDS position accuracy requirements.

- Based on extrapolations from past experience, the S-band system should be capable of providing sufficient data to give orbit arcs with 3-sigma equivalent tangent height errors under 100 m, exclusive of drag uncertainty.

- The principal problem in accurate position determination is atmospheric drag uncertainity. Adequate smoothing intervals may possibly be too long to account for the position error due to this uncertainity for altitudes near 500 km.

- Provision exists to raise orbit altitude to decrease drag uncertainty error should this be necessary to expand the tracking pass intervals, or to allow for greater drag uncertainty or model errors. In making such a change, the increased error in tangent height due to increased sensitivity to angular errors must be considered. In general, an "optimum-accuracy" altitude should exist for a given configuration.

DATA ACQUISITION

INTRODUCTION AND OBJECTIVE

The data acquisition study was concerned with assuring command and telemetry compatability between the satellite and STADAN. The basic areas of investigation included maintaining cognizance of telemetry and command requirements, determining STADAN and GSFC Data Processing Center capabilities, investigating satellite-STADAN interface considerations, and establishing preliminary data acquisition plans. The objective of the study was to define, from system requirements and feasible subsystem concepts, the data acquisition concept utilizing STADAN with a minimum of modification. The details of the areas of investigation outlined above are presented in the following paragraphs.

DATA ACQUISITION REQUIREMENTS

The functions of data acquisition of concern are those of command and telemetry. The basic requirement is to utilize STADAN with a minimum amount of modification being required. The general telemetry and command requirements are outlined below.

Telemetry Requirements

The horizon definition study satellite will generate three major types of data which will be transmitted to ground stations. These are radiometric data, attitude sensing data, and status data. The satellite will have an orbit altitude of 500 km, an orbit inclination angle of 97.38° and a data storage capability of approximately one orbit. The basic telemetry requirement is to transmit the accumulated data at least once per orbit for the lifetime of the satellite which is a minimum of one year. For an estimated storage capability (ref. 3) of 500 kilobits to 1 megabit and assuming a nominal 2 minute contact time, the transmission rate will be in the range of 5 to 10 kilobits/sec. The anticipated data rate for this program is approximately 5 kilobits/sec.

Command Requirements

It will be necessary to activate certain functions within the orbiting spacecraft at various phases of the orbit and of the satellite lifetime. The commands envisioned at present are only of the ON-OFF type. The number of different commands is estimated to be as follows:

Subsystem	Number of Commands
Attitude Control	17
Structures	3
Communications & Tracking	5
Radiometer Control	4
Starmapper - Sun Sensor	3
Power	18
Data Handling	8
Total	58

During the early orbits (post-injection) there will be the requirement to receive data, process, and issue commands within a short period of time (one orbit period, for example). In this case it will be necessary to quite frequently use those ground stations which have a microwave link with GSFC. After the satellite has been stabilized in orbit, this requirement will drop off to a frequency interval of several days.

STADAN DATA ACQUISITION CAPABILITIES

STADAN consists of three major functional systems. The first of these is the Minitrack system which is basically a tracking system but has the facilities for receiving and recording telemetry data. The second functional system is the Data Acquisition Facilities (DAF) which is equipped with multifrequency, high-gain antennas and has the capability of handling large quantities of data at high data rates. The third system is the Goddard Range and Range-Rate (R&RR) tracking system which has the potential capability of both vhf and S-band telemetry. A summary of the telemetry and command capability of these three systems is presented in the next few paragraphs while certain specific details are referenced to Appendix G. Table 1 presents a list of the STADAN stations and identifies the capability of the station with respect to these three major STADAN functions. The geodetic locations of these stations are listed in Table G1 of Appendix G. The essential functional elements of a data acquisition station are shown in Figure 25.

Telemetry Capabilities

The available telemetry frequencies associated with each of the stations is shown in Table 2. The data channel bandwidths of the 136 MHz and 400 MHz carrier are 30 kHz and 50 kHz, respectively. Wider bandwidths recommended are 90 and 300 kHz for the two respective carrier frequencies. The channel bandwidth of the 1700 MHz carrier is approximately 1.5 MHz. Another possibility for a telemetry channel is the R&RR system, with the satellite transponder functioning as a command receiver, tracking source,

TABLE 1. - STADAN STATIONS

Stations	Minitrack	R&RR	DAF
Alaska		X	X
Orroral	X		X
Carnarvon		X	
College	X		
Fort Myers	X		
Gilmore			X
Johannesburg	X		
Lima	X		
Quito	X		
Rosman		X	X
St. Johns	X		
Santiago	X	X	
Tananarive		X	
Winkfield	X		

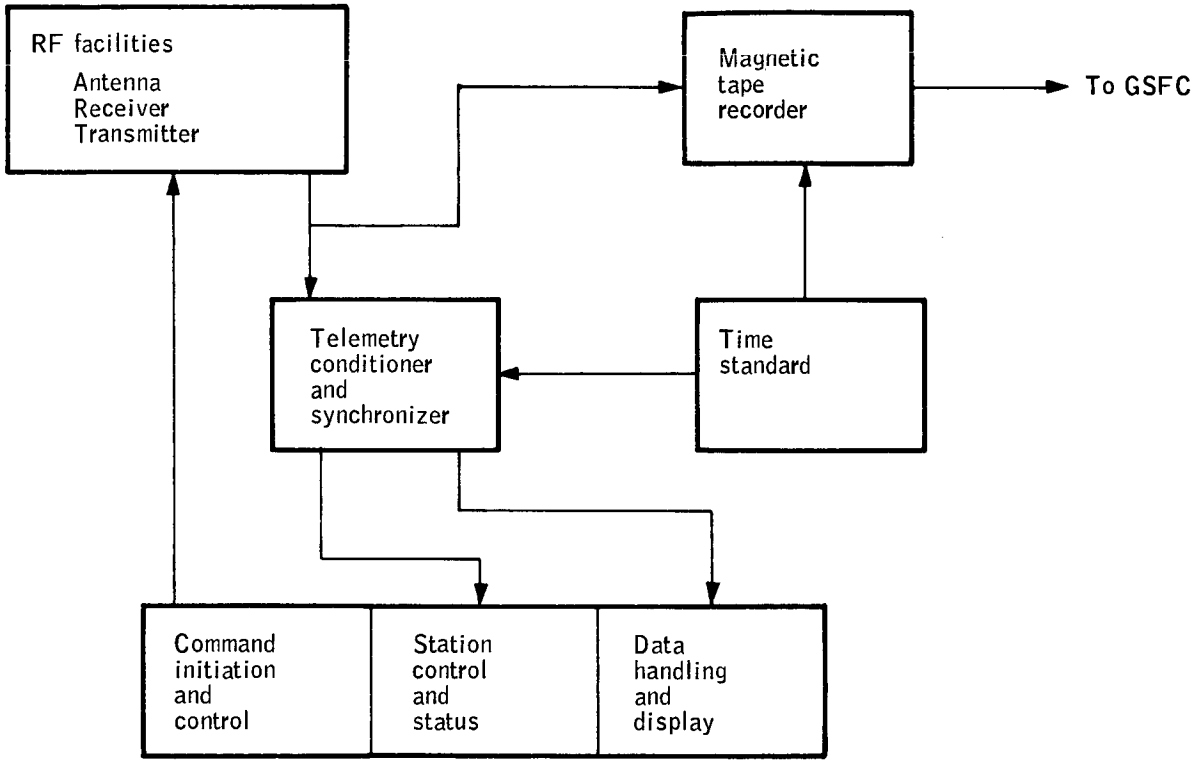


Figure 25. Data Acquisition Station

TABLE 2. - STADAN TELEMETRY FREQUENCIES

Stations	136 MHz	400 MHz	1700 MHz	2253 MHz (R&RR)
Alaska	X	X	X	X
Orroral	X	X		
Carnarvon				X
College	X			
Fort Myers	X			
Gilmore	X	X		
Johannesburg	X	X		
Lima	X			
Quito	X	X		
Rosman	X	X	X	X
St. Johns	X			
Santiago	X	X		X
Tananarive				X
Winkfield	X			

and telemetry transmitter. The two carrier frequencies associated with the R & RR system are 136 MHz and 2253 MHz. The respective channel bandwidth capabilities are on the order of 20 kHz and 1 MHz. Details of STADAN station characteristics pertinent to satellite systems interface analysis are presented in Appendix G, Tables G2 through G6. Further details are found in references 4 and 5 from which most of this information was obtained.

Command Capabilities

The STADAN system has three basic command systems. These include the tone command, tone-digital command and PCM instruction command systems. A description of command capabilities for each system follows:

Tone command system. -- This system is intended for use where only a few "on-off" commands are required. Sequential transmission is employed with the address tone sent first to "arm" the decoder. The execute tones follow to accomplish the particular command function and may consist of up to three tones in a sequence. There are seven tones allotted for executing commands.

A tone command system is not a secure system and is thus prone to spurious commands from other radiating systems. This is probably the biggest source of error, assuming the system is not operating under marginal S/N ratios. It is quite difficult to put a quantitative number on expected errors in this case, and if this system were to be used, design considerations should be given to this problem.

Tone-digital command system. -- This system was developed for simple real time "on-off" commanding and is capable of transmitting up to 70 commands. This is essentially a PDM command system.

A command in this system consists of a series of five words, each consisting of eight bits, one sync bit and one blank period. The series consists of a unique address word sent twice and an execute word sent three times. The address word identifies the spacecraft and enables the command hardware. The execute word contains the specific command function to be performed. Receipt of one correct address word and one valid execute word is sufficient to effect the command. Repeating of the words increases the probability of reception under adverse conditions.

Each word is generated from a fixed number of zeros and ones for error detection and interference rejection. The address word consists of some combination of six ones and two zeros and is assigned by GSFC to the spacecraft. The execute word consists of combinations of four ones and four zeros. A total of 70 execute words can be generated from these combinations. With this coding, all odd errors and 43 percent of all two-bit errors can be detected. To further decrease the possibility of spurious commands, the execute word must be received within a fixed time period after the address command.

Proper design of equipment for use with this system will allow a pulse error rate of less than one per 5000 bits for a subcarrier S/N ratio of 0 dB.

PCM instruction command system. -- This is a high capacity binary system with word lengths of 64 bits. The maximum number of data bits in a word is 46. The remainder are synchronization bits. Various command functions such as event timing, error checking, subsystem control, etc., can be performed.

A properly designed spacecraft command receiver will have a probability of bit error versus S/N capability of within 4 dB of the theoretical curve for an FSK, matched filter, incoherent detector. For a bit energy-to-noise ratio of 10, the corresponding probability of bit error is 0.002. Spacecraft data verification methods should also be used. Several methods are word repetition, word feedback, code check, and signal acquisition and acknowledgement.

There are three types of command am transmitters that can be used with the station command consoles. They are identified by the output power levels which are 5 kW, 2.5 kW, and 200 W. The characteristics of these transmitters and available command antenna systems are presented in Tables G7 and G8, respectively, in Appendix G. Reference 5 provides further details on these command systems.

DESCRIPTION OF GSFC DATA PROCESSING CENTER

Data Processing Functions

A functional block diagram of the GSFC Data Processing Center is shown in Figure 26. The data is received on tape as recorded directly out of the station receivers with ground time recorded in parallel. The first requirement is to catalog, screen, and order the data according to the manner in which it was taken. The next step in the process is the conversion of the data to a computer format. Ground time is inserted at this time as required by the measurement program. The remaining operations produce the experimental data in a suitable form for further data reduction and analysis by the experimenter. Compliance with the PCM telemetry standards, Appendix E, assures compatibility between spacecraft, ground station, and the Data Processing Center. Further details of telemetry processing can be obtained from reference 6. A summary of the pulse code modulation (PCM) systems described in that document is presented in the following paragraphs.

Processing Capabilities

The data processing PCM systems are designed to process any pulse code modulated telemetry data that uses split phase or non-return-to-zero coding. Spacecraft data that is recorded in serial binary code at the ground receiving

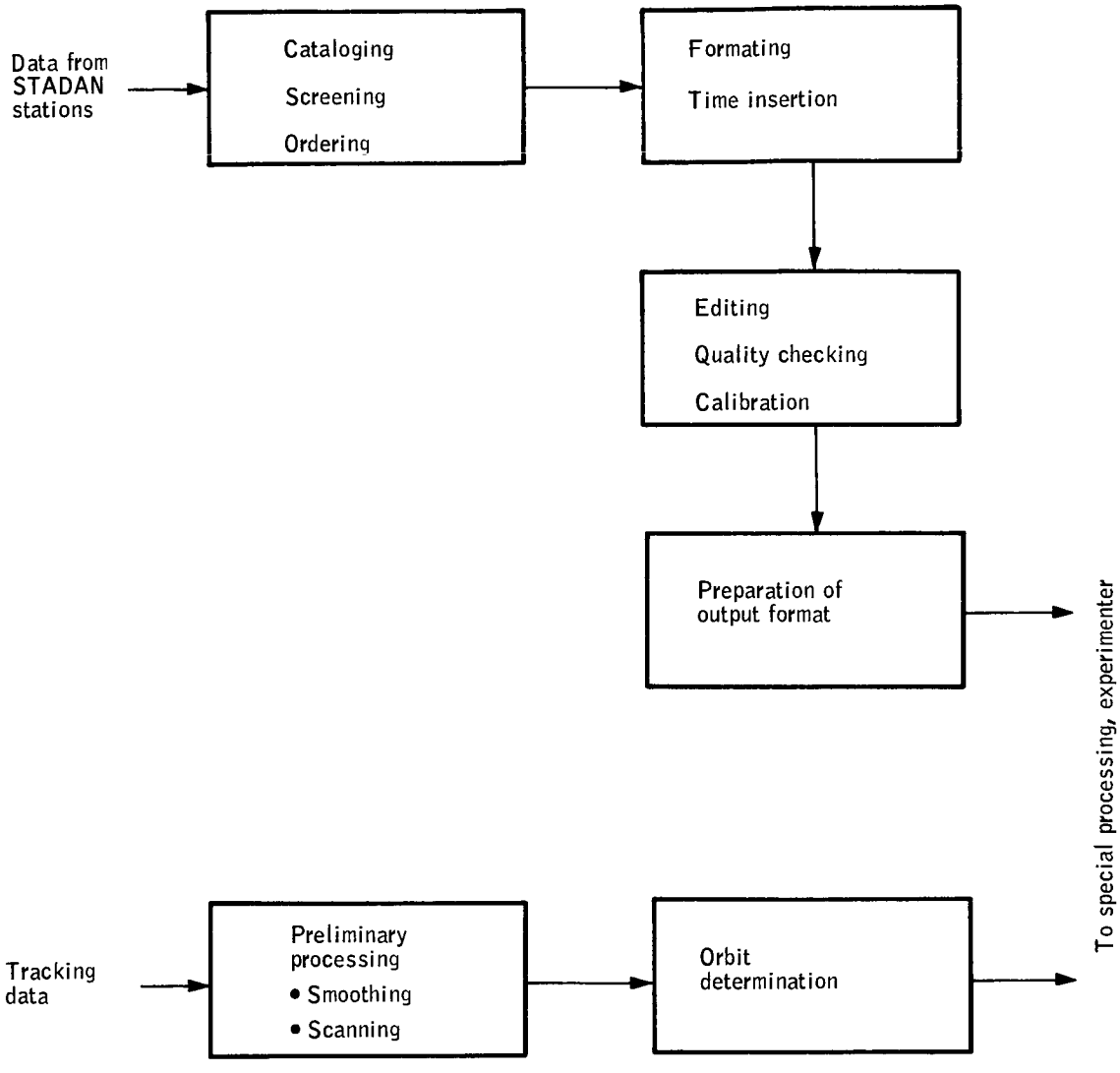


Figure 26. GSFC Central Processing Facility Functions

stations are the inputs to a typical pulse code modulation processing line. Programming is accomplished by means of patch panels to accommodate any known format of a particular satellite. The programming includes selection of word length, frame length, permissible frame sync bit errors, subcom frame length, number of frames to acquire frame sync, number of frames to flywheel, number of bad frames after which to revert to search mode, and setting up the frame and subcom frame sync recognizers for particular frame sync codes. In addition, patching is used to program the generation of buffer command signals in accordance with the desired buffer tape format and buffer requirements to produce buffer tapes.

The spacecraft data which is to be reduced is a pulse code modulated serial train of binary bits representing digital and analog measurements. The serial train of pulses (bits) is divided into equal groups of N bits, each called words. The presence or absence of each of the N bits describes the level of the sample of the analog quantity to the nearest discrete step between zero and full scale. Each analog measurement made aboard a satellite is digitized with the same sampling rate and number of bits representing full scale.

The split-phase or bi-phase code, where a 1 bit is identified by a downward transition and a zero bit is identified by an upward transition, hence bi-phase, is the code used predominantly in GSFC's spacecraft. Other codes in which the digitized quantity may be encoded for transmission include: 1) NRZ-change which maintains one level for 1 bits and a different level for zero bits; 2) NRZ-M where there is a transition (positive or negative) for every 1 bit and no transition for 0 bits; and 3) return-to-zero level code in which there is a pulse for every 1 bit and no pulse for 0 bits.

The pulse code modulated signal as received from the spacecraft, recorded by the ground station and reproduced by the pulse code modulated line tape recorders, can be noisy, distorted, and degraded. To reconstruct its waveform the signal is transmitted to the bit synchronizer unit where it is filtered, bit synchronized, and reconditioned for use by the search and lock unit. The bit synchronizer is capable of handling any of the codes discussed in the previous paragraph.

The main purpose of the pulse code modulated data reduction system is to reduce the data received from the satellite into a format acceptable by an IBM, Univac 1107, or equivalent computer for complete decummutation and generation of experimenter's tapes. The above goal is accomplished by use of the data processor to: 1) present to the buffer the serial train of telemetry data in terms of digital words of proper length and location in the main frame; 2) supply the required commands to the buffer to sample the presented data in proper order, as well as sample time presented by the time decoder; 3) generate special buffer commands to properly begin and terminate data blocks; 4) check the frame sync code and bit errors, and flag the status thereof; and 5) generate special flags such as subcom word(s) location, signal mode, etc., to minimize the effort required in decommutating and further processing of experimenter's data.

SATELLITE - STADAN INTERFACE CONSIDERATIONS

The major interface considerations evolved from the desire to assure satellite - STADAN compatibility. As a result, the primary concern centered around carrier frequency and bandwidth compatibility of spacecraft and ground station, and the telemetry coverage capability (the latter being related to on-board storage capability, data transmission rates, and station location). The frequencies and bandwidths were considered in previous paragraphs, as were the telemetry requirements. Since any of the carrier frequencies have sufficient bandwidth capability for the HDS system, the criteria for selection of carrier frequencies becomes that of adequate telemetry coverage. This analysis and command system considerations are discussed in the following paragraphs:

Telemetry Coverage

The coverage analysis utilized the SICO computer program discussed in the section on position determination. The major changes in input parameters for utilization in telemetry coverage consisted of setting the minimum elevation angle to 5° and increasing the minimum "time in sight" to be recorded to three minutes. That is, any contact time under three minutes is not counted as a contact. Contacts under three minutes could be useful for a limited amount of status monitoring but would probably not suffice for transmitting two minutes of experiment data and the associated commands.

Telemetry coverage capability of stations with 136 MHz, 400 MHz, and 2200 MHz (R & RR) carrier frequencies was determined. Table 3 lists the input parameters and the output data for the vhf station for a typical day of operation. The complete tables listing all typical days anticipated over the year for the vhf and S-band stations are presented in Appendix H. It has been assumed that R & RR stations will have telemetry capability by 1970.

Analysis of the telemetry coverage capabilities of the R & RR stations indicates that there are periods up to approximately 3.3 orbits where no telemetry contacts are made. Assuming that the on-board storage capability can handle only the data accumulated over one orbit period, then a considerable amount of data is lost due to storage overflow. The loss of 2.3 orbits of data can be expected frequently.

The 400 MHz stations and the vhf stations were analyzed for telemetry coverage in a similar manner. The 400 MHz telemetry coverage has more holes which occur more frequently than either the R & RR or vhf stations. On this basis, a carrier frequency of 400 MHz does not appear to be very useful for this experiment. Utilization of a vhf telemetry link will provide better coverage than the other two. In this case there are up to 1.75 orbits during which no telemetry contacts are made for the typical day considered.

TABLE 3. - VHF TELEMETRY COVERAGE

VHF TELEMETRY COVERAGE PROFILES

		NORTH LAT. DEG	EAST LONG. DEG	MIN ELEV. DEG
STATION 1	COLLEGE	64.90	212.10	5.00
STATION 2	FT. MYERS	26.50	278.10	5.00
STATION 3	JOHANNESBURG	-25.90	27.70	5.00
STATION 4	LIMA	-11.80	282.80	5.00
STATION 5	ORRORAL	-35.60	148.90	5.00
STATION 6	QUITO	-.60	281.40	5.00
STATION 7	ROSMAN	35.20	277.10	5.00
STATION 8	ST. JOHNS	47.70	307.30	5.00
STATION 9	SANTIAGO	-33.20	289.30	5.00
STATION 10	WINKFIELD	51.50	359.30	5.00

ORBIT ALT= 500.0 KM.
ORBIT INCL= 97.38 DEG.
NODAL LONGITUDE STEP SIZE= 1.00 DEG.
ORBIT PERIOD= 94.62 MINUTES
EARTH RADIUS= 33.3 PERCENT OVER ACTUAL (REFRACTION CORRECTION)
MINIMUM TIME= 3.00 MIN
WESTWARD SHIFT OF ASC. NODE= 23.65 DEG./ORBIT

STATION	MAX. ARC RANGE VISIBLE(DEG)	MAX. DIST.KM.
1	19.73	2331.1
2	19.73	2331.1
3	19.73	2331.1
4	19.73	2331.1
5	19.73	2331.1
6	19.73	2331.1
7	19.73	2331.1
8	19.73	2331.1
9	19.73	2331.1
10	19.73	2331.1

TABLE 3. - VHF TELEMETRY COVERAGE - Concluded

EAST LONGITUDE,ASC. NODE (TIME=0) = .00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE F.LONG.,DEG.
8.67	WINKFIELD	9.64		.00
24.55	COLLEGE	9.35	6.24	
53.75	ORROPAL	9.30	19.85	
104.19	ST. JOHNS	8.62	41.14	-23.65
118.56	COLLEGE	6.88	5.76	
146.92	ORROPAL	9.05	21.48	
196.74	ST. JOHNS	10.17	40.76	-47.31
211.76	COLLEGE	4.72	4.85	
270.18	SANTIAGO	9.96	53.70	
276.65	LIMA	9.47	.00	
279.16	QUITO	9.60	.00	-70.96
286.13	FT. MYERS	10.08	.00	
288.36	ROSMAN	10.22	.00	
303.07	COLLEGE	5.85	4.49	
366.03	SANTIAGO	7.53	57.11	
372.06	LIMA	7.04	.00	
382.16	FT. MYERS	6.05	3.06	-94.62
384.35	ROSMAN	6.39	.00	
393.90	COLLEGE	8.52	3.17	
485.92	COLLEGE	10.21	83.51	-118.27
525.68	JOHANNESBURG	7.17	29.55	
579.83	COLLEGE	9.91	46.98	-141.93
617.21	JOHANNESBURG	9.88	27.48	
676.39	COLLEGE	6.23	49.30	-165.58
691.59	WINKFIELD	9.01	8.97	
785.53	WINKFIELD	10.10	84.93	-189.23
837.18	ORROPAL	10.08	41.55	
881.31	WINKFIELD	5.01	34.05	-212.89
882.29	ST. JOHNS	7.90	.00	
906.62	SANTIAGO	6.91	16.43	
933.14	ORROPAL	7.39	19.61	
975.80	ST. JOHNS	10.27	35.27	-236.54
981.96	ROSMAN	4.30	.00	
983.94	FT. MYERS	5.44	.00	
989.91	QUITO	9.04	.53	
992.51	LIMA	9.88	.00	
997.61	SANTIAGO	10.16	.00	
1071.77	ST. JOHNS	5.14	64.00	-260.20
1073.78	ROSMAN	10.35	.00	
1076.15	FT. MYERS	10.15	.00	
1084.36	QUITO	7.68	.00	
1088.27	LIMA	5.63	.00	
1255.95	COLLEGE	8.24	162.06	-307.50
1313.04	JOHANNESBURG	9.94	48.84	
1334.93	WINKFIELD	9.08	11.95	-331.16
1349.75	COLLEGE	10.31	5.75	
1409.16	JOHANNESBURG	6.73	49.10	
1427.78	WINKFIELD	10.14	11.88	-354.81
1443.90	COLLEGE	9.74	5.98	
1474.22	ORROPAL	7.97	20.58	
1525.93	WINKFIELD	3.08	43.75	-378.47
1524.58	ST. JOHNS	7.28	.00	
1537.99	COLLEGE	7.49	6.13	
1565.96	ORROPAL	9.96	20.48	

To obtain average telemetry contacts over long periods of time, charts were prepared which indicate the frequency of occurrence of specific "time since last contact" values. Figure 27 illustrates the "time since last contact" for vhf telemetry coverage with 10 stations and the average frequency of occurrence of these times. For example, over a 100-day interval, it can be expected that the occurrence of a 160 to 170 minute time-since-last-contact will happen roughly 25 times. It should be pointed out that in no case will there ever be completely empty space cells due to lost data. The maximum loss will be 50 percent since coverage will be obtained when the satellite pass comes from the other direction. Assuming a 94-minute orbit and assuming a storage capability for one orbit, then the dashed vertical line represents the point beyond which data is lost when the time-since-last-contact exceeds this point. Figure 28 illustrates the telemetry coverage for S band (R&RR) in the same way as Figure 27 does for vhf telemetry coverage. Note that the R&RR system has two quite large values for time-since-last-contact, both of which correspond to several orbits of lost data. For a 100-day period of time, the 225 minutes since last contact will occur roughly 70 times. This is quite frequent and of large magnitude in comparison to the Minitrack coverage. This fact makes vhf telemetry preferable to S-band telemetry. Figure 29 illustrates the same type of information for the stations with 400 MHz capability. This figure illustrates the relatively large number of telemetry holes and the frequency of occurrence which is also relatively large.

It can be concluded that a 136 MHz carrier frequency will provide the best telemetry coverage and should therefore be considered as the primary link. Since the R&RR system will be used for tracking, minor modifications can provide the capability of using the R&RR S-band carrier as a backup link with degraded telemetry coverage. This mode of operation is recommended for the HDS satellite, based on the foregoing telemetry coverage analysis, assuming a one-orbit storage capability.

The location and shape of the vhf telemetry hole is illustrated in Figure 30. The shaded section represents the area in which data is lost due to storage overflow. The polar map presented covers the Northern Hemisphere. The shaded wedge extends from 10°N latitude down through the Southern Hemisphere and back up to the north polar region where contact is finally made with the College station. The effect of the missed data is to slightly lower the confidence interval of estimated parameters of the final data analysis.

Command System Consideration

The quantity and type of commands required suggest that the tone-digital command system has sufficient capability for the program being considered. The PCM digital system has a much larger capability but also requires correspondingly more complex equipment on the spacecraft. There is no further tradeoff required in this area since the only command frequency is nominally 148 MHz and the types of transmitter and antenna is established by what is available at a particular station.

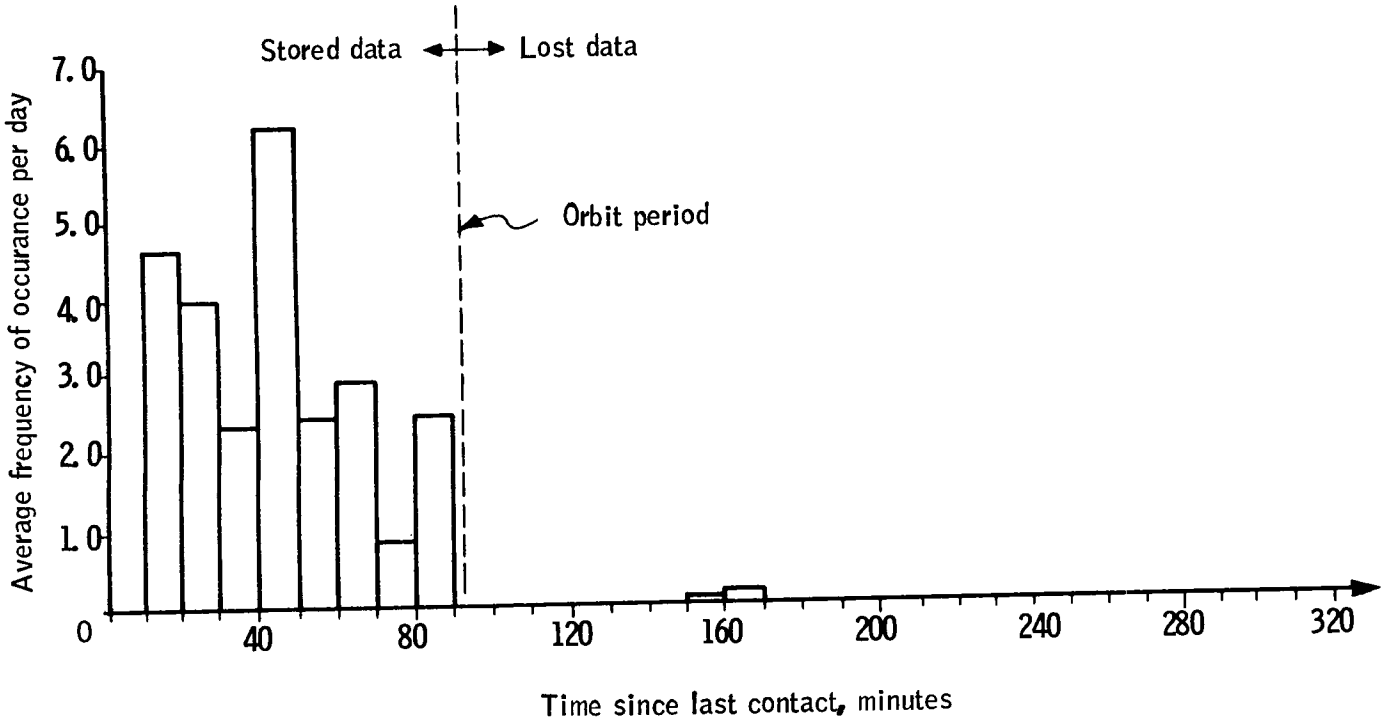


Figure 27. VHF Telemetry Contacts

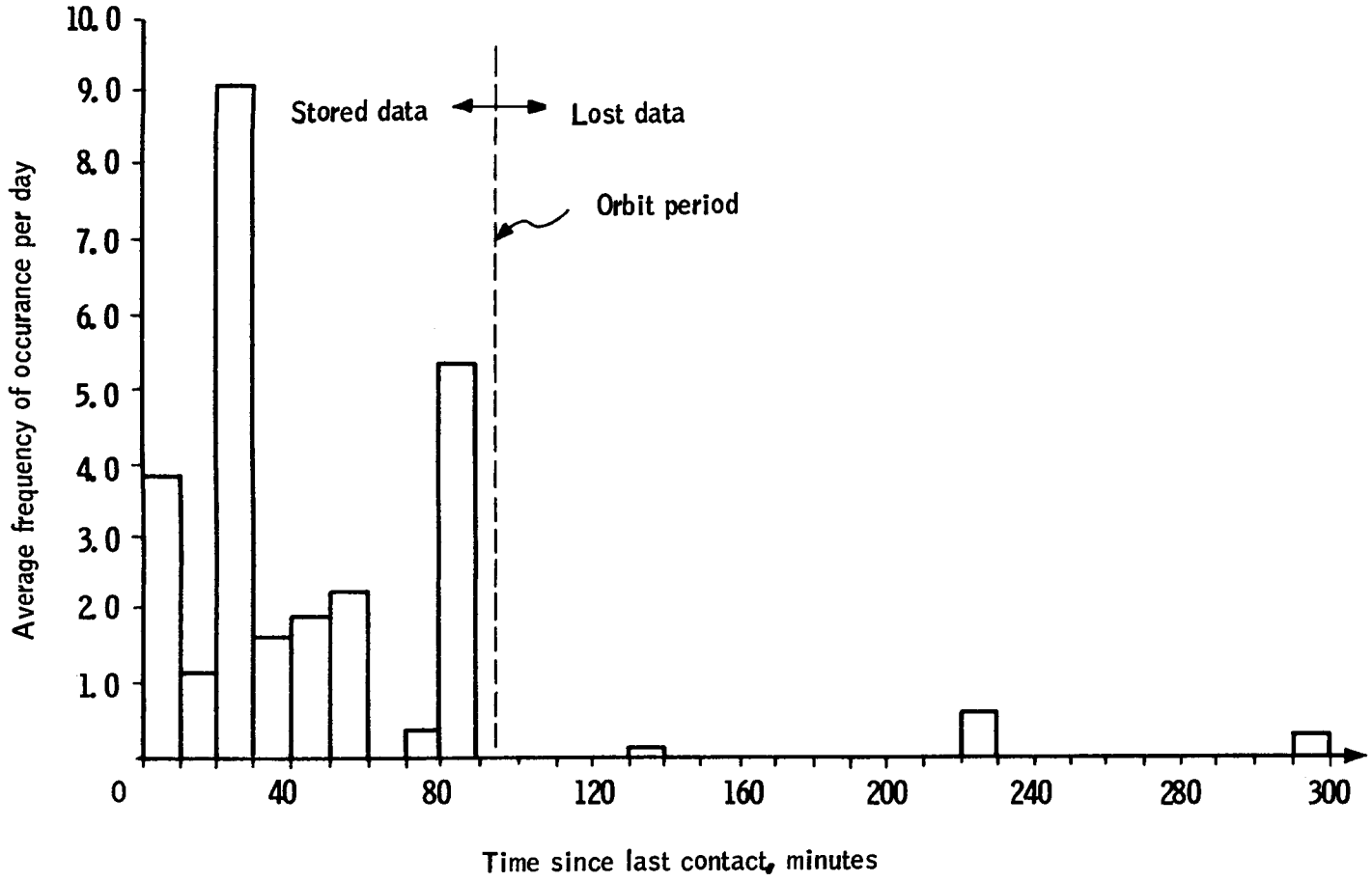


Figure 28. R&R Telemetry Contacts

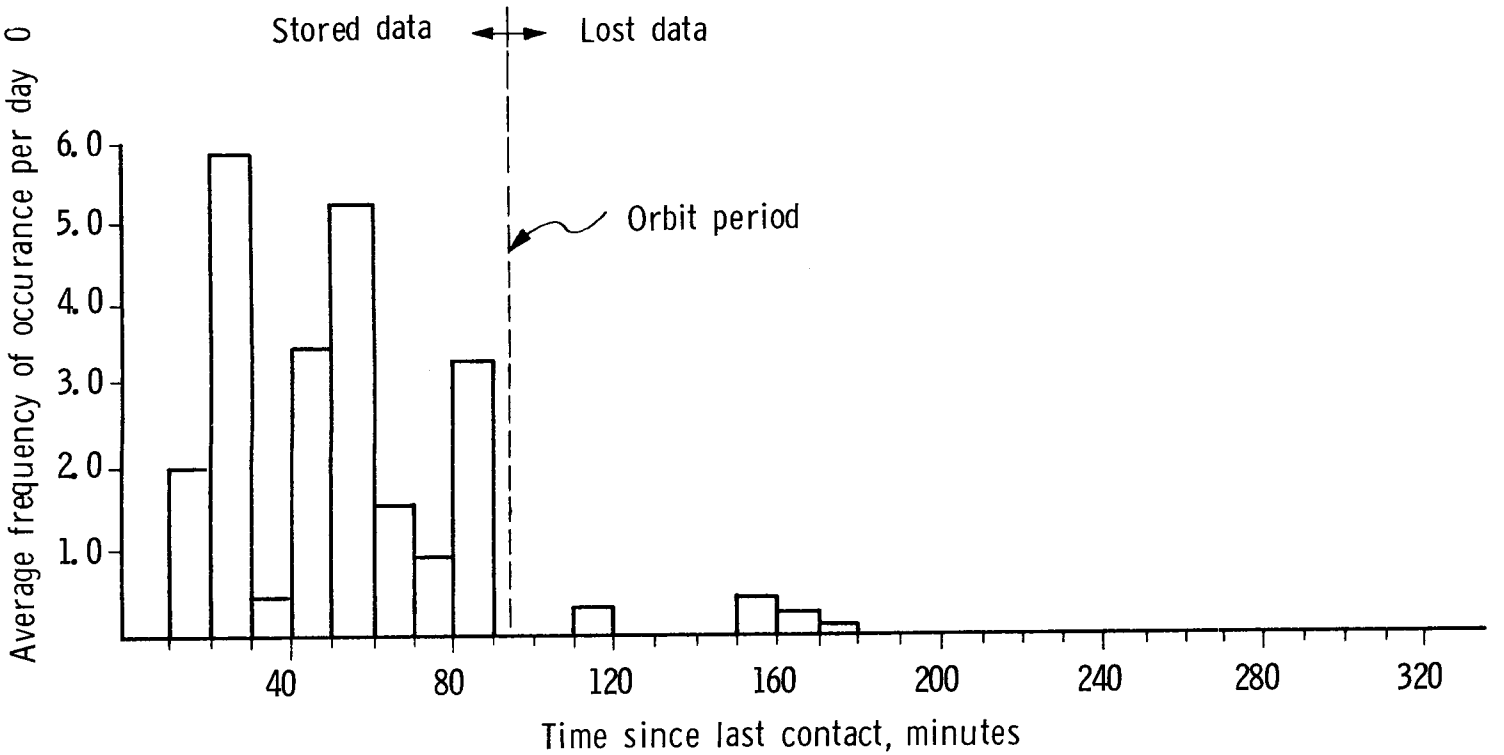


Figure 29. 400 MHz Telemetry Contacts

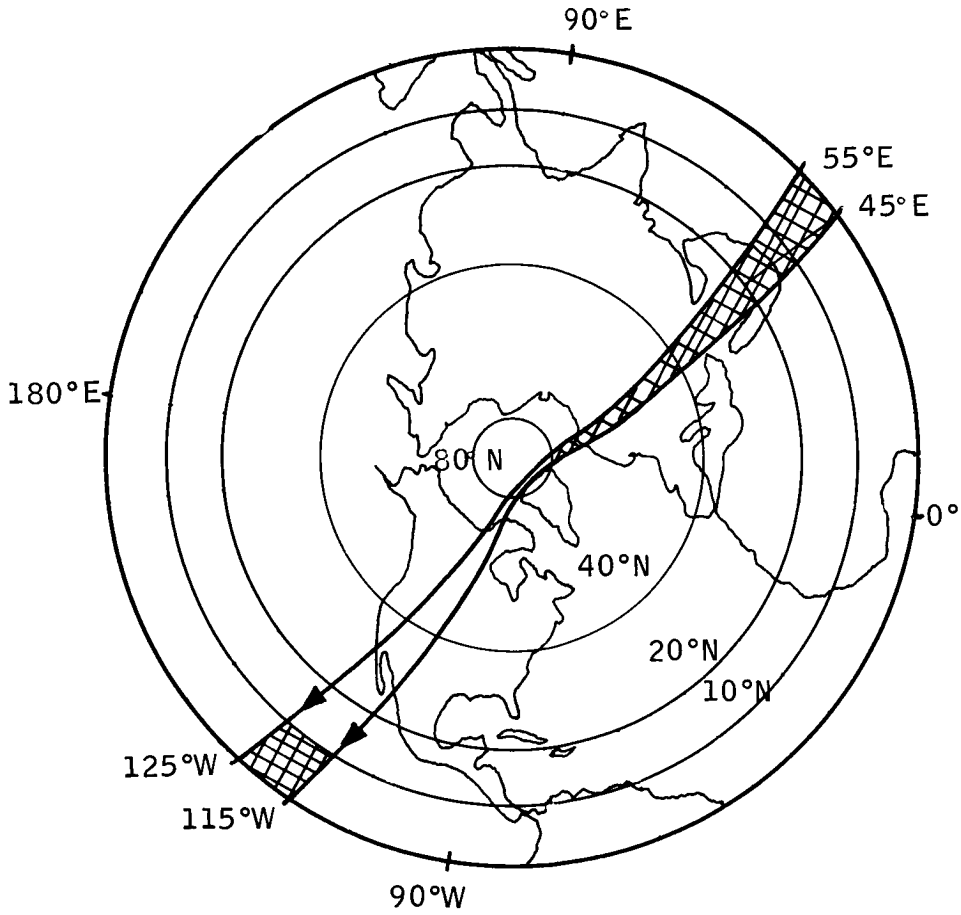


Figure 30. Illustration of VHF Telemetry Hole

DATA ACQUISITION PLANS

The process of data acquisition is explained in the following paragraphs in terms of data flow in the experiment, the early orbit plan and the data acquisition process for a typical day of operation.

Data Flow

The manner in which the data is acquired, centrally accumulated, and eventually processed is conveniently described in terms of data flow diagrams. Figure 31 outlines in block diagram form the satellite equipments which sense, condition, handle, store, and transmit the data to be received by the ground station. Also included are the equipments required for the command and tracking functions. The primary telemetry link under consideration is the vhf carrier modulated such that it is compatible with Minitrack stations. Selection of vhf was based on telemetry coverage and data rate considerations. A back-up link was selected using the S-band R&RR system. As can be seen from Figure 31, the operations necessary to provide sensed data to the experimenter are:

- Obtain tracking predictions so that the satellite can be located
- Command the satellite to transmit data
- Transmit the data to ground station
- Receive and record the data at the ground station
- Deliver the data to GSFC
- Process the data so that it is in a useful form for the experimenter.

The basic equipment at the ground receiving stations is illustrated in Figure 32, along with the general flow of data. Although the R&RR system is shown as being physically associated with the vhf Minitrack station, this is not the case. The R&RR systems are separate independent stations. It was included here only for convenience of illustration since it is used for tracking and as a backup telemetry system. The operations at the ground station consist primarily of acquiring the satellite (aided by tracking predictions), commanding the satellite to transmit data, receiving and recording the data, and displaying selected status data. The received telemetry can be mailed or transmitted to GSFC, depending on the station location. College and Rosman stations have microwave links connected with GSFC. A similar situation exists with regard to commands. The standard commands are initiated at the station; however, special commands can be transmitted by microwave link where possible or by TWX.

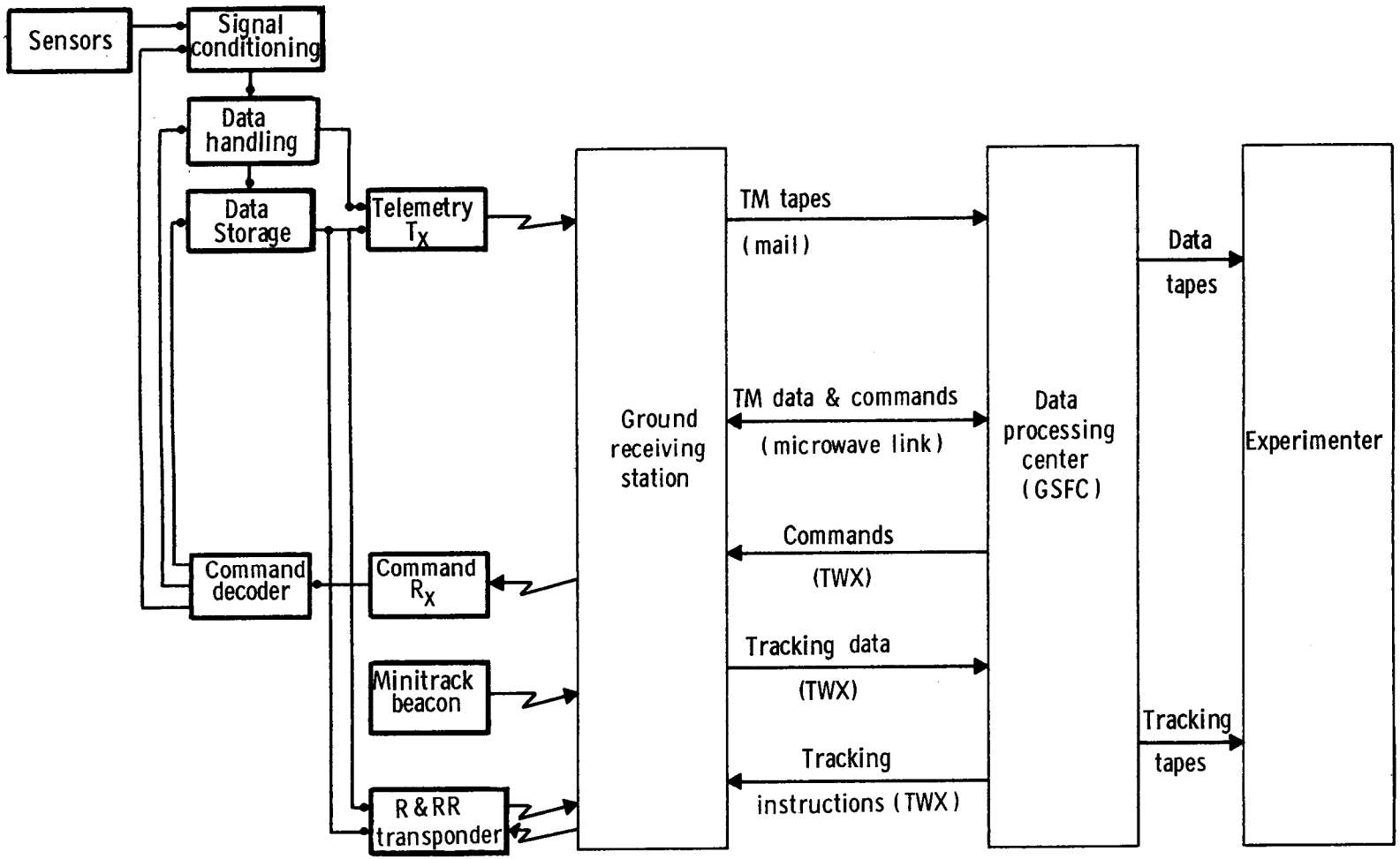


Figure 31. Satellite Data Flow Chart

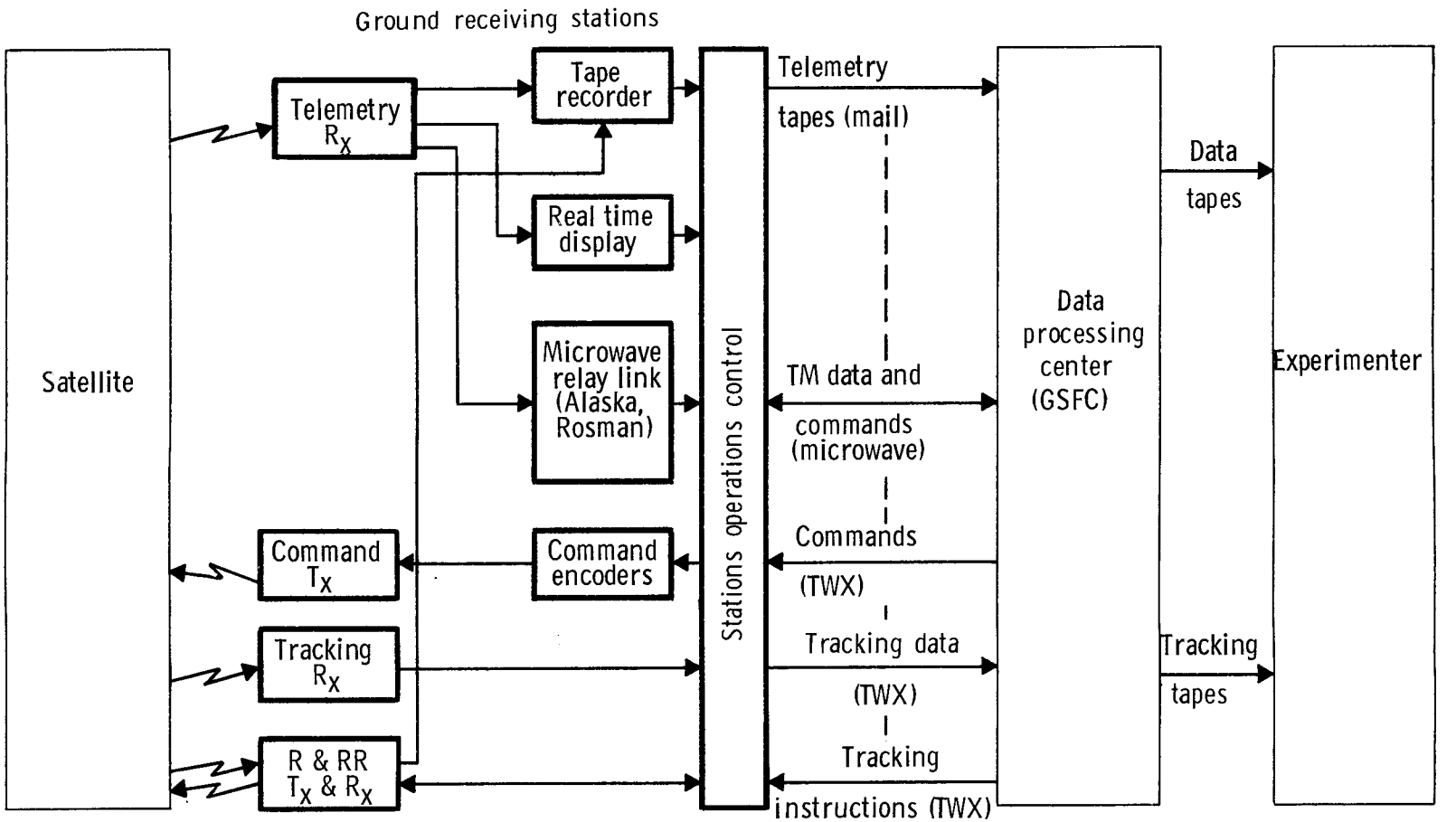


Figure 32. Ground Receiving Station Data Flow Chart

The Data Processing Center is the hub of the STADAN system. All the data received at the outlying stations is accumulated, ordered, and initially processed by this center for presentation to the experimenter in a suitable format. Figure 33 illustrates the flow of data within the GSFC data processing center. As indicated here, there would be an experimenter's control center for the purpose of monitoring the experiment and to make operational decisions. A certain portion of all data received, whether by mail or microwave link, would be monitored to ensure that certain data outputs were satisfactory. The output of the center will consist of an experiment data tape, orbital data tape, and possibly an attitude data tape. The subject of attitude determination will be discussed in a subsequent section. The data reduction function will be the responsibility of the experimenter and may not involve GSFC computing facilities.

Early Orbit Data Acquisition Plan

Data acquisition during early orbits will consist primarily of obtaining starmapper and spacecraft status data for purposes of establishing the proper satellite conditions prior to collection of experimental data. Associated command functions will also be performed. Since a large amount of starmapper data reduction is required during the early orbits, the majority of satellite contacts will be made at the Rosman and College stations which have direct microwave links with GSFC. Telemetry coverage for the first 17 orbits is shown in Table 4. The table presents time of contact, minutes in sight, minutes since last contact, last ascending node before contact, and the number of revolutions since launch time. Appendix F contains tables for the first 10 000 minutes of orbital lifetime.

The PICO computer program described in the section on position determination was utilized here. As can be seen in the table, there are occasions when contacts are not made for several orbits when only the Rosman and College stations are used. This should not pose a problem in the early stages of the experiment. The use of only the College and Rosman stations will ease the problem of initiating commands and making decisions at the receiving stations where the station personnel are not usually involved in decision making functions. After the satellite is ready for gathering scientific data, the remainder of the networks may be used to ensure that large amounts of scientific data are not lost due to lack of sufficient telemetry coverage.

Figure 34 illustrates the telemetry contacts at the College, Rosman, Winkfield, and St. John's stations for the first 1600 minutes of orbit lifetime. Note that the majority of telemetry contacts can be made at College, assuming there are no priority problems. It is assumed that all commands and data necessary to establish the required operational status of the satellite can be handled with the College station. Certainly status data can be obtained from any of the other nine stations and this mode of operation is recommended when possible.

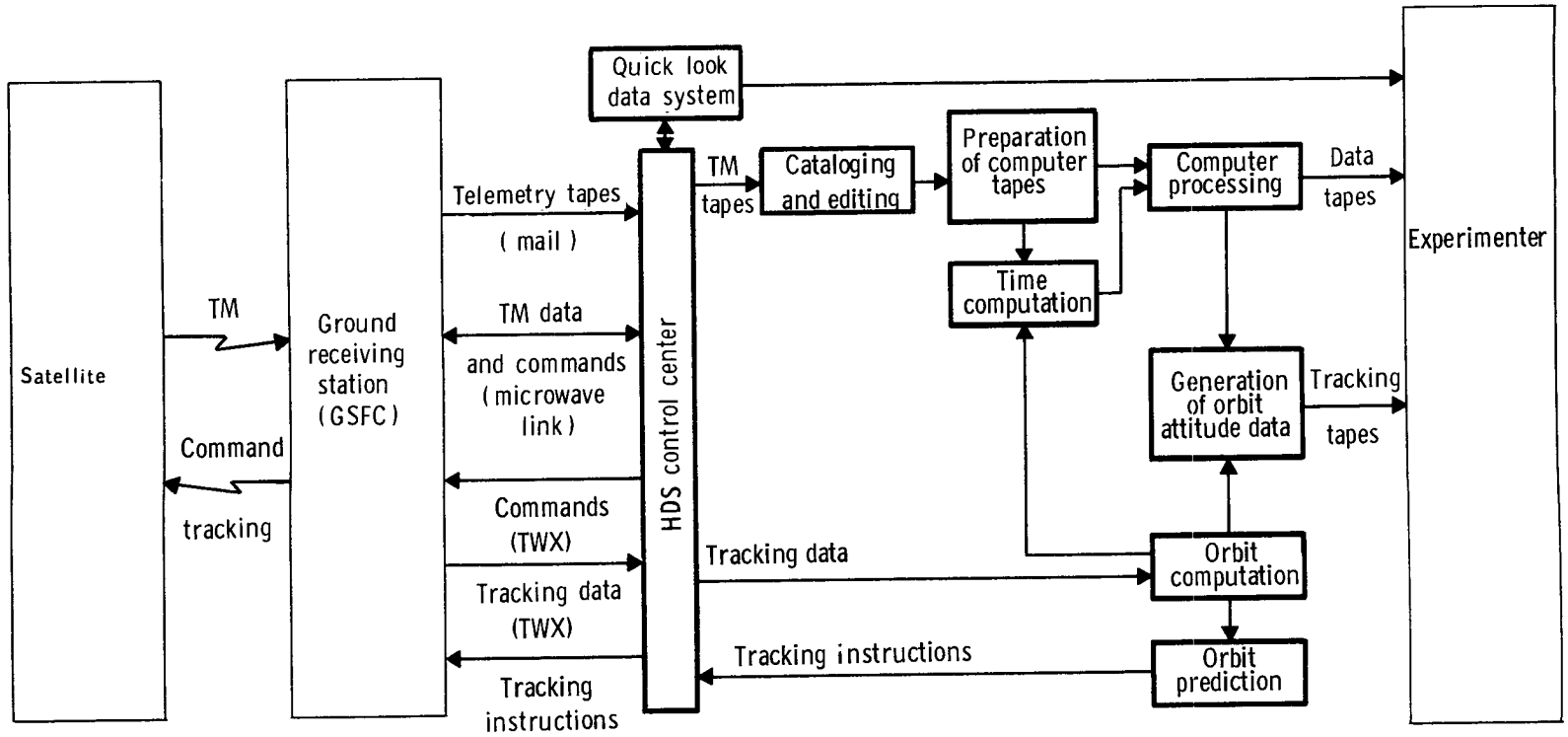


Figure 33. Data Processing Center Data Flow Chart

TABLE 4. - POST-INJECTION VHF TELEMETRY COVERAGE SEQUENCE

POST-INJECTION VHF TELEMETRY COVERAGE SEQUENCE

			NORTH LAT. DEG	EAST LONG. DEG	MIN ELEV. DEG
STATION	1	COLLEGE	64.90	212.10	5.00
STATION	2	FT. MYERS	26.50	278.10	5.00
STATION	3	JOHANNESBURG	-25.90	27.70	5.00
STATION	4	LIMA	-11.80	282.80	5.00
STATION	5	CORDRAL	-35.60	148.90	5.00
STATION	6	QUITO	-.60	281.40	5.00
STATION	7	ROSMAN	35.20	277.10	5.00
STATION	8	ST. JOHNS	47.70	307.30	5.00
STATION	9	SANTIAGO	-33.20	289.30	5.00
STATION	10	WINKFIELD	51.50	359.30	5.00

ORBIT ALT= 500.0 KM.
ORBIT INCL= 97.38 DEG.
LAUNCH-TO-INJECTION ANGLE= 20.00 DEG.
ORBIT PERIOD= 94.62 MINUTES
EARTH RADIUS= 33.0 PERCENT OVER ACTUAL (REFRACTION CORRECTION)
MINIMUM TIME= .00 MIN
WESTWARD SHIFT OF ASC. NODE= 23.65 DEG./ORBIT
LAUNCH LONGITUDE= -120.63 DEG. EAST
LAUNCH LATITUDE= 34.76 DEG. NORTH
LAUNCH VELOCITY HAS SOUTHERLY COMPONENT
LAUNCH TO INJECTION TIME= 10.00 MIN.
TOTAL TIME= 10000.00 MIN.

STATION	MAX. ARC RANGE VISIBLE(DEG)	MAX. DIST.KM.
1	19.71	2329.1
2	19.71	2329.1
3	19.71	2329.1
4	19.71	2329.1
5	19.71	2329.1
6	19.71	2329.1
7	19.71	2329.1
8	19.71	2329.1
9	19.71	2329.1
10	19.71	2329.1

TABLE 4. - POST-INJECTION VHF TELEMETRY COVERAGE SEQUENCE - Concluded

POST INJECTION COVERAGE SEQUENCE (INJECTION TIME= 10.00 MIN. AFTER LAUNCH)

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.	REV. NO.
46.42	JOHANNESBURG	6.21		63.73	1
69.19	WINKEFIELD	6.40	16.56	40.08	1
81.95	COLLEGE	9.74	6.36	40.08	1
139.60	JOHANNESBURG	9.99	47.91	40.08	2
160.03	WINKEFIELD	10.28	10.44	16.42	2
176.01	COLLEGE	10.26	5.70	16.42	2
255.04	WINKEFIELD	8.31	68.78	-7.23	3
270.17	COLLEGE	8.69	6.81	-7.23	3
298.42	CORCORAL	10.22	19.56	-7.23	4
348.84	ST. JOHNS	9.77	40.20	-30.88	4
364.05	COLLEGE	6.03	5.43	-30.88	4
393.79	CORCORAL	6.41	23.71	-30.88	5
424.72	SANTIAGO	1.41	24.52	-30.88	5
441.76	FT. MYERS	3.26	15.63	-54.54	5
442.70	ROSMAN	6.07	.00	-54.54	5
442.79	ST. JOHNS	9.31	.00	-54.54	5
456.72	COLLEGE	4.65	4.62	-54.54	5
515.88	SANTIAGO	10.36	54.51	-54.54	6
521.90	LIMA	10.35	.00	-54.54	6
531.48	FT. MYERS	10.33	.00	-78.19	6
533.79	ROSMAN	10.29	.00	-78.19	6
547.63	COLLEGE	6.65	3.54	-78.19	6
614.29	SANTIAGO	2.09	60.00	-78.19	7
638.71	COLLEGE	9.18	22.34	-101.85	7
731.25	COLLEGE	10.36	83.35	-125.50	8
769.62	JOHANNESBURG	9.45	28.02	-125.50	9
825.85	COLLEGE	9.25	46.77	-149.16	9
863.60	JOHANNESBURG	8.06	28.50	-149.16	10
923.90	COLLEGE	3.20	52.24	-172.81	10
936.97	WINKEFIELD	9.98	9.86	-172.81	10
990.52	CORCORAL	4.00	43.57	-172.81	11
1031.39	WINKEFIELD	9.33	36.88	163.54	11
1082.95	CORCORAL	10.35	42.23	163.54	12
1127.42	ST. JOHNS	9.49	34.13	139.88	12
1150.46	SANTIAGO	9.20	13.55	139.88	13
1181.37	CORCORAL	1.96	21.72	139.88	13
1221.66	ST. JOHNS	9.62	38.33	116.23	13
1225.96	ROSMAN	8.26	.00	116.23	13
1228.10	FT. MYERS	8.85	.00	116.23	13
1234.79	QUITO	10.27	.00	116.23	14
1237.67	LIMA	10.35	.00	116.23	14
1243.64	SANTIAGO	9.98	.00	116.23	14
1319.69	ROSMAN	9.71	67.07	92.57	14
1322.35	FT. MYERS	8.84	.00	92.57	14
1408.94	COLLEGE	3.05	77.74	68.92	15
1490.17	WINKEFIELD	4.13	78.19	45.26	16
1501.39	COLLEGE	9.24	7.10	45.26	16
1558.68	JOHANNESBURG	10.36	48.05	45.26	17

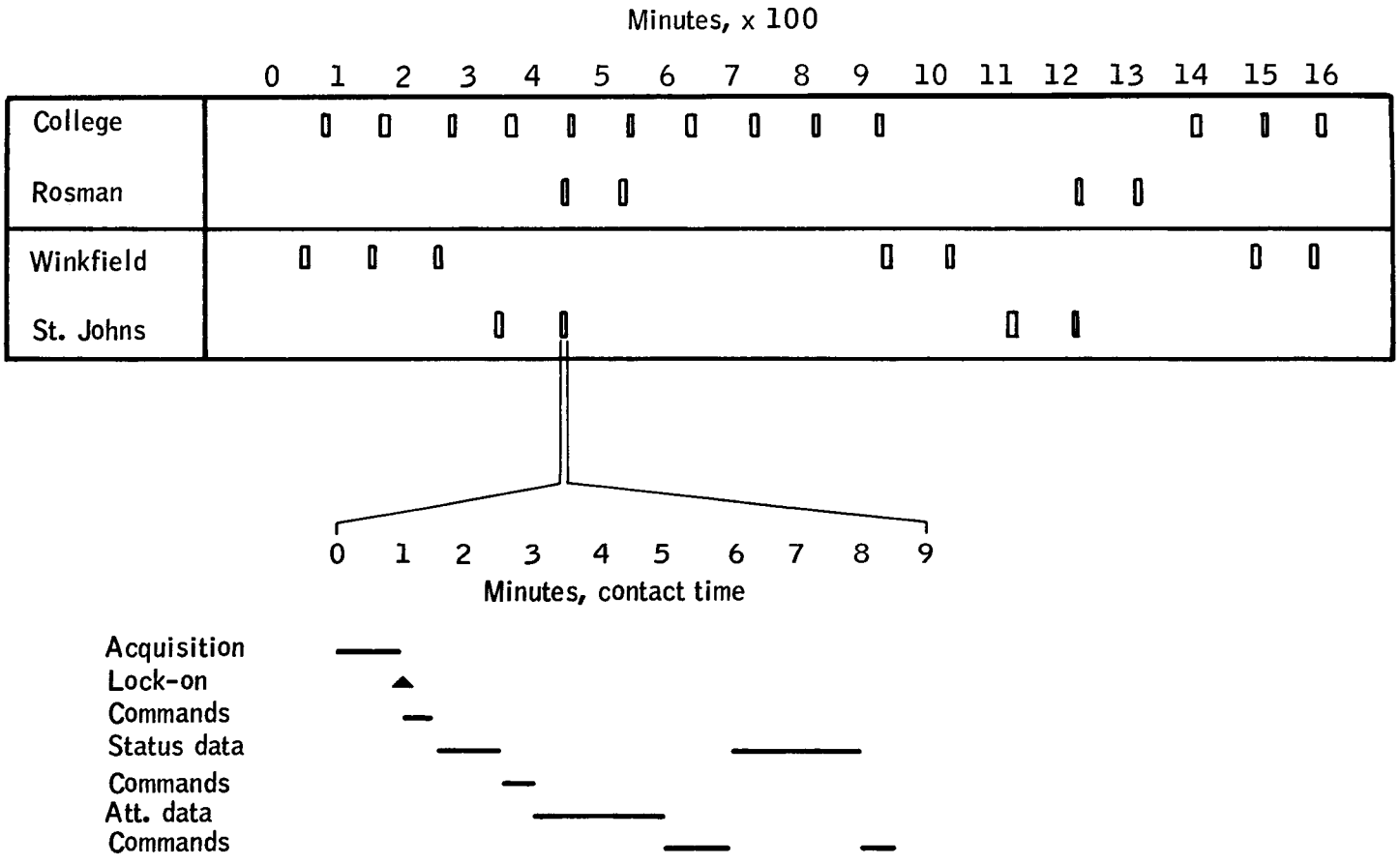


Figure 34. VHF Telemetry Contacts and a Typical Sequence of Events

Also included in Figure 34 is the sequence of events or operations associated with a typical telemetry contact. The sequence indicated is one which would likely be used at College or Rosman while the sequence at any of the other stations would consist of only the first four operations listed. The amount of time that the satellite is in contact with the station certainly governs the length and type of sequences to be performed.

The acquisition and lock-on operation is essentially that of achieving automatic tracking of the satellite. When this is accomplished, commands can then be transmitted to request transmission of status data. After a sufficient amount of status data has been received, further commands can request transmission of the data in storage (starmapper data, etc.)

There may be occasions when it may be advantageous to set some conditions into the satellite for the forthcoming orbits (attitude control, calibration, etc.). These commands and the verification thereof would then conclude the contact with the satellite.

Data Acquisition Plan for a Typical Day of In-Orbit Operation

The acquisition of data during a typical day can be outlined by referring back to Table 3. This table represents one of the 24 typical days of operation. Assuming a storage capability of one orbit (94 minutes), then data dumps must be accomplished such that the accumulated time since the last contact be less than one orbit time. For the particular day represented by the passes in Table 3, the first data dump could be at Winkfield, the second at St. John's, etc. A graphical presentation of station contacts is shown in Figure 35, using the data presented in Table 3. Note that the station contacts have been categorized into two groups and called primary and secondary contacts. Primary contacts are identified as those contacts which are either absolutely necessary for proper telemetry coverage and/or the station making the contact is on the North American Continent. Station contacts within the continent result in the shortest delay of data delivery to GSFC. The solid rectangles in Figure 35 indicate a set of particular station contacts made during the typical day presented while the open rectangles represent alternate station contacts that could have been made. There may be a problem of satellite priority and thus, selection of secondary station contacts will have to be made. The detailed weekly plan for this phase of data acquisition will be established by GSFC in advance of actual acquisition with active satellite priorities incorporated.

The manner in which data is acquired during each contact is conveniently described in terms of a sequence of events. A typical sequence of events would be as follows. After contact is established with the satellite on the basis of tracking predictions, the telemetry status data would be received, conditioned, and duplexed to determine satellite status. Commands would then be initiated to establish the desired conditions in the satellite data handling system and to initiate playback of the scientific data from storage. The remainder of the contact may be used to set up further commands, if required, and to exercise the experiment equipment for calibration or diagnostic purposes. Primary command and control of the spacecraft should be retained at a central HDS control office while certain routine commands can be handled by the local ground station

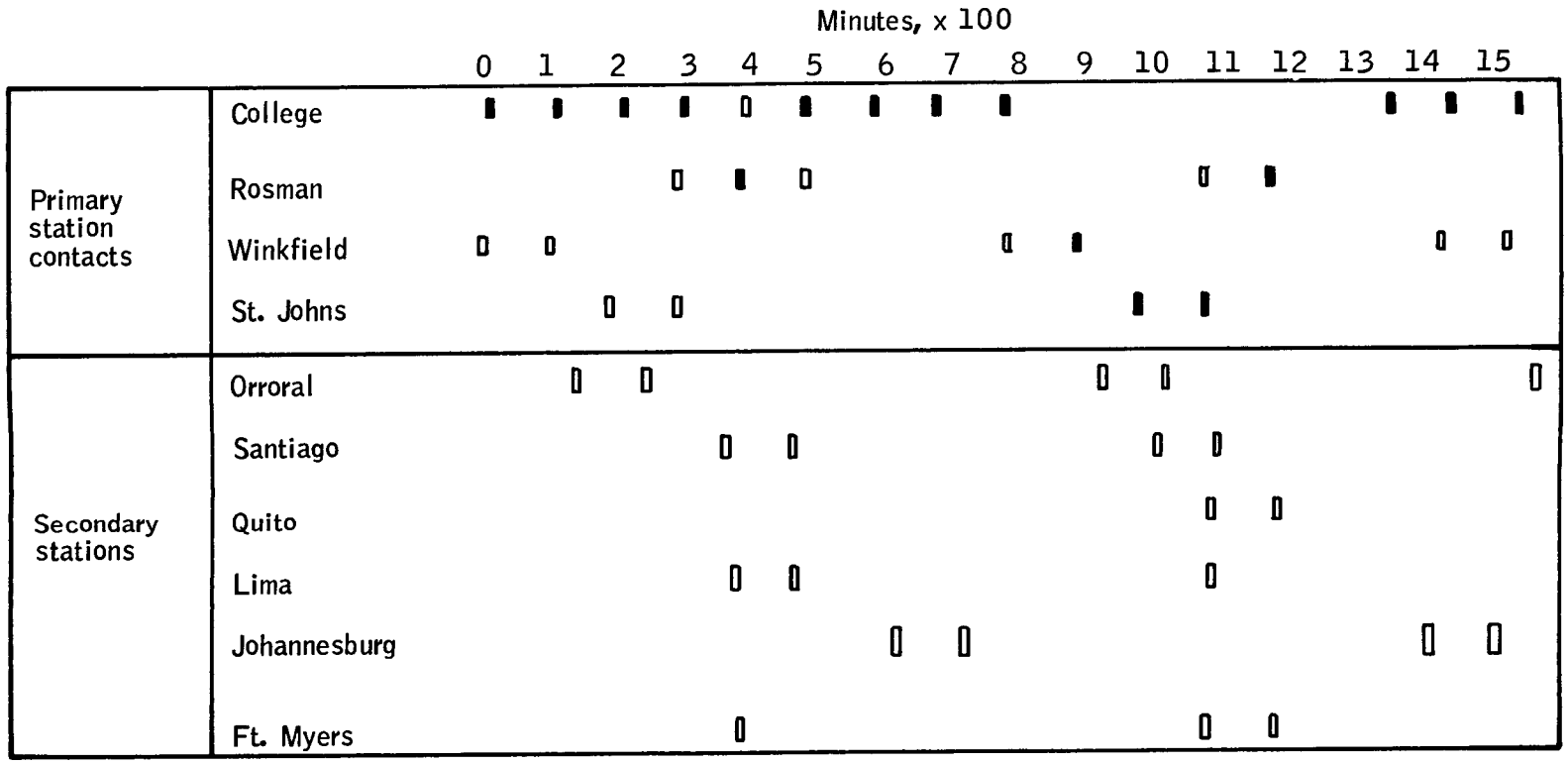


Figure 35. VHF Telemetry Contacts for a Typical Day of Operation

as required. The minimum useful contact time is estimated to be approximately three minutes with two of these being allotted to telemetering of scientific data. The maximum contact time is on the order of ten minutes, assuming a minimum elevation of 5 deg from the horizon. This can be seen by referring to Table 3 in the column Min in Sight. A typical contact is diagrammed in Figure 36 to show the sequence of events performed during the contact. When a short contact is made, it is obvious that certain operations must be shortened or eliminated. For example, if it is necessary to make contact where the satellite is in sight for only four minutes, only the operations absoluately necessary will be performed.

After data has been received and recorded at the ground station, it is mailed to the GSFC Data Processing Center. Delivery time ranges from two days to two weeks depending upon the station location. The Alaska and Rosman stations have direct microwave links with GSFC and any data received at these stations is usually transmitted over the links with a very short delay from the time of satellite contact. This allows certain data to be processed at the control center for quick look purposes when it is necessary to react rapidly to conditions on the satellite. Figure 36 also indicates the mode of data delivery from the station to GSFC and the approximate delay in delivery.

CONCLUSIONS

The following conclusions regarding data acquisition considerations have been formed:

- The vhf (136 MHz) STADAN telemetry link should be used as the primary link since it provides the best telemetry coverage and satisfies the data bandwidth requirements.
- The R&RR S-band carrier can conveniently be used as a back-up link since the basic system is required for the tracking function.
- The tone-digital command system is recommended for the spacecraft system since it can handle the quantity and type of commands required.
- The primary stations recommended for telemetry contacts are College, Rosman, St. Johns, and Winkfield since these stations provide adequate coverage and will permit transmission of the data to GSFC in the least amount of time. Satellite priorities will interfere with this plan; however, it is expected that the preference will be given to these stations when possible.

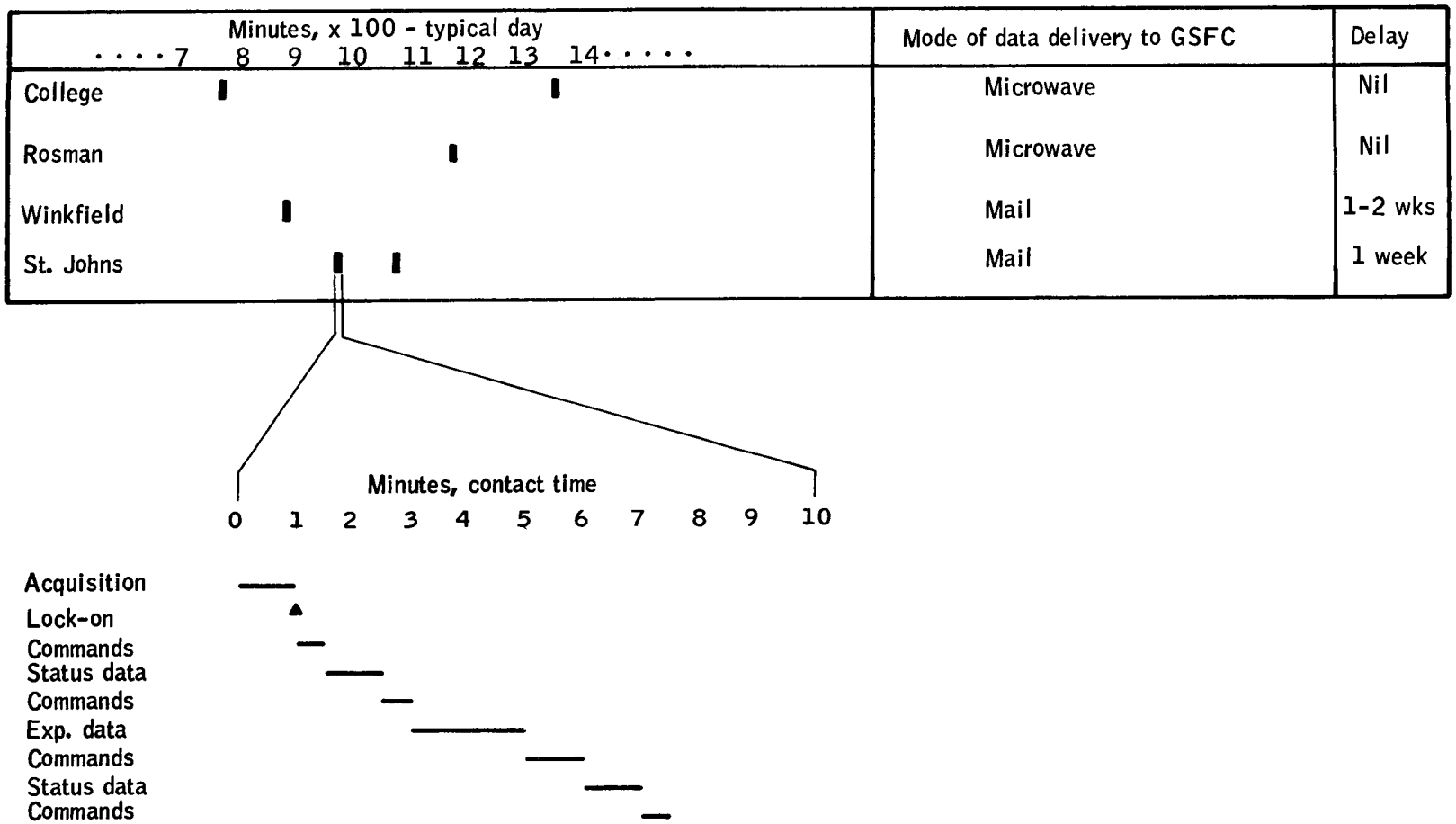


Figure 36. Sequence of Operations During a Telemetry Contact

ATTITUDE DETERMINATION

Attitude determination is defined as the estimation of the spacecraft (measurement system) attitude with respect to some known frame of reference. The conceptual design of the attitude measurement system consists of defining the required measurement devices and ground data processing system. This section describes the conceptual design feasibility study conducted, assuming a passive starmapper/sun sensor instrument system in the satellite, and a least-squares attitude estimation algorithm programmed in a ground-based computer.

INTRODUCTION AND STATEMENT OF THE PROBLEM

The detailed analyses of the attitude measurement and determination system mechanization is an extension of the studies conducted in Phase A, Part I. Considering spacecraft system mechanization including reliability and experiment requirements, the spacecraft concept was determined to be a spin-stabilized wheel configuration with the angular momentum vector nominally perpendicular to the spacecraft orbit plane. An important consideration in the selection of an attitude measurement system concept is the lack of a requirement for an on-board, real-time knowledge of the precise attitude of the vehicle.

When considering the rolling-wheel spacecraft conceptual system operating for one year in space, inertial sensors, such as gyroscopes, prove unacceptable. Coupling this with the lack of a requirement for real-time attitude knowledge, the attitude measurement system selected is one which utilizes the spacecraft motion to scan the celestial sphere, a starmapper concept.

Data storage and transmission equipment are assumed to be aboard the satellite so that ground based a posteriori attitude estimation can be accomplished. The problem, then, becomes one of defining the detailed data processing algorithm to be used and the data requirements from the satellite.

The problem has several interesting features. First, the starmapper is an instrument which emits a time pulse whenever a star comes into the field of view. To interpret such signals in terms of attitude, it is necessary to integrate a set of model differential equations. (It is also necessary to know what star produced what pulse. The matching of time pulses to stars is assumed to have been done.) Thus, one must define a model for the spacecraft. The principal task here is the determination of the torques acting on the vehicle. This is not a trivial problem, even though many of the torque terms are found to be negligible. The major torques are magnetic moment and eddy current torques and their forms are difficult to define with exactness. Moreover, unpredictable torques, such as those produced by meteoroid impacts, produce additional uncertainties in the model. Thus, the vehicle model is not perfect and the integrated path, in general, departs

from reality. Additionally, the time pulses from the starmapper may be in error by some random amount. It is, thus, necessary to consider the statistics of the timing pulse error in the interpretation of the signal.

Finally, practical considerations of the orbit and the starmapper instrument design modify the starmapper concept to some extent. A circular, sun-synchronous orbit was chosen for the radiometer experiment. This orbit is such that the vehicle is in the sunlight almost 70 percent of the time. To see stars during this time, the starmapper would require a baffle with an attenuation on the order of 10^{-12}. Present state of the art in the design of baffles makes it difficult (if not impossible) to guarantee that this attenuation can be met. Thus, the starmapper may be useless during most of the orbit. The model uncertainties and the accuracy requirements on the attitude determination rule out attitude prediction over this part of the orbit. Thus, some kind of attitude measurements must be made.

The measurement problem is resolved by introducing a sun sensor into the starmapper concept. This device produces signals, comparable to those of the starmapper, whenever the sun crosses the field of view. The difference in observations is that the sun sensor sees but one body.

The problem may now be redefined as that of estimating the vehicle attitude, as a function of time, on the basis of an assumed model, and starmapper and sun sensor time pulses.

The chosen approach to the problem is first to set up the model differential equations as accurately as possible, in order that the solution approximate, as closely as possible, the motion of the vehicle. The solution of the differential equations can be expressed as a function of the initial conditions, the model parameters, and time. The problem, then, becomes one of finding those initial conditions and parameters that best explain (in some sense) the observed star and sun sighting time pulses. The attitude estimate is recovered from integration of the differential equations with the determined set of initial conditions and parameters.

The problem of finding the initial conditions and the model parameters is termed the initial value problem. The method chosen to solve this problem defines the ground based data processing algorithm to be used.

Three methods for solving the initial value problem were considered. These include the Kalman interpolation problem, the Cox nonlinear estimation problem, and the method of least squares. The Kalman and Cox approaches have the advantage that model and measurement statistics can be brought directly into the problem formulation. However, the Kalman approach requires a fairly good reference solution, which may not be available in a practical situation, and it would be difficult to determine the adequacy of a given reference. The objective is to determine the best reference solution, so the Kalman approach was eliminated. The Cox nonlinear approach allows for a nonlinear solution to the initial value problem. The formulation, however, leads to a two-point boundary value problem, whose solution would

require a large (and consequently slow) computer program. The method of least squares was chosen as the algorithm to be used because of its relative simplicity in comparison to the Cox approach and because the method has been successfully used in reducing similar data in the Scanner program.

The following paragraphs detail the development of the least-squares data reduction algorithm and the resultant computer simulation program. A data generation program, used to generate star and sun-sighting instants, is also described. Results of computer runs to determine feasibility of the star-mapper and sun sensor instrument combination are displayed. The overall approach to the attitude determination study is illustrated in Figure 37.

NOTATION

State Variables

$\omega_x, \omega_y, \omega_z$	Vehicle angular rates along principal body axes
ψ, ϕ, θ	Euler angles relating principal axes to inertial space
t	Time (independent variable)
x	State vector with components $(\omega_x, \omega_y, \omega_z, \psi, \phi, \theta)$

Subscript (o) on state variables indicates initial conditions, usually taken at $t_o = 0$.

Model Parameters

I_1, I_2, I_3	Vehicle moments of inertia along principal x, y, and z axes, respectively
A, C	Moment of inertia ratios, taken as I_1 and I_3, respectively, divided by I_2
M_x, M_y, M_z	Vehicle magnetic moment coefficients with respect to principal coordinates
M'_x, M'_y, M'_z	Magnetic moment coefficients divided by I_2
K	Vehicle magnetic eddy current coefficient
K'	Magnetic eddy current coefficient divided by I_2
$\epsilon_1, \epsilon_2, \epsilon_3$	Vehicle offset angles relating experimental axes to principal coordinates

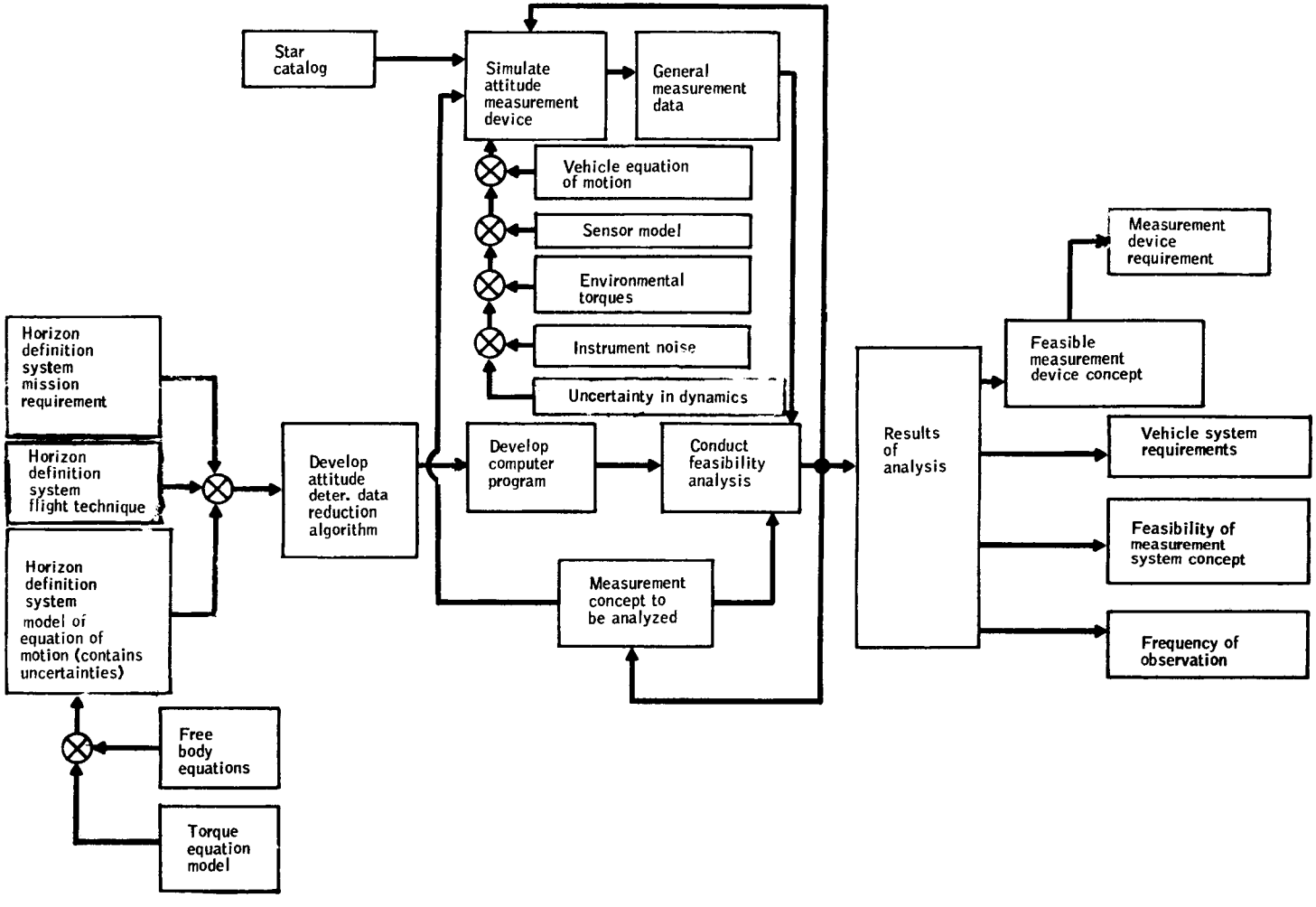


Figure 37. Attitude Determination Analysis Study Plan

ϵ The vector $(\epsilon_1, \epsilon_2, \epsilon_3)$

a Parameter vector with components $(A, C, M'_x, M'_y, M'_z, K')$

y Complete parameter vector with components (x_o, a, ϵ)

Orbit Parameters

Ω Longitudinal of the ascending node

i Inclination

ν True anomaly

Transit Time Model

f Half field of view angle

F Constraint equation as used in the generation of transit times

$\hat{n}$ Unit vector normal to the plane of $\hat{O}$ and $\hat{S}_i$

$\hat{O}$ Unit vector in direction of the optical axis

p Star and slit parameter vector in F

$\hat{S}$ Unit vector pointing to a star

$\hat{S}_i$ Unit vector pointing to the ith star

t° Rotational reference time

t°_i Initial estimate of transit time for the ith star

t_i Estimate of transit time for the ith star from Newton's method

$\hat{z}$ Unit vector pointing from earth center to vehicle (zenith)

β Rotation angle of slit plane about optical axis

γ Angle between optical axis and j_E

Γ Earth blocking angle

η Angle between line of sight to star and j_S axis the instant the star lies in the slit plane

θ_i The angle between the ith star and the optical axis $\hat{O}$ (or j_S)

Star Parameters

α Right ascension of a given star with respect to inertial space

δ Declination of a given star with respect to inertial space

Coordinate Frames and Vectors

i_I, j_I, k_I Unit vectors in the inertial x, y, and z directions, respectively. i_I points toward the first point, Aries k_I points toward north pole, and j_I completes the right-handed triad.

i_O, j_O, k_O Unit vectors defining the orbit coordinate frame. i_O points toward the vehicle from the center of the earth (this is the same as $\hat{z}$) and k_O is normal to the orbit plane. j_O completes the right-handed triad.

i_B, j_B, k_B Unit vectors along the body principal x, y, and z coordinate axes, respectively.

i_E, j_E, k_E Unit vectors along the experimental x, y, and z coordinate axes, respectively.

i_S, j_S, k_S Unit vectors along the slit frame x, y, and z coordinate axes, respectively. i_S is normal to the slit plane and j_S defines $\hat{O}$

i_m, j_m, k_m $m=1\ldots,7$ Unit vectors for intermediate coordinate frames in the x, y, and z directions.

x_I A vector (usually a unit vector) with components along the inertial x, y, and z axes, respectively.

x_B A vector (usually a unit vector) with components along the principal body x, y, and z coordinate axes, respectively.

x_E A vector (usually a unit vector) with components along the experimental x, y, and z coordinate axes, respectively.

x_S A vector (usually a unit vector) with components along the slit frame x, y, and z coordinate axes, respectively.

Transformation Matrices

$E(\psi, \phi, \theta)$ Euler transformation from inertial space to principal body coordinates.

$C(\varepsilon_1, \varepsilon_2, \varepsilon_3)$ Transformation from body coordinates to experimental coordinates.

$A(\beta, \gamma)$ Transformation from experimental coordinates to slit frame.

$A_1(\beta, \gamma)$ First row vector in $A(\beta, \gamma)$, representing direction cosines of the normal to the slit plane in experimental coordinates.

Least Squares

$H(t_k, y)$ Constraint for k^{th} transit time as a function of parameter vector y.

H Vector of constraints for all transit times in a given interval of time.

G Matrix of partials of H with respect to y.

J Least-squares function to be minimized.

Miscellaneous

B_x, B_y, B_z Earth magnetic field components in principal coordinates.

T_x, T_y, T_z Torque components in principal coordinates divided by I_2.

$\sigma(\delta t_j)$ Variance of starmapper (sun sensor) time pulse error.

$(\cdot)$ Time derivative $\frac{d}{dt}$

$(')$ The prime on a vector or a matrix represents the transpose of the vector or the matrix.

COORDINATE FRAME RELATIONSHIPS

Inertial Space

All coordinate systems used are referred to a single inertial coordinate frame. This frame has its x axis pointing towards the first point of Aries, its z axis pointing toward Polaris, and the y axis makes up a right-handed triad. Let i_I, j_I, and k_I be unit vectors in the inertial x, y, and z directions, respectively. Then Figure 38 illustrates the inertial coordinate frame in terms of the unit vectors.

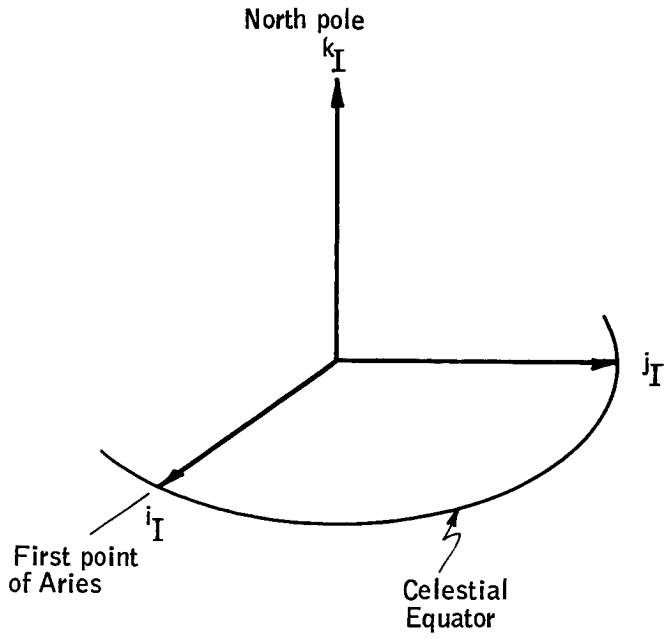


Figure 38. The Inertial Coordinate Frame

Star Coordinates

The line of sight to a given star is related to inertial space by two angles. These are α, the right ascension, and δ, the declination. The angles are illustrated in Figure 39. Usually, the direction cosines of the star line of sight are used. If $\hat{S}$ is the vector of direction cosines, then one sees from Figure 39 that

$$\hat{S} = \begin{bmatrix} \cos\delta \cos\alpha \\ \cos\delta \sin\alpha \\ \sin\delta \end{bmatrix}$$

The Orbit Frame

The line of sight from the center of the earth to the satellite is described in terms of three rotations. The first rotation is angle Ω (longitude of the ascending node) about the inertial z axis. This is illustrated in Figure 40(a). The second rotation is i (inclination) about the new x axis. This is shown in Figure 40(b) as an additional rotation. The i_2 and j_2 vectors now define the orbit plane. The final rotation ν (true anomaly) is about the new z axis, and is such that the x axis in the orbit frame (subscript O) points at the satellite. Figure 40(c) shows all of these rotations.

Principal Axes Coordinate Frame

The satellite (or body) principal coordinate frame is related to inertial space by three Euler angle rotations, as illustrated in Figure 41. The angles are interpreted as yaw (ψ), roll (ϕ) and pitch (θ). In the ideal situation, angle ψ would be the same as angle Ω in Figure 40, and ϕ would equal (i - 90°). The body y axis, j_B, would be the spin axis, which would then be normal to the orbit plane.

Experimental Coordinate Frame

The experimental coordinate frame is defined by the starmapper and sun sensor instruments, which are rigidly attached to the radiometer. This frame is ideally the same as the body principal coordinate frame. In practice, the two frames differ by small amounts. Let ϵ_1, ϵ_2, and ϵ_3 be three (small) rotation angles relating the two frames. Then the ordering of the rotations from body principle to experimental coordinate frames is illustrated in Figure 42.

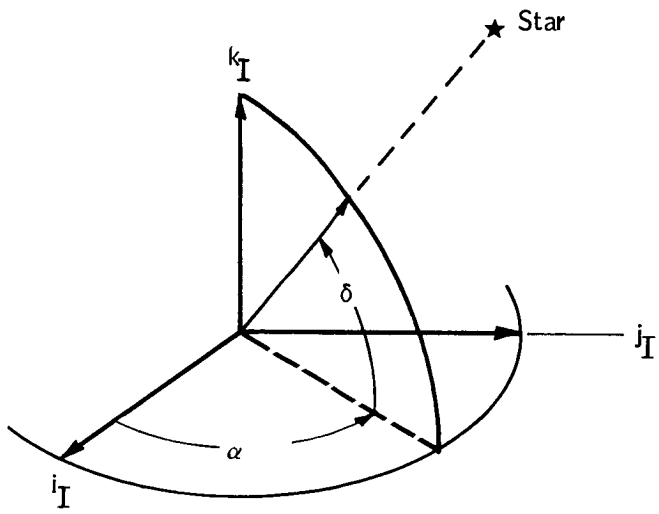


Figure 39. Relationship of Line of Sight to a Given Star to Inertial Space

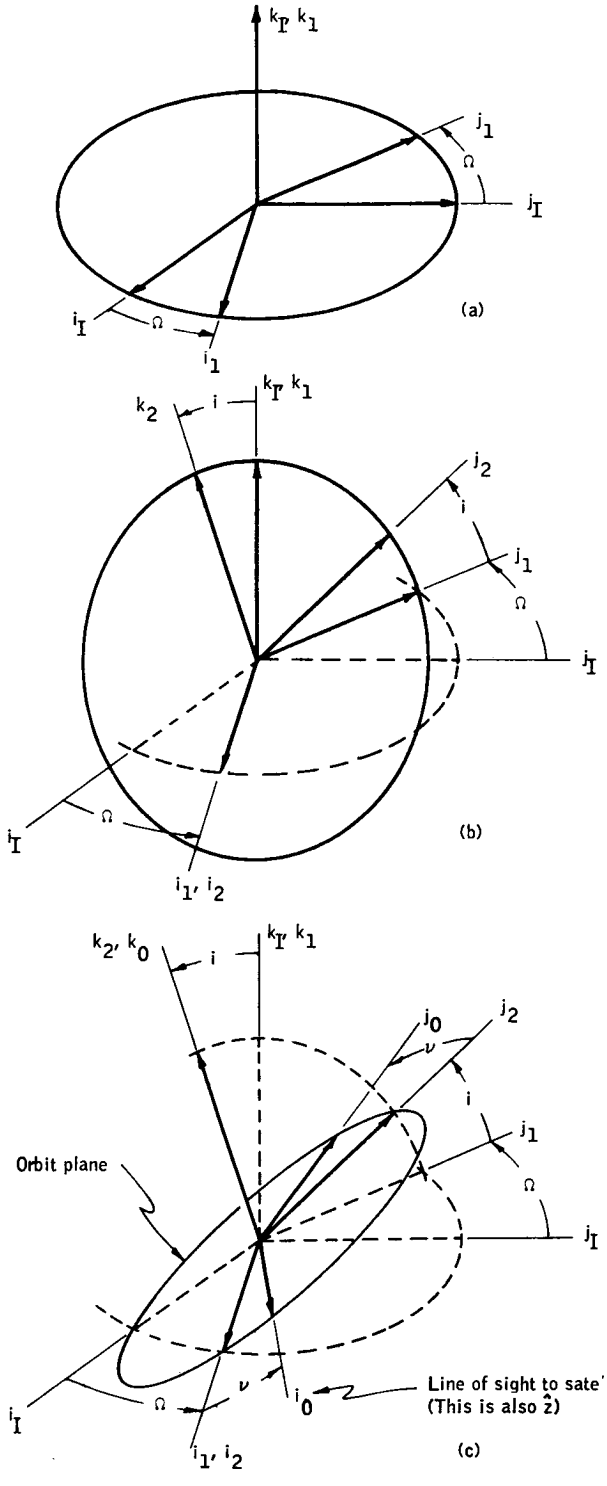


Figure 40. Relationship of Satellite Line of Sight to Inertial Space

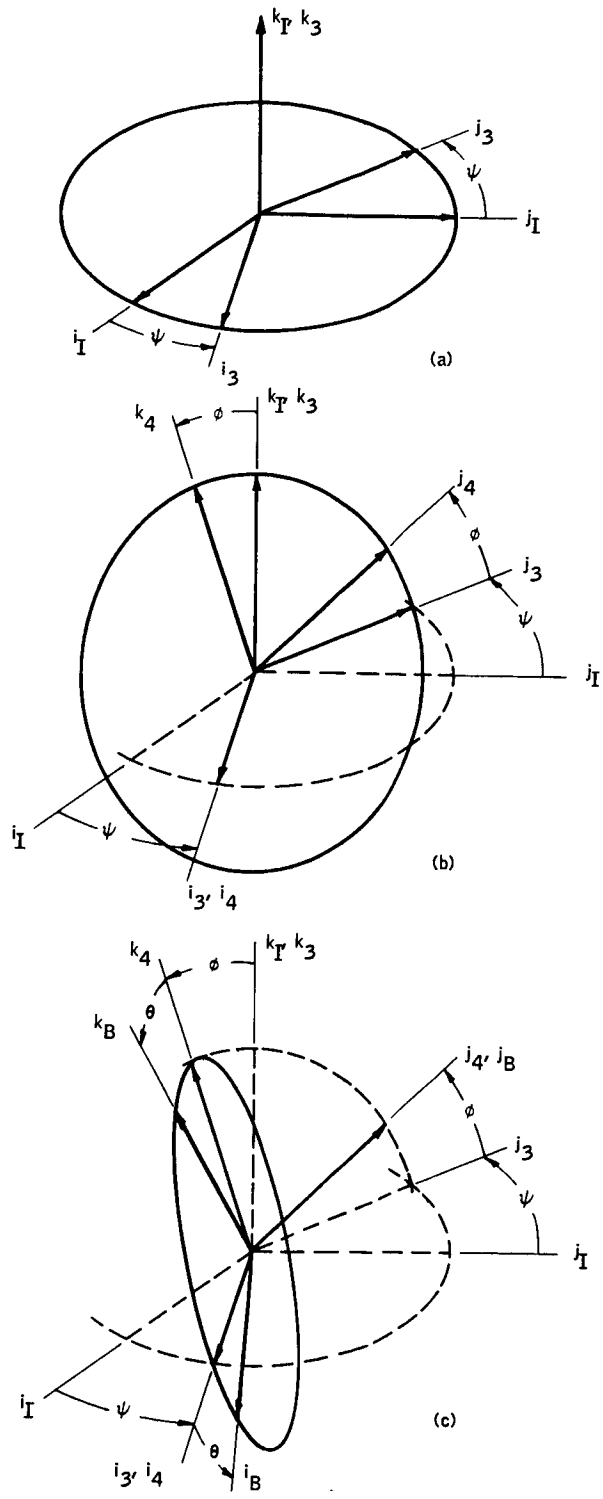


Figure 41. Relationship of the Principal Axis Coordinate Frame to Inertial Space

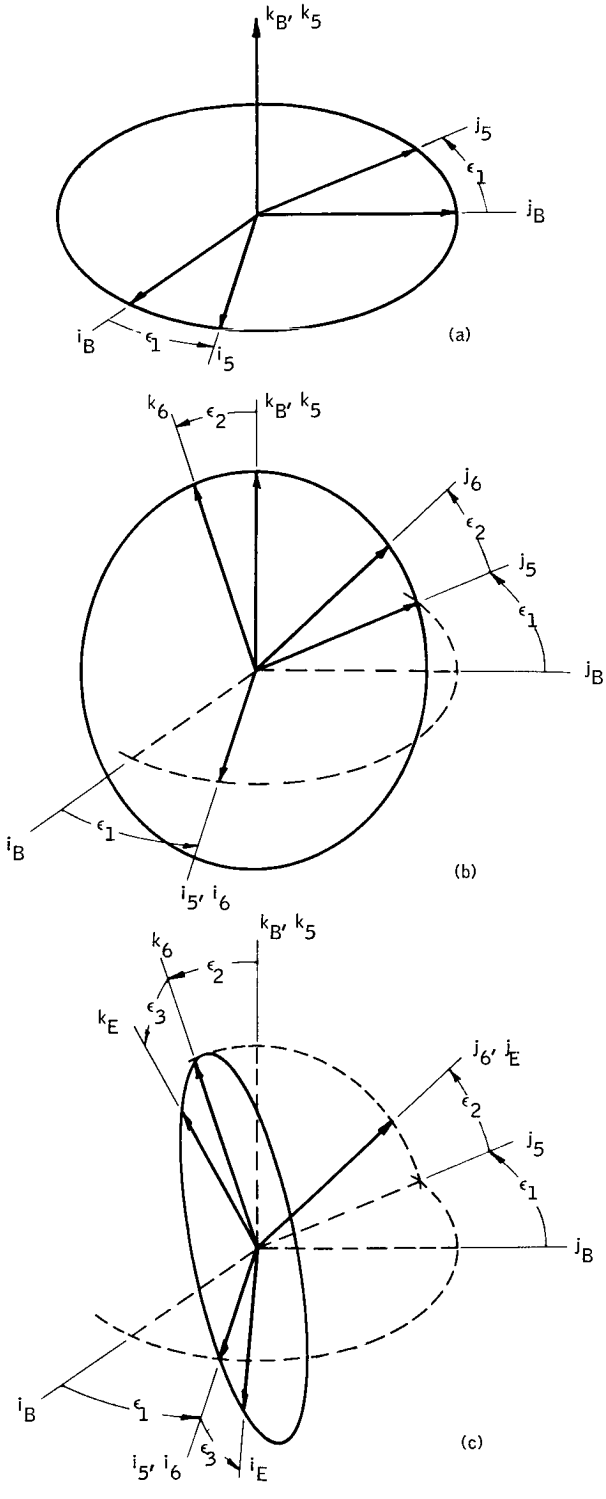


Figure 42. Relationship of the Experimental Coordinate Frame to the Principal Axis Coordinate Frame

Slit Coordinate Frame and Slit Plane

Both the starmapper and the sun sensor instruments are characterized by slits which have known relationships with respect to the experimental coordinate frame. In the study, the slits were simulated as slit planes, one of which is shown in Figure 43(a). Two known rotation angles, γ and β, are required to transform from the experimental frame to the slit frame. The slit plane is defined as the $j_S - k_S$ plane of the slit frame. The field of view of the slit is limited by the half field of view angle f, as shown in Figure 43(b), which correspond to the instrument field of view.

The slit frame rotates with the body , and the slit sweeps the celestial sphere. A time pulse is emitted by the instrument (ideally) the instant the line of sight to a star of sufficient magnitude lies in the slit plane. The geometry at this instant is illustrated in Figure 44. Notice that this figure holds only for sighting instants since $\hat{S}$ is fixed in inertial space, and the slit moves as the vehicle rotates. At the sighting instant, the line of sight to the star lies in the slit plane, so that angle η describes the relationship of $\hat{S}$ to the slit coordinate plane. Notice that $|\eta|$ must be less than f at this instant for the simulated (ideal) instrument to emit a time pulse.

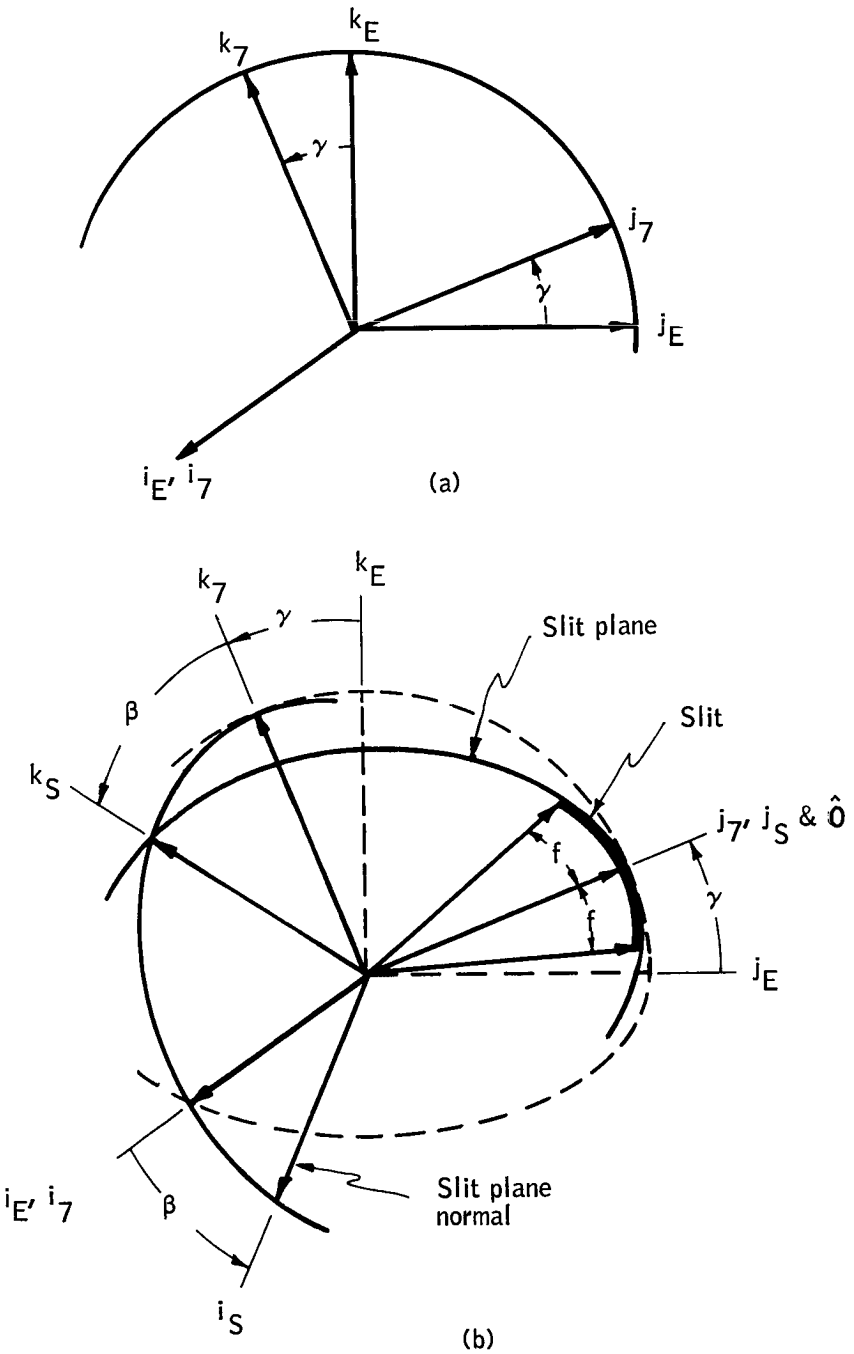


Figure 43. Relationship of the Slit Coordinate Frame to the Experimental Coordinate Frame, Showing the Slit Plane and Slit

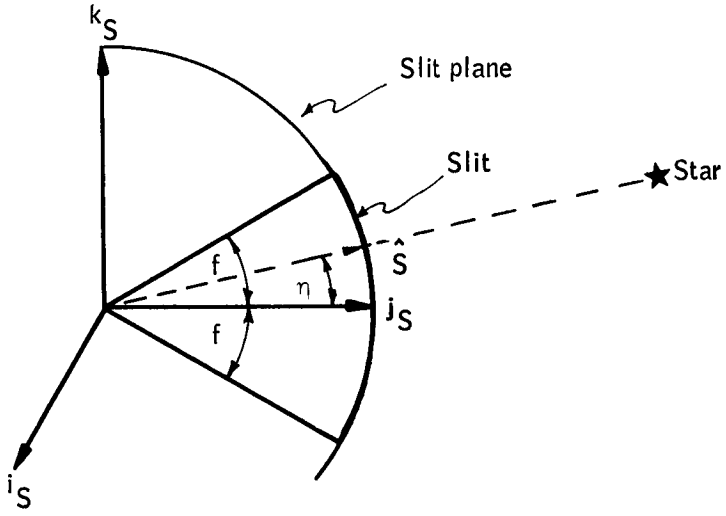


Figure 44. Relationship of the Line of Sight to a Star to the Slit Plane at the Sighting Instant

INPUT MODEL

Vehicle Model

The differential equations for the vehicle rotary motion may be written as

$$\left.\begin{aligned} \dot{\omega}_x &= \left[\omega_y \omega_z (1-C) + \tau_x\right]\frac{1}{A} \\ \dot{\omega}_y &= \left[\omega_x \omega_z (C-A) + \tau_y\right] \\ \dot{\omega}_z &= \left[\omega_x \omega_y (A-1) + \tau_z\right]\frac{1}{C} \end{aligned}\right\} \qquad (5)$$

and

$$\left.\begin{aligned} \dot{\psi} &= \left[-\omega_x \sin\theta + \omega_z \cos\theta\right]\frac{1}{\cos\phi} \\ \dot{\phi} &= \omega_x \cos\theta + \omega_z \sin\theta \\ \dot{\theta} &= \omega_y - \dot{\psi}\sin\phi \end{aligned}\right\} \qquad (6)$$

where ω_x, ω_y, and ω_z are angular rates about the body principal axes and ψ, ϕ, and θ are Euler angles relating body and inertial coordinates (see Figure 41), A and C are the inertia ratios

$$\left.\begin{aligned} A &= I_1/I_2 \\ C &= I_3/I_2 \end{aligned}\right\} \qquad (7)$$

and τ_x, τ_y, and τ_z are the disturbing torques divided by I_2. At present, the torques are taken as magnetic moment and eddy current torques, which have the largest magnitudes of all the torques studied to date. The torque equations are

$$
\left.
\begin{aligned}
\tau_x &= M_y' B_z - M_z' B_y + K' \left[-(B_y^2 + B_z^2)\,\omega_x + B_x (B_y \omega_y + B_z \omega_z) \right] \\
\tau_y &= M_z' B_x - M_x' B_z + K' \left[-(B_x^2 + B_z^2)\,\omega_y + B_y (B_x \omega_x + B_z \omega_z) \right] \\
\tau_z &= M_x' B_y - M_y' B_x + K' \left[-(B_x^2 + B_y^2)\,\omega_z + B_z (B_x \omega_x + B_y \omega_y) \right]
\end{aligned}
\right\} \quad (8)
$$

The coefficients M_x, M_y and M_z are magnetic moment coefficients, K is the eddy current coefficient, and the primes indicate that the coefficients have all been divided by I_2, the moment of inertia about the principal y axis. The magnetic field components of the earth, B_x, B_y, and B_z are in body coordinates.

A vector x_I in inertial coordinates is seen in the body frame as x_B. The transformation matrix is $E(\psi, \phi, \theta)$, where

$$
x_B = E x_I \tag{9}
$$

and

$$
E = \begin{bmatrix}
(\cos\theta\cos\psi - \sin\theta\sin\phi\sin\psi) & (\cos\theta\sin\psi + \sin\theta\sin\phi\cos\psi) & -\sin\theta\cos\phi \\
-\cos\phi\sin\psi & \cos\phi\cos\psi & \sin\phi \\
(\sin\theta\cos\psi + \cos\theta\sin\phi\sin\psi) & (\sin\theta\sin\psi - \cos\theta\sin\phi\cos\psi) & \cos\theta\cos\phi
\end{bmatrix} \tag{10}
$$

Constraint Equation

The constraint equation is a relationship that should hold the instant the line of sight to a star is in the instrument slit. It states that the line of sight to the star and the slit plane normal ($\hat{S}$ and i_S in Figure 44) are orthogonal at sighting instants.

The derivation of the constraint equation follows that of reference 7. The transformation from inertial space to the slit coordinate system is first determined. This relates a vector in inertial space to the same vector as seen in the slit frame. The vector is taken as the direction cosine vector of a star in these two frames, as determined from Figures 39 and 44. The constraint equation follows by equating the two vectors through the transformation matrix.

We assume that the experimental package coordinate frame is displaced from the body principal coordinate system, and that the relationship between the two frames is described by rotations through the three angles ϵ_1, ϵ_2, and ϵ_3. The order of these rotations is illustrated in Figure 42, and the transformation matrix is $C(\epsilon_1, \epsilon_2, \epsilon_3)$. A vector x_B in the body frame is seen as x_E in the experimental frame, where

$$x_E = Cx_B \tag{11}$$

and

$$C = \begin{bmatrix} (\cos\epsilon_3 \cos\epsilon_1 - \sin\epsilon_3 \sin\epsilon_2 \sin\epsilon_1) & (\cos\epsilon_3 \sin\epsilon_1 + \sin\epsilon_3 \sin\epsilon_2 \cos\epsilon_1) & (-\sin\epsilon_3 \cos\epsilon_2) \\ -\cos\epsilon_2 \sin\epsilon_1 & \cos\epsilon_2 \cos\epsilon_1 & \sin\epsilon_2 \\ (\sin\epsilon_3 \cos\epsilon_1 + \cos\epsilon_3 \sin\epsilon_2 \sin\epsilon_1) & (\sin\epsilon_3 \sin\epsilon_1 - \cos\epsilon_3 \sin\epsilon_2 \cos\epsilon_1) & (\cos\epsilon_3 \cos\epsilon_2) \end{bmatrix} \tag{12}$$

A given slit frame of either the starmapper or the sun sensor is related to the experimental coordinate frame through rotation angles γ and β. The order of these rotations is γ about the experimental x axis and β about the new y axis (see Figure 43). If x_S is a vector in the slit frame and x_E is the vector in the experimental frame, then

$$x_S = A\, x_E \tag{13}$$

where

$$A = \begin{bmatrix} \cos\beta & \sin\beta \sin\gamma & -\sin\beta \cos\gamma \\ 0 & \cos\gamma & \sin\gamma \\ \sin\beta & -\cos\beta \sin\gamma & \cos\beta \cos\gamma \end{bmatrix} \tag{14}$$

The combination of equations (9), (11) and (13) is

$$x_S = ACE\, x_I \tag{15}$$

Let x_I be the vector $\hat{S}$ of direction cosines of a star in inertial space. If the star has right ascension α , and declination δ , then

$$x_I = \hat{S} = \begin{bmatrix} \cos\delta \cos\alpha \\ \cos\delta \sin\alpha \\ \sin\delta \end{bmatrix} \tag{16}$$

The slit plane is defined as the slit frame $j_S - k_S$ plane. If the star is in this plane at a particular instant of time, then x_S corresponding to x_I is the vector

$$x_S = \begin{bmatrix} 0 \\ \cos\eta \\ \sin\eta \end{bmatrix} \tag{17}$$

where η is the angle between the line of sight to the star $\hat{S}$ and the j_S axis (Figure 44).

Equations (15) through (17) can then be written

$$\begin{bmatrix} 0 \\ \cos\eta \\ \sin\eta \end{bmatrix} = ACE \begin{bmatrix} \cos\delta \cos\alpha \\ \cos\delta \sin\alpha \\ \sin\delta \end{bmatrix} \tag{18}$$

which is the vector relationship that must be satisfied the instant the star is in the slit plane. The constraint equation is the first component of equation (18), namely

$$0 = A_1 C E \begin{bmatrix} \cos\delta \cos\alpha \\ \cos\delta \sin\alpha \\ \sin\delta \end{bmatrix} \tag{19}$$

where A_1 is the first row of (14). This equation holds for each of the three slits in the starmapper (with appropriate values for β and γ) and for each visible star in the field of view of the starmapper at the proper instants of time. It is also used for the slits of the sun sensor with α and δ taken as coordinates of the sun.

Transit Time Generating Program

It is necessary to have a sequence of transit time pulses for the starmapper and the sun sensor in order to determine feasibility of the least-squares data reduction algorithm on the computer. The following paragraphs describe a method for finding these transit times. The approach is to first determine a set of star candidates on the celestial sphere which will be in the field of view of the instrument. A subset of these candidates is rejected if the stars are blocked (during a vehicle revolution time) by the earth. Transit times for the remaining stars are generated from a time estimate and application of Newton's method to the constraint equation.

The computer program constructed to generate the transit times is also described.

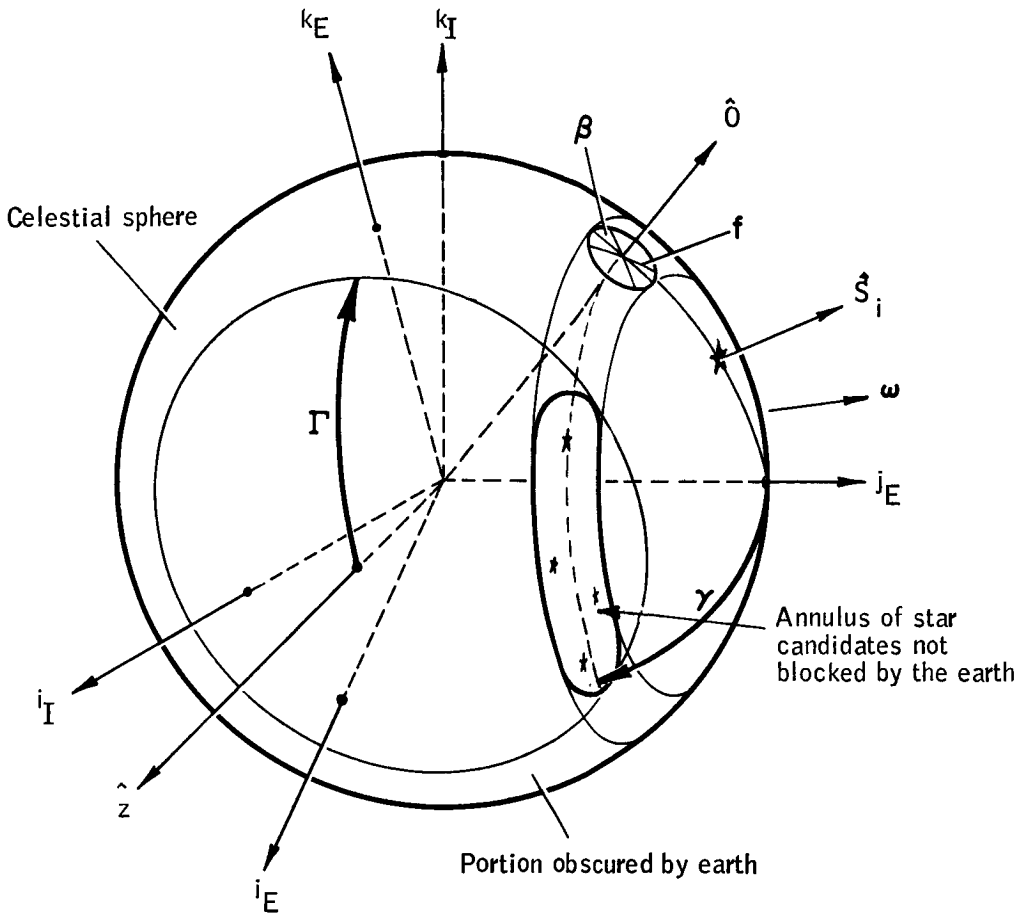
Assume that the vehicle is on a circular, near-polar orbit with its angular velocity vector approximately normal to the plane of the orbit. The major contribution to the spin rate will be along the principal y axis of the vehicle.

As the vehicle moves along its orbit, an optical system rotates with the vehicle, oriented in such a way that its optical axis sweeps alternately across the earth and the sky so that part of each revolution is spent looking away from the earth toward the stars. The portion of the sky in which the optical system can see stars is the intersection (common region) of the annulus swept out by the field of view of the optical system and the complement of that part of the celestial sphere blocked out by the earth. This can be precisely formulated in terms of j_E, $\hat{S}_i$, and f as defined in Figure 45.

Clearly, the angle between $\hat{S}_i$ and j_E must lie within $\gamma + f$ and $\gamma - f$ in order to be in the annulus. For the values of γ and f considered, the cosine is a decreasing function of these angles. Thus to be in the annulus, the cosine of the angle between $\hat{S}_i$ and j_B (which is $\hat{S}_i \cdot j_B$) must satisfy the inequality

$$\cos(\gamma + f) \leq j_B \cdot \hat{S}_i \leq \cos(\gamma - f) \tag{20}$$

Those star candidates that satisfy (20) must be further limited because some of them are blocked by the earth disk. Now the zenith direction $\hat{z}$ points away from the center of the earth, and thus defines the center of the open region of the celestial sphere. This open region is defined by the circle of radius Γ on the celestial sphere. Since the cosine function is a decreasing function of its argument, it follows that the inequality



β = Slit plane rotation angle about optical axis

Γ = Earth blocking angle

f = Half field of view

γ = Angle between optical axis and j_E

i_I = Inertial x axis unit vector

j_E = Experimental y axis unit vector

ω = Angular velocity vector of vehicle

$\hat{O}$ = Optical axis

$\hat{S}_i$ = Star position

$\hat{z}$ = Zenith direction through vehicle

k_I = Inertial z axis unit vector

Figure 45. Scanning Geometry of Starmapper

$$\hat{S}_i \cdot \hat{z} \geq \cos \Gamma \tag{21}$$

must be satisfied for the star to be within the circle of radius Γ on the celestial sphere, and hence, visible to the starmapper if the star is of sufficient magnitude. The intersection is further limited by requiring the instrument field of view to be interior to the restricted region if a star is observed (see Figure 38).

Let t° be a time just prior to the time that the instrument field of view enters the restricted region. To estimate the transit time of a star candidate $\hat{S}_i$ satisfying (20) and (21), observe that θ_i, the angle between $\hat{S}_i$ and the optical axis $\hat{O}$, is the approximate angle through which the vehicle must turn in order to bring the star into the instrument field of view. The time it takes for this to happen is approximated by the angle θ_i divided by the angular rate normal to the plane of $\hat{S}_i$ and $\hat{O}$. The normal is determined from

$$\sin \theta_i \, \hat{n} = \hat{O} \times \hat{S}_i \tag{22}$$

and θ_i is determined from the dot product

$$\cos \theta_i = \hat{O} \cdot \hat{S}_i \tag{23}$$

since $\hat{O}$ and $\hat{S}_i$ are unit vectors. From the definition of t° and the above discussion it follows that the approximate transit time is given by

$$t_i^\circ = t^\circ + \frac{\theta_i}{\omega \cdot \hat{n}} = t^\circ + \frac{\theta_i \sin \theta_i}{\omega \cdot (\hat{O} \times \hat{S}_i)} \tag{24}$$

An algorithm to give the exact transit times can now be constructed. For convenience, equation (19) is written as follows:

$$F(\gamma, \beta, \delta, \alpha, \phi, \psi, \theta) = F(p, \phi, \psi, \theta) = 0 \tag{25}$$

where for a given star the right ascension, α, and the declination, δ, are constant, and for a given slit, γ and β are constant. The parameters ϵ_1, ϵ_2, and ϵ_3 have been suppressed in this equation. Assume that $\phi(t)$, $\psi(t)$, and $\theta(t)$ are the solutions to the differential equations (5) and (6). Equation (25) can be written explicitly as a function of time,

$$F[p, \phi(t), \psi(t), \theta(t)] = 0. \tag{26}$$

Expanding (26) in a Taylor series in t_i about the point t_i^o and keeping terms to the first power in t_i gives,

$$\left.\begin{aligned} 0 = {} & F[p, \phi(t_i^o), \psi(t_i^o), \theta(t_i^o)] + (F_\phi \dot{\phi})_{t_i=t_i^o} (t_i - t_i^o) \\ & + (F_\psi \dot{\psi})_{t_i=t_i^o} (t_i - t_i^o) + (F_\theta \dot{\theta})_{t_i=t_i^o} (t_i - t_i^o) \quad . \end{aligned}\right\} \tag{27}$$

Solving for t_i gives

$$t_i = t_i^o - \left(\frac{F(p, \phi, \psi, \theta)}{F_\phi \dot{\phi} + F_\psi \dot{\psi} + F_\theta \dot{\theta}}\right)_{t_i=t_i^o} \tag{28}$$

In view of equation (19), this becomes

$$t_i = t_i^o - \frac{A_1 CE \begin{pmatrix} \cos\delta \cos\alpha \\ \cos\delta \sin\alpha \\ \sin\delta \end{pmatrix}}{A_1 C(E_\phi \dot{\phi} + E_\psi \dot{\psi} + E_\theta \dot{\theta}) \begin{pmatrix} \cos\delta \cos\alpha \\ \cos\delta \sin\alpha \\ \sin\delta \end{pmatrix}} \tag{29}$$

This algorithm is to have the following interpretation. Starting from the initial time, t_o, solve the differential equations (5) and (6) out to $t = t_i^o$ and evaluate the time increment

$$- \frac{A_1 CE \begin{pmatrix} \cos\delta \cos\alpha \\ \cos\delta \sin\alpha \\ \sin\delta \end{pmatrix}}{A_1 C(E_\phi \dot{\phi} + E_\psi \dot{\psi} + E_\theta \dot{\theta}) \begin{pmatrix} \cos\delta \cos\alpha \\ \cos\delta \sin\alpha \\ \sin\delta \end{pmatrix}} \tag{30}$$

If this time increment is sufficiently small, the solution is complete; if not, continue the solution of the differential equation out to the new time given by the right-hand side of equation (29) and again test. This procedure is repeated until the system converges. Continuing in this manner for each star candidate, the exact transit times for one sweep of the sky can be computed.

To bring the optical system again into position to make another sweep, it is observed that the time taken by the vehicle to make one complete revolution is approximately

$$\Delta t = \frac{2\pi}{|\omega|} \tag{31}$$

so that an estimate of the beginning time for the next sweep is

$$t = t^{\circ} + \frac{2\pi}{|\omega|} \tag{32}$$

The flow diagram corresponding to the above discussion is shown in Figure 46.

Output from the computer program includes transit time, right ascension and declination of sighted star (or sun), slit viewing the star, and the state vector (ω_x, ω_y, ω_z, ψ, ϕ, θ) at the transit time. An initial set of output (once per run) identifies the vehicle, the starmapper and sun-sensor parameters, and the orbit.

Star Catalog

A list which gives the right ascension, declination, and stellar magnitude of all the brighter stars must be provided. The right ascension and declination obtained from this list are of necessity at a given epoch. Hence, a method of updating these quantities must be given. The updated declination and right ascension should be accurate to within one arc second so these quantities can be assumed to contribute negligible error.

Stellar magnitude is a number which indicates the relative intensity of a star. More precisely,

$$m = -2.5 \log_{10} \frac{I}{I_o} \tag{33}$$

where

m = stellar magnitude

$$I = \int_0^{\infty} F(\lambda)\, K(\lambda)\, d\lambda$$

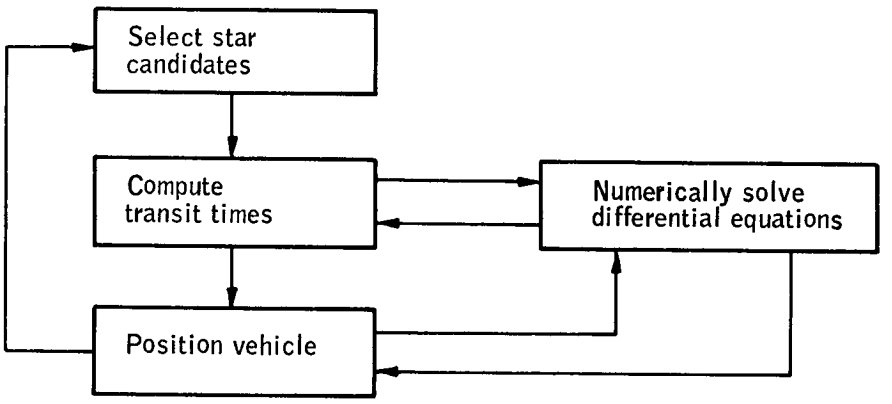


Figure 46. Flow Diagram For State Generating Program

$$I_o = \int_0^\infty F_o(\lambda)\, K(\lambda)\, d\lambda$$

$K(\lambda)$ = instrument response as a function of wavelength

$F(\lambda)$ = stellar intensity as a function of wavelength

$F_o(\lambda)$ = stellar intensity of reference star, i.e., a zero magnitude star

This definition shows that the magnitude of a star depends on the instrument used to observe the star. Thus, in performing a star availability investigation, it would be most accurate to correct the magnitude listed in the star catalog for the expected instrument response. However, the "photographic" magnitude is reasonably close to the expected instrument response so that this quantity can be used in a star availability investigation. Such a procedure is used here.

The star catalog utilized for these studies was the Albany General Star Catalog which lists 33 342 stars. This catalog yields the "visual" magnitude. A discussion of the conversion from visual to photographic magnitude is given by Farrell and Zimmerman in reference 8.

ERROR SOURCES

The error sources which affect the attitude determination may be classified into three main categories: (1) instrument errors; (2) errors in the mathematical model; and (3) errors due to inaccuracies in the computational process.

Instrument Errors

The time at which a star crosses a slit or the time the sun's disk first touches a slit is the basic quantity measured by the starmapper and sun sensor. The principal instrument error is then an error in measuring and recording such times. A secondary source of instrument error may occur because of misalignment of the slits with respect to each other, but careful design and alignment procedures will minimize such errors.

Consideration of the optical and detection systems implies that a random error in the determination of the line of sight to a star whose rms error is about ten seconds of arc is reasonable. For a scan period of the satellite of 20 seconds, this error yields a corresponding transit time error such that

$$\sigma(\delta t_j) = 0.155 \times 10^{-3} \text{ second}$$

In addition to a random error, the transit time may possess a systematic error due to an inaccuracy in estimating the delay of the filtered output of the photomultiplier. These systematic time errors would result in a computed attitude which systematically lags or leads the true attitude. Since the desired attitude accuracy is 10 arc seconds, the instrument must be designed so the systematic component of the transit time error must be less than about 0.5 the random error, or some independent method of removing a constant bias error in the attitude must be established.

Errors in the Mathematical Model

The most general treatment of the attitude motion of a rigid satellite requires a system of six second order differential equations to describe this motion, since the translational and rotational motions are not independent. However, for satellites of small dimensions, this dependence is extremely weak (ref. 9). Hence, the translational motion may be derived by assuming a point mass and the rotational motion derived by assuming motion about the mass center. Thus when concerned with the satellite orientations, the translational motion, except for its influence on the torque applied to the satellite, may be disregarded.

The current model assumes a rigid satellite. If this assumption were not satisfied, the principal moments of inertia would be functions of time. If this effect were present but neglected in the model, a quite substantial error could result. Thus, great care must be taken to ensure that the satellite is a rigid body in the time interval over which measurements are taken.

The applied torques, however, must be given careful consideration. A functional form for these torques must be assumed, but unfortunately these torques may not be known with adequate accuracy. To overcome this difficulty, unknown, or poorly known multiplicative constants are applied to the major torques. These unknowns are then computed as part of the overall problem. To test the adequacy of such a process, two extreme forms for the torque may be utilized. One form is used to compute the time of transit across the slit, the other to recover the attitude which produced these times. If the recovery is not satisfactory, emphasis must be placed on obtaining a more accurate model of the torques.

Errors in the Computational Process

An analytical solution to the differential equations which govern the attitude motion of the satellite does not appear to exist. Hence, a solution through a numerical solution to differential equations technique or some approximation technique must be sought.

The problem of obtaining an accurate attitude over a long time duration is not trivial, even if the initial conditions which define the satellite attitude and the form of the differential equations are error-free.

The error in solution of the differential equations over the period of the experiments performed in the analysis are neglible, as shown in Appendix I.

LEAST-SQUARES DATA REDUCTION ALGORITHM

The least-squares data reduction algorithm is developed in the following paragraphs. It is shown that the solution of the model differential equations can be expressed in terms of twelve parameters, and that the constraint equation is a function of these and three more (for a total of fifteen parameters). The least-squares problem is posed as that of finding those fifteen parameters that best satisfy the constraint equations at starmapper (sun sensor) time pulse instants. Since there is no reason for assuming that certain pulse times are better than others, unity weighting is assigned to each observation. The normal equations for the least squares problem are derived, and an iterative method for finding the solution to these equations is developed. This is the general least-squares data reduction algorithm. Later paragraphs consider the least-squares problem where some of the fifteen parameters are held fixed at pre-assigned values. As might be expected, this leads to least-squares data reduction algorithms of reduced dimension.

General Method

The differential equations (5) and (6) with torques (8) have solutions which can be expressed as functions of time, the initial conditions, and the parameters. The initial conditions are the set $\left(\omega_{x_o}, \omega_{y_o}, \omega_{z_o}, \psi_o, \phi_o, \theta_o\right)$ taken at time $t=t_o$, and the parameters are $(A, C, M'_x, M'_y, M'_z, K')$. The constraint equation (19) contains angles ψ, ϕ, and θ (through the E matrix) evaluated at specific instants of time. Thus, (19) can be expressed, in part, as a function of the initial conditions and parameters, and the time instant. Equation (19) is also a function of the mismatch angles $(\epsilon_1, \epsilon_2, \epsilon_3)$, so the complete set of parameters for (19) is the 15 dimensional vector

$$y = (\omega_{x_o}, \omega_{y_o}, \omega_{z_o}, \psi_o, \phi_o, \theta_o, A, C, M'_x, M'_y, M'_z, K', \epsilon_1, \epsilon_2, \epsilon_3) \quad (34)$$

and the time instant at which ψ, ϕ, and θ are evaluated. (The slit plane angles β and γ, and the star angles α and δ are omitted in the y vector, since they are assumed to be known quantities).

Now consider a time interval $t_o \leq t \leq T$. Let N be the total number of observations of the stars through all the slits during the time interval. Let t_k, $k = 1, \ldots, N$, be the observation instants, as seen by the starmapper, at which (19) is supposed to hold. In general, t_k is not the exact instant that will cause (19) to be true. Moreover, the model differential equations (5) and (6) with torques (8) may differ from the exact differential equations, so

that actual attitude may differ from the computed attitude. This could cause (19) to be violated, even if t_k were the exact transit time. In view of this, let $H(t_k, y)$ be the right-hand side of (19) and consider the equations

$$H(t_k, y) = R_k, \quad k = 1, \ldots, N \tag{35}$$

The least squares problem to be solved is that of minimizing the sum

$$J(y) = \sum_{k=1}^{N} \left[H(t_k, y) \right]^2 \tag{36}$$

with respect to the fifteen dimensional vector y of equation (34).

The necessary condition for (36) to be a minimum is

$$\sum_{k=1}^{N} H(t_k, y) \frac{\partial H(t_k, y)}{\partial y_i} = 0, \quad i=1, \ldots, n, \tag{37}$$

where n is taken as 15. To construct the least squares algorithm, assume a linear expansion for H of the form

$$H(t_k, \tilde{y}) = H(t_k, y) + \sum_{j=1}^{n} \frac{\partial H(t_k, y)}{\partial y_j} \Delta y_j \tag{38}$$

and re-phrase (36) in terms of the vector Δy. Thus,

$$J(\Delta y) = \sum_{k=1}^{N} \left[H(t_k, y) + \sum_{j=1}^{n} \frac{\partial H(t_k, y)}{\partial y_j} \Delta y_j \right]^2 \tag{39}$$

is the function to be minimized, and the normal equations (37) become

$$\sum_{k} \frac{\partial H(t_k, y)}{\partial y_i} H(t_k, y) + \sum_{k,j} \frac{\partial H(t_k, y)}{\partial y_i} \frac{\partial H(t_k, y)}{\partial y_j} \Delta y_j = 0 \tag{40}$$

$$i=1, \ldots, n$$

In matrix notation, this is

$$G'H + G'G\,\Delta y = 0 \tag{41}$$

where

$$H = \begin{bmatrix} H(t_1, y) \\ \vdots \\ H(t_N, y) \end{bmatrix}, \qquad G = \begin{bmatrix} \dfrac{\partial H(t_1, y)}{\partial y_1}, \ldots & \dfrac{\partial H(t_1, y)}{\partial y_n} \\ \vdots & \vdots \\ \dfrac{\partial H(t_N, y)}{\partial y_1}, \ldots & \dfrac{\partial H(t_N, y)}{\partial y_n} \end{bmatrix} \tag{42}$$

If the approximation (38) is good enough, the Δy computed from (41) will cause $J(\Delta y)$ in (39) to be less than $J(0)$. If Δy is then added to y, and new Δy's are computed iteratively, the process should converge to a solution which satisfies (37). Convergence should be quadratic, since (41) is the Newton-Raphson method.

To determine the partial derivatives required in (42), notice first that $H(t_k, y)$, may be differentiated directly with respect to the mismatch angles ϵ_1, ϵ_2, and ϵ_3. The other partials are evaluated from the expression

$$\frac{\partial H}{\partial b}(t_k, y) = A_1 C \left[\frac{\partial E}{\partial \psi}\frac{\partial \psi}{\partial b} + \frac{\partial E}{\partial \phi}\frac{\partial \phi}{\partial b} + \frac{\partial E}{\partial \theta}\frac{\partial \theta}{\partial b} \right] \hat{S} \tag{43}$$

where ψ, ϕ, θ and their partials are evaluated at $t=t_k$, b is one of (ω_{x_o}, ω_{y_o}, ω_{z_o}, ψ_o, ϕ_o, θ_o, A, C, M_x', M_y', M_z', K') and $\hat{S}$ is the vector in (19). The partials of ψ, ϕ, and θ come from solution of linearized versions of equations (5) and (6) with torques (8). For convenience, let $x = (\omega_x, \omega_y, \omega_z, \psi, \phi, \theta)$ and let $a = (A, C, M_x', M_y', M_z', K')$.

Then equations (5) and (6) with torques (8) have the form

$$\dot{x} = f(t, x, a), \quad x(t_o) = x_o \tag{44}$$

and the corresponding linear differential equations are

$$\frac{d}{dt}\frac{\partial x}{\partial x_o} = \frac{\partial f}{\partial x}\frac{\partial x}{\partial x_o}, \quad \frac{\partial x}{\partial x_o}(t_o) = I \tag{45}$$

$$\frac{d}{dt}\frac{\partial x}{\partial a} = \frac{\partial f}{\partial x}\frac{\partial x}{\partial a} + \frac{\partial f}{\partial a}, \quad \frac{\partial x}{\partial a}(t_o) = 0 \tag{46}$$

Equations (45) and (46) are solved simultaneously with equation (44), and values at $t = t_k$ are used to evaluate (43).

In summary, the method proceeds as follows:

1. An initial estimate for $y = (x_o, a, \epsilon)$ is provided.
2. Equations (44) through (46) are integrated.
3. At each star observation instant t_k, $k = 1, \ldots, N$, the constraint H and its partials are computed [equation (38) and the remarks above this equation] and inserted in (42).
4. Δy is computed from (41) after the last observation has been processed.
5. Δy is added to y
6. Steps 2-5 are repeated until Δy becomes negligible.

The mathematical flow diagram of their process is shown in Figure 47.

Extension of the Method

In the sequel it will be necessary to consider least squares problems where some of the 15 variables of (34) are held fixed at known values. The objective of this section is to develop the normal equations (40) to be used in this event. Thus, consider the problem of minimizing (36) subject to the single constraint

$$y_m = y_{m_o} \tag{47}$$

where y_{m_o} is the fixed value for the mth component of vector y.

The time honored approach to this problem is to use Lagrange multipliers and to minimize the function

$$F(y) = \sum_{k=1}^{N} H(t_k, y)^2 + \lambda_m \left\{y_m - y_{m_o}\right\}. \tag{48}$$

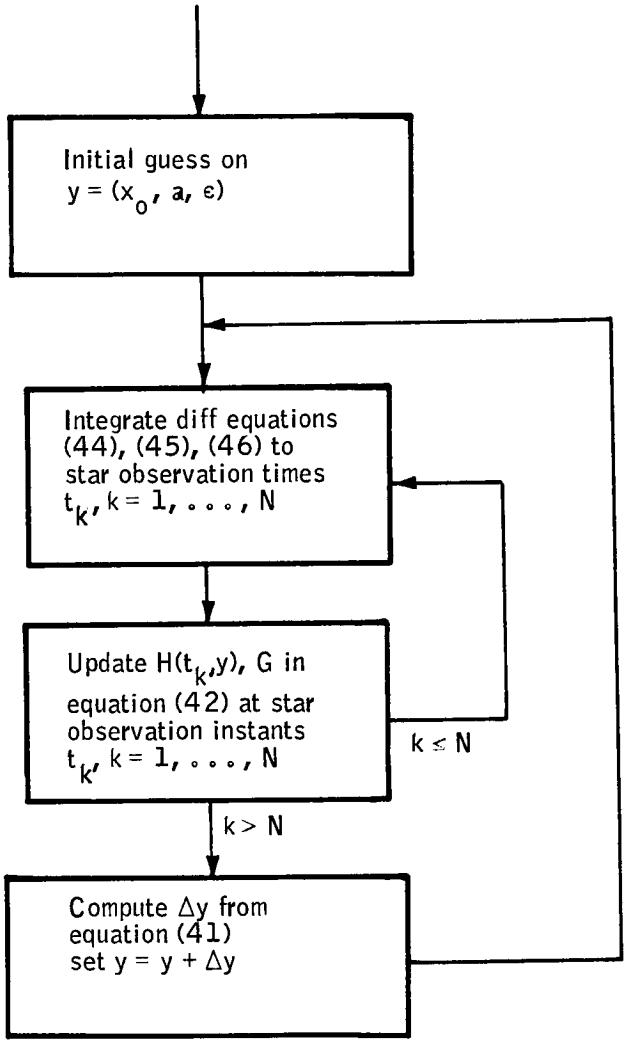


Figure 47. Mathematical Flow Diagram of the Least-Squares Attitude Determination Simulation

Thus, it is found that

$$\sum_{k=1}^{N} H(t_k, y) \frac{\partial H}{\partial y_j} (t_k, y) = 0, \; j \neq m \tag{49}$$

and

$$\sum_{k=1}^{N} H(t_k, y) \frac{\partial H}{\partial y_m} (t_k, y) + \lambda_m = 0 \tag{50}$$

where y_m satisfies (47). Equation (50) can always be satisfied by proper choice of λ_m, and equation (49) is the (n-1) - dimensional version of (37). In terms of the linearized version (39) of the problem, the constraint (47) becomes

$$\Delta y_m = 0 , \tag{51}$$

and the function to be minimized is

$$F(\Delta y) = J(\Delta y) + \lambda_m \Delta y_m, \tag{52}$$

where $J(\Delta y)$ is defined by equation (39). The solution to this problem is

$$\sum_{k=1}^{N} \frac{\partial H(t_k, y)}{\partial y_i} H(t_k, y) + \sum_{k,j} \frac{\partial H(t_k, y)}{\partial y_i} \frac{\partial H(t_k, y)}{\partial y_j} \Delta y_j = 0, \; i \neq m \tag{53}$$

$$\sum_{k=1}^{N} \frac{\partial H(t_k, y)}{\partial y_m} H(t_k, y) + \sum_{k,j} \frac{\partial H(t_k, y)}{\partial y_m} \frac{\partial H(t_k, y)}{\partial y_j} \Delta y_j + \lambda_m = 0 \tag{54}$$

with $\Delta y_m = 0$. As before, equation (54) can always be satisfied, and equation (53) is the (n-1) - dimensional form of (40). In terms of the matrix notation of equations (41) and (42), only the mth column of matrix G is deleted, and (41) is solved for the (n-1) - dimensional vector Δy.

More variables may be made constants by an obvious extension of the results. The effect is to delete more columns of matrix G and to reduce the dimension of Δy.

Other Methods

Two other approaches to the attitude determination problem were considered in addition to the least squares method: (1) the Kalman linear interpolation problem (ref. 10); and (2) the Cox nonlinear estimation problem (ref. 11). Both approaches allow for additive noise in the differential equations (5) and (6) and in the observation instants t_k. These methods were rejected in favor of least squares for the following reasons.

The Cox nonlinear approach has two major weaknesses:

- Second partials of the solution are required, which requires a large amount of computer time. The effects of neglecting second partials are unknown.
- The noise term in the Cox difference equation should be a function of the state vector as well as time. This complicates the two point boundary value problem, resulting in a larger program and more computer time.

The Cox (Kalman) linear approach assumes a fairly good reference solution. In practice, a good reference may not be known, and it would be difficult to determine the adequacy of a given reference. This reference would undoubtedly come from integration of a set of differential equations, whose form might not correspond to reality. Thus, the solution to the Cox linear problem might not correspond to reality.

A further difficulty with the Cox approach is that some of the noise in this problem may not be white noise. For example, the earth's magnetic variation from the model varies slowly as a function of time -- it is strongly correlated from one star sighting to the next. Moreover, some of the variations are not random functions of time, and these would be difficult to incorporate in the model. Thus, there is some doubt that the Cox approach is appropriate for the problem under consideration.

The least squares method has several advantages:

- A solution to the nonlinear problem is realized.
- Only first partials of the state vector are required, which means a simpler computer program and faster running time.
- Convergence characteristics are similar to those experienced in reducing the Scanner data.
- Results can be easily interpreted.
- Adequacy of the results can be interpreted quite easily.

- Results can be easily refined, for example, by breaking the solution into two or more subarcs.

- A large amount of experience has been accumulated using the method.

SIMULATION DESCRIPTION

The computer block diagram for the least squares solution of the attitude determination problem is shown in Figure 48, and the mathematical flow diagram for the process is shown in Figure 47. The program operates in the following manner. Guesses for initial conditions and parameters are read in from cards. After initialization, the program proceeds to the "real time" branch of the first test, and then to the first output. The data tape is then read, to establish the first star observation time. (The data tape is constructed by the data generating program described in the previous section.) Other data on the tape includes star coordinates, star or sun sensor slit, real time, and the state vector. The state vector is used to establish the difference between estimated and actual state of the vehicle at the true star observation instant. The program then proceeds to integrate to the first observation point. The differential equations include (44) through (46). The break time (TB) is either the actual time of the star sighting or the recorded time of the sighting (real time suitable corrupted by noise). There is also the possibility that the two times are equal. If TB = real time, then the difference between estimated and actual state vectors are generated for the output. If TB = star time, then G'H and G'G of equation (41) are updated for the observation. If star time = real time, both branches of the block diagram are taken. The logic is such that both branches must be taken before the first output is reached. For example, if real time = star time, TB = real time. After preparing the output, JOP = 1. (JOP is J output). TB is then set to star time, and integrations proceed to that point. After updating, K = 5, and JOP = 2. The program then outputs selected data, and reads the next star observation tape record.

The program proceeds through all observations in the above fashion. After the last star sighting has been processed, the initial conditions x_o, and the parameters a and ϵ are updated through equation (41). A convergence test is then performed. If the process has not converged, the program prepares for another iteration, using updated values.

In the solution for Δy through equation (41), the user has the ability to delete as many variables as he wishes. Thus, solutions for problems with less than 15 variables are readily obtained.

An editing routine is also included in the program. This allows the user to select a given number of stars per revolution of the satellite from those generated by the data generating program, and to add noise to the selected instrument transit times. The stars are selected on the basis of brightness (magnitude). If two or more stars have the same magnitude, then the sighting occurring first in time is selected. The editing routine is used to generate the input tape for the simulation program.

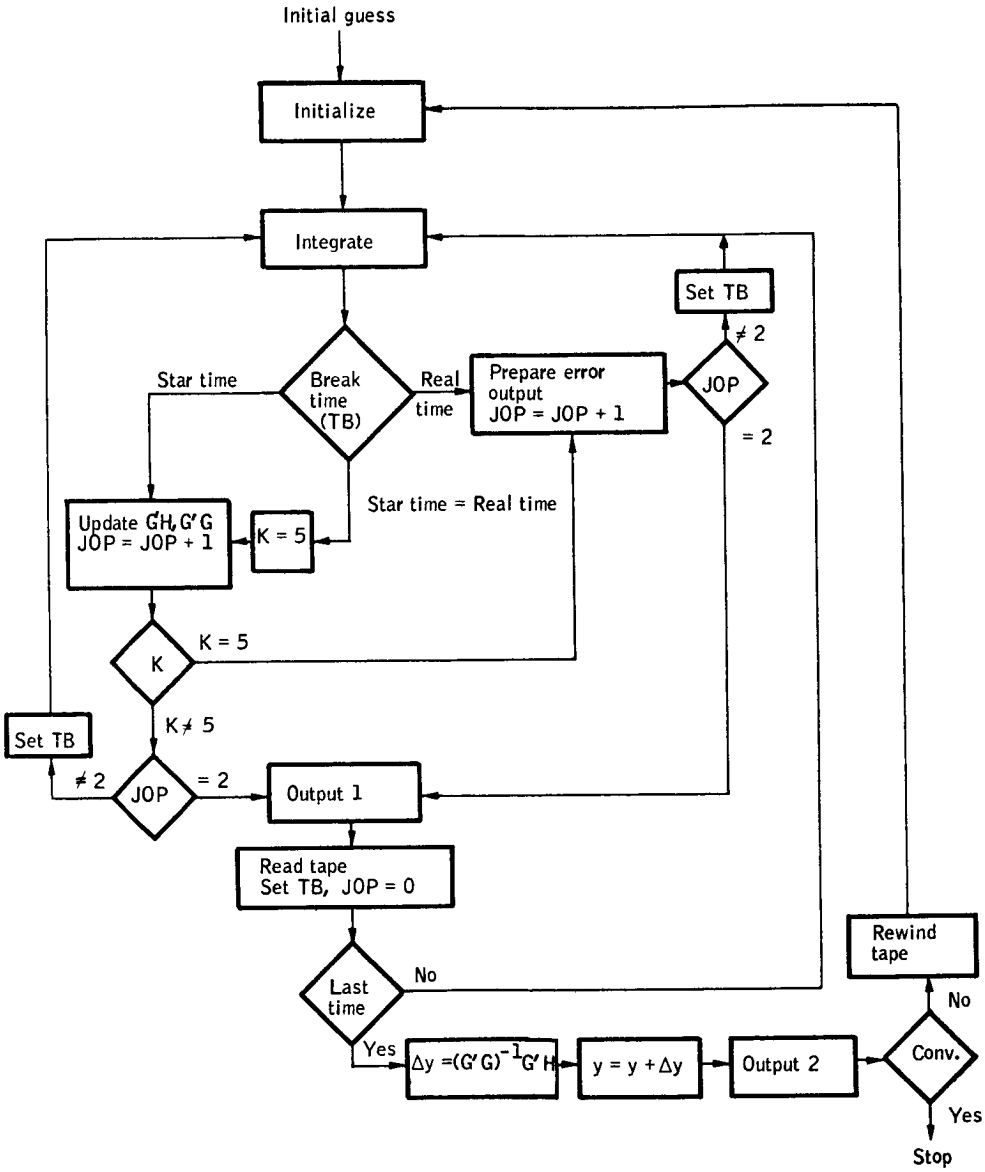


Figure 48. Block Diagram for Solution of the Attitude Determination Problem by Least Squares

Physically, the routine exists in two forms. One of these assumes that the star data is on cards, whereas the other assumes the data to be on magnetic tape. In the tape version, three times are required as additional input. The first time is the initial point, the second time is the first observation point, and the third time is the last observation point. This input makes the tape version almost as flexible as the card version of the routine.

A listing of the simulation program appears as Appendix J of this report. The tape version of the editing routine is included in this listing, as well as all subroutines.

RESULTS AND ANALYSIS

Experiments Performed

The vehicle is assumed to be in a circular, 500-km orbit about a spherical rotating earth. The date is taken as the first day of spring, so that the sun is out the inertial x axis. The orbit parameters (see Figure 42) are taken as $\Omega = 45°$ and $i = 97.38°$.

Figure 49 shows the planar relationship of the sun and the orbit. Only the bottom half of the orbit is used during simulation runs, since the problem is mathematically symmetric with respect to a point halfway through the daylight portion. Therefore, demonstration of feasibility requires only a half an orbit of data. Also, simulation of a complete orbit would have resulted in excessive computer usage.

Computer runs start at $t = 0$ in the center of the dark side of the orbit (Figure 49). This corresponds to a true anomaly of $\nu = 187.3°$ (see Figure 48). The dividing point between daylight and dark (twilight) is approximately one-sixth of an orbit later, at about $t = 940$ seconds. Star data is collected over the interval $0 < t < 880$ seconds. Thus, a data gap of about one minute is introduced in the star data to allow for earth atmospheric refraction of sun rays and earth glow effects on the starmapper optics. Computer results indicate that the solution from the dark side can be extrapolated over this time period within 10 arc seconds of error.

An additional time gap of one minute is allowed from the twilight point to the first sun sighting data point. This is sufficient time for the vehicle to rise above the earth's atmosphere, so that refraction effects can be neglected. Sun data is collected for the remainder of the half orbit.

Initial conditions and parameter values at the center of the dark are taken as:

$$\omega_{x_o} = .2094 \text{ deg/sec}$$

$$\omega_{y_o} = 18 \text{ deg/sec}$$

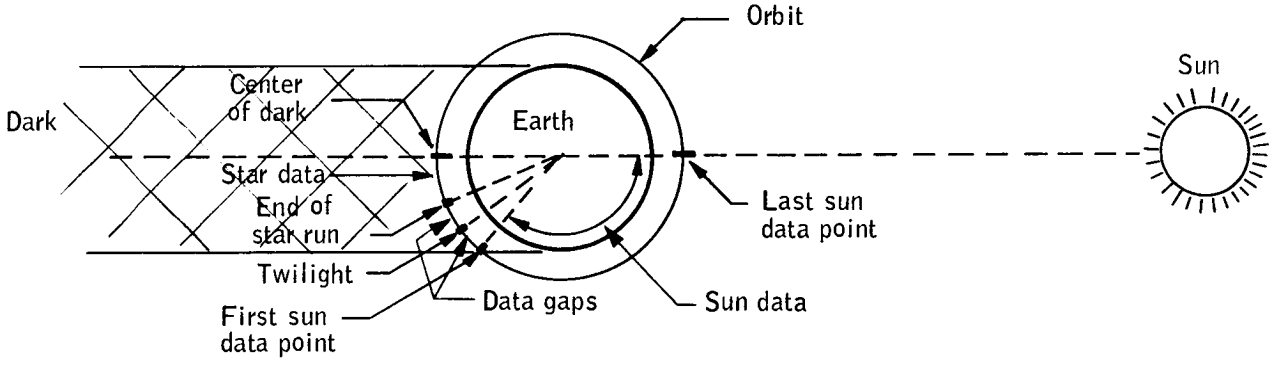


Figure 49. Relationship of Orbit and Sun Showing Those Portions of the Orbit Over Which Star and Sun Data are Used

$\omega_{z_o} = 0$

$\psi_o = 45$ deg

$\phi_o = 190$ deg

$\theta_o = 180$ deg

$I_1 = 54.68$ slug - ft^2

$I_2 = 65.62$ slug - ft^2

$I_3 = 54.68$ slug - ft^2

$\epsilon_1 = 0$ deg

$\epsilon_2 = 0$ deg

$\epsilon_3 = 0$ deg

Values for M_x, M_y, M_z and K are discussed below.

From the initial conditions and parameters, it can be shown that the vehicle is symmetric ($I_1 = I_3$), that it spins at roughly 3 rpm about the principle y axis, and that the cone angle is about 0.7 degrees. From the orbit parameters, the spin vector is misaligned with respect to the orbit normal by about 2.6 degrees.

The torque equations (8) may not represent the exact torques acting on the vehicle. Reasons for this are (1) that the forms of the torques may only approximate the exact forms for magnetic moment and eddy current torques; (2) the earth's magnetic field is known to about ±1 percent of the computed value, and (3) additional torques have been neglected. To simulate these effects, the magnetic field components (in local vertical coordinates) are perturbed in the data generating program by the amounts

$$\left.\begin{aligned} \Delta B_{x_L} &= (a_1 \sin \omega_1 t)\ B_{x_L} \\ \Delta B_{y_L} &= (a_2 \sin \omega_2 t)\ B_{y_L} \\ \Delta B_{z_L} &= (a_3 \sin \omega_3 t)\ B_{z_L} \end{aligned}\right\} \qquad (55)$$

The rates ω_1, ω_2 and ω_3 correspond to periods of 1/2, 1/3 and 1/5 of an orbit to simulate long period effects, and values for a_1, a_2 and a_3 are discussed below.

It is also known that the magnetic moment coefficients M_x, M_y, and M_z have different values during the sunlight portion of the orbit then they do over the dark part. To simulate this effect in the data generating program, the values of the coefficients are perturbed at the twilight point by the amounts

$$\Delta M_x = .05\ M_x$$

$$\Delta M_y = -.05\ M_y$$

$$\Delta M_z = .05\ M_z$$

The data generating program generates star crossing instants for the star-mapper over the dark portion of the orbit to the twilight point. Stars down to 3.4 magnitude are used. The sun-sensor slits are then used to generate sun data for the remainder of the orbit.

During runs of the least squares attitude determination program, it became evident that the offset angle ϵ_3 in (34) was difficult to determine. The reason for this is that the last column of matrix G in (42), representing partials with respect to ϵ_3, is approximately the same as the column containing partials with respect to θ_o. This is especially true when $\epsilon_1 = \epsilon_2 = 0$. In this case θ and ϵ_3 are additive rotations about the same axis. The vehicle is also nearly symmetric, which aggrevates the situation. The result of these factors is to make the matrix G'G nearly singular, so that poor estimates of θ_o and ϵ_3 are obtained. The angle ϵ_3 was consequently set to zero during the runs described below.

It is recognized that ϵ_3 may be important for the satellite under consideration. Appendix K describes a method that might be used to determine this angle.

Runs of the least squares data processing program are split into two parts, one for the dark part and one for the sunlit part of the orbit. Thus, star data (suitably edited) is used to determine the attitude from the center of the dark to approximately one minute before the twilight point. Results obtained to date during these computer runs are discussed first. The converged terminal conditions for these runs become the initial conditions for the sunlit portion

of the orbit. Since a complete solution to the attitude determination problem cannot be obtained from sun sightings alone, problems with reduced dimension are considered for this part of the orbit. Experiments to determine the dimensionality of the problems, and the attitude results obtained are discussed below.

Another possibility is that of finding a solution to the attitude determination problem for the full half orbit using all data collected. In Appendix L, feasibility for this approach is demonstrated for the no torque problem. Such a solution for the torqued problem is valid only if torque uncertainties are sufficiently low. No experiments were performed on the computer to determine if this is so, since computer time for the solution would have been excessive.

Star Sighting Results

Several computer runs were made to test the adequacy of the least squares approach to the attitude determination problem. The effects of model perturbations, residual magnetic moment and eddy current torque levels, and number of stars sighted per revolution were examined. The starmapper parameters for these runs are given in Table 5.

TABLE 5. - STARMAPPER PARAMETERS

Slit	β, deg	γ, deg
1	-20	90
2	0	90
3	20	90

During editing of the star sighting instants, only one noise set was used. The length of the set was determined from the six star per revolution case. When fewer stars per revolution were simulated (four stars and two stars) noise values at the bottom of the set were deleted.

Several of the computer runs are discussed below. All runs have 14 variables and converged to solutions.

Case I: six stars per revolution. -- The parameter values

$$M_x = M_y = M_z = 5.16 \times 10^{-6} \text{ ft - lb/gauss}$$

$$K = 1.42 \times 10^{-5} \text{ ft-lb - sec/gauss}^2$$

and magnetic field perturbation constants

$$a_1 = a_2 = a_3 = 0.02$$

were used to generate the star sighting instants. Data was edited to obtain the six brightest stars per revolution.

The residual magnetic moment vector has a 0.1 amp-turn-m^2 magnitude with equal components along each of the three body coordinate axes. A 1 amp-turn-m^2 residual corresponds to measured moments gathered on the early Tiros spacecraft. Further study has shown that the HDS spacecraft is magnetically cleaner than Tiros because of the nature of the solar-cell configuration on Tiros. Current loops on the Tiros are changing due to the unsymmetrical illumination of the spacecraft and the spin of the spacecraft.

The eddy current coefficient was selected based on spin down data of various satellite programs. The value given is 1/2 of the derived value. In general, the spin down criteria is that the spacecraft will reach 1/2 of the initial spin rate in 100 days of operation. Using this criteria, the eddy current coefficient was derived for analysis. Techniques may be applied to reduce the effect of the eddy currents by designing to reduce the magnitude of the eddy current coefficients.

Output from the least squares program included differences in angles at the true star sighting instants. The angles from the data generating program represent true angular relationship of the body principle axes with respect to inertial space [see equations (9) and (10)]. They also relate experimental axes to inertial space, since the offset angles ϵ_1 and ϵ_2 have been assumed to be zero. In the attitude determination program, the computed angles relate principal axes with inertial space. It is the differences between these angles that appear in the output. The extreme values of these differences after convergence and over the entire run(848 seconds) are given in Table 6.

TABLE 6. - EXTREME ERRORS IN EULER ANGLES RELATING PRINCIPAL AXES TO INERTIAL SPACE AT STAR SIGHTING INSTANTS

$\Delta\psi$ arc sec		$\Delta\phi$ arc sec		$\Delta\theta$ arc sec	
Max.	Min.	Max.	Min.	Max.	Min.
-3.04	-13.25	4.21	-5.90	0.31	-3.75

The least squares program provides a very accurate fit to the data. Angles ψ and ϕ are well within required bounds, so far as tangent-height calculations are concerned, and angle θ (the angle of interest) is in error by less than 4 arc seconds.

The converged values for the offset angles were calculated as:

$$\epsilon_1 = -.0021 \text{ deg}$$

$$\epsilon_2 = -.0014 \text{ deg}$$

This means that the experimental axes are misaligned with respect to the principal axes, so far as the attitude determination program is concerned. To estimate the errors for the experimental axes, consider new angles ψ', ϕ', θ' which relate experimental coordinates to inertial axes. Then from (9) through (11)

$$E(\psi', \phi', \theta') = C(\epsilon_1, \epsilon_2)\ E(\psi, \phi, \theta) \tag{56}$$

where E is computed assuming ψ', ϕ', and θ' rotations in the same order as for ψ, ϕ and θ.

Now let

$$\left.\begin{aligned} \psi' &= \psi + \delta\psi \\ \phi' &= \phi + \delta\phi \\ \theta' &= \theta + \delta\theta \end{aligned}\right\} \tag{57}$$

Then if ϵ_1, ϵ_2, $\delta\psi$, $\delta\phi$, and $\delta\theta$ are assumed to be small angles, (56) can be solved to give

$$\delta\psi = \frac{1}{\cos\phi}[\epsilon_1 \cos\theta - \epsilon_2 \sin\theta] \tag{58}$$

$$\delta\phi = \epsilon_1 \sin\theta + \epsilon_2 \cos\theta \tag{59}$$

$$\delta\theta = -\delta\psi \sin\phi \tag{60}$$

$\delta\psi$, $\delta\phi$, and $\delta\theta$ are correction terms which, when added to $\Delta\psi$, $\Delta\phi$, and $\Delta\theta$, determine angular errors in the experimental axes of the vehicle. Typical errors in the pitch angle (sum of (60) and $\Delta\theta$) are plotted in Figure 50. The upper and lower envelopes (dashed lines) represent the values of maximum and minimum errors at star sighting instants. The curves joining the envelopes (solid lines) are the errors over star sighting intervals. Time between these curves represents the rest of the rotation period of the vehicle, over which no data is available from this program.

The moment of inertia ratios were calculated as:

$$A = .83325$$

$$C = .83333$$

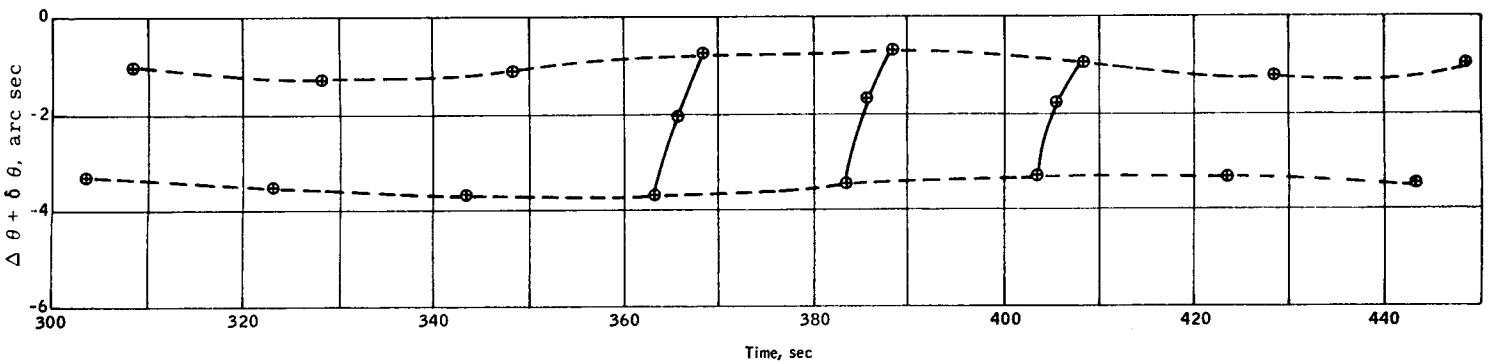


Figure 50. Experimental Axes Pitch Angle Error for Case I

as compared to the ideal value .83328 used in the data generating program. The vehicle thus turned out to be nearly symmetrical, and the star observations determined the inertia ratios quite well. However, the magnetic moment coefficients were calculated as:

$$M_x = -3.58 \times 10^{-5}$$

$$M_y = 3.87 \times 10^{-6}$$

$$M_z = 5.17 \times 10^{-5}$$

as compared to 5.16×10^{-6} ft - lb/gauss. Thus, the magnetic field perturbations caused the program to compute drastically different values for these quantities to best explain the transit times of the stars. The eddy current coefficient K was correctly determined in this case. However, other results (see below) indicate that the value of this quantity is also juggled somewhat by the program to best explain the data. (Of course, M_x, M_y, M_z and K can be computed only if I_2 is known. The program finds M_x', . . . , K', which are the coefficients divided by I_2. Values given above are presented only for comparison purposes.)

Case II. - This is the same as Case I above, except that the editing routine selected the four brightest stars per revolution. The extreme errors in angles relating principal axes of the body are shown in Table 7. It is evident that the spread in the results is larger than for Case I, although still well within bounds. The larger spread is also seen in Figure 51 , where errors in the pitch angle relating experimental coordinates to inertial space are shown. Parameter values obtained for this case are:

TABLE 7. - EXTREME ERRORS IN EULER ANGLES RELATING PRINCIPAL AXES TO INERTIAL SPACE AT STAR SIGHTING INSTANTS

Case	$\Delta\psi$, arc sec		$\Delta\phi$, arc sec		$\Delta\theta$, arc sec	
	Max.	Min.	Max.	Min.	Max.	Min.
I	-3.04	-13.25	4.21	-5.90	0.31	-3.75
II	9.41	-16.83	20.23	-8.1	1.14	-6.47
III	86	40	129	100	18.15	8.76
IV	1.85	-14.4	5.99	-9.96	3.44	-5.84
V	0.24	-20.38	6.94	-13.56	5.73	-6.08

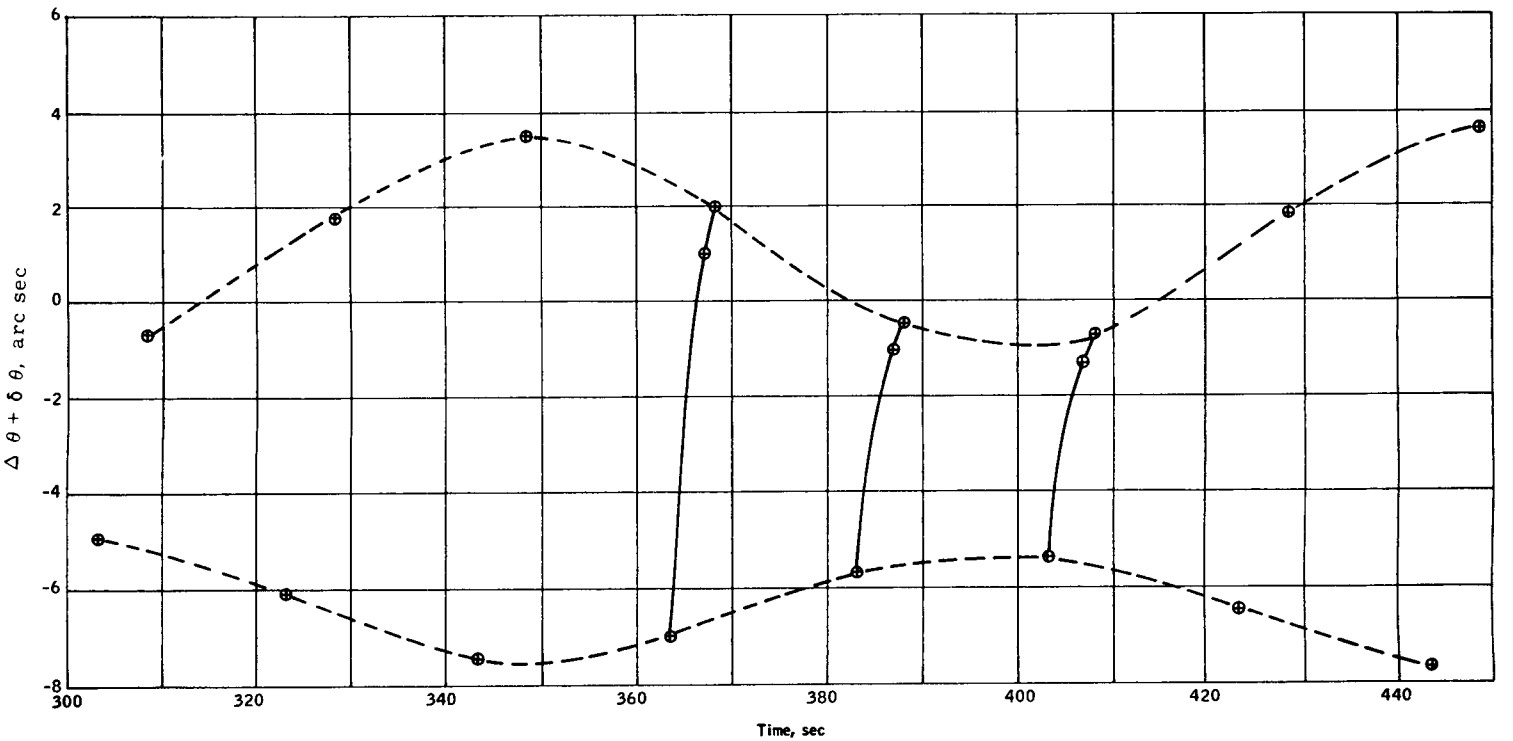


Figure 51. Experimental Axes Pitch Angle Error for Case II

$$\epsilon_1 = -.0059 \text{deg}$$

$$\epsilon_2 = -.0012 \text{deg}$$

$$A = .83420$$

$$C = .83235$$

$$M_x = -6.42 \times 10^{-5} \text{ ft-lb/gauss}$$

$$M_y = 5.84 \times 10^{-6} \text{ ft-lb/gauss}$$

$$M_z = 1.61 \times 10^{-4} \text{ ft-lb/gauss}$$

$$K = 1.44 \times 10^{-5} \text{ ft-lb/sec/gauss}^2$$

The offset angle ϵ_1 is about three times that for Case I, whereas ϵ_2 is a little better. The vehicle is not as symmetrical as before, but good values for the inertia ratios are obtained. The magnetic moment coefficients are somewhat less well determined than in the case examined above and K is still well determined. On the basis of these results, it is concluded that four stars per revolution can be used to determine attitude within the required accuracy.

Case III. - This is the same as Cases I and II, except that two stars per revolution are assumed.

The principal axis angular errors of Table 7 show large biases. However, the offset angles are quite large, namely,

$$\epsilon_1 = .036 \text{ deg}$$

$$\epsilon_2 = -.0193 \text{ deg},$$

and these with corrections (58-60) cause the experimental axes angle errors to be small at star sighting instants. This is shown, for a few calculated points along the trajectory, in Table 8. The same conclusion is evident in Figure 52

TABLE 8. - EXTREME ERRORS IN ANGLES RELATING EXPERIMENTAL AXES TO INERTIAL SPACE BASED ON A SPOT CHECK OF RESULTS

$\Delta\psi$, arc sec		$\Delta\phi$, arc sec		$\Delta\theta$, arc sec	
Max.	Min.	Max.	Min.	Max.	Min.
4.2	-12.3	8	-28	3.6	-5.15

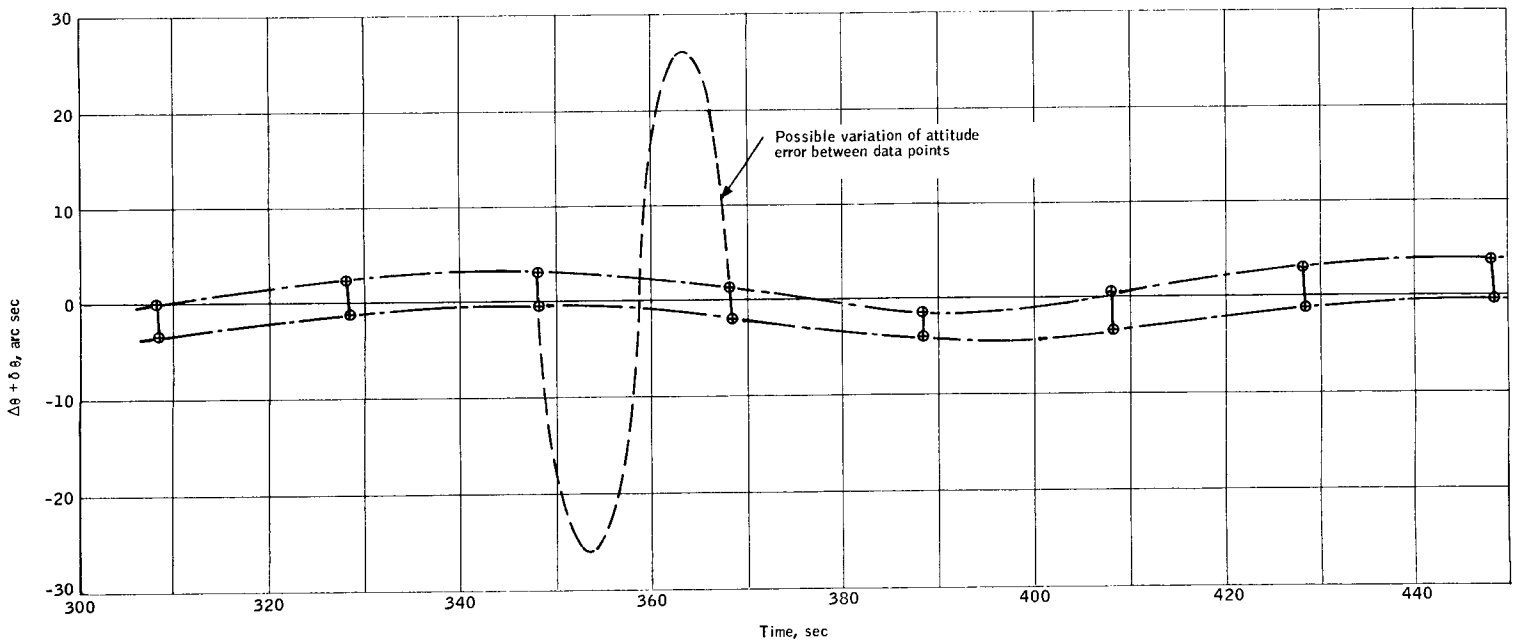


Figure 52. Experimental Axes Pitch Angle Error for Case III

where the pitch angle error alone is shown. Also shown in Figure 52 is a possible worst case error between star sighting instants. This was derived by assuming long term variations of the pitch angle error to be within the error envelope, and then superimposing the solution from (60). In the actual situation, there are probably compensating effects that lessen the overall error somewhat. However, these results indicate that two stars per revolution do not yield sufficient accuracy for the attitude determination problem.

Other results for this case are

$$A = .83356$$

$$C = .83301$$

$$M_x = 1.74 \times 10^{-3} \text{ ft-lb/gauss}$$

$$M_y = -9.58 \times 10^{-6} \text{ ft-lb/gauss}$$

$$M_z = 2.36 \times 10^{-3} \text{ ft-lb/gauss}$$

$$K = 1.54 \times 10^{-5} \text{ ft-lb-sec/gauss}^2$$

The moment of inertia ratios are still well defined, but the other values are drastically different from those used in the data generating program.

Case IV. - Six stars per revolutions are again assumed, and parameter values used in the data generating program are:

$$M_x = M_y = M_z = 5.16 \times 10^{-5} \text{ ft-lb/gauss}$$

$$K = 2.86 \times 10^{-5} \text{ ft - lb -sec /gauss}^2$$

$$a_1 = a_2 = a_3 = .05$$

The magnetic moment coefficients are a factor of 10 larger than those used in the previous cases, to correspond with those estimated for the early Tiros spacecraft. The eddy current coefficient is twice that used previously, and this is the estimated value based on several satellites. The magnetic field perturbation is 5 percent instead of the 2 percent of the previous cases.

Table 7 shows the principle axis angular errors obtained. These are seen to be within bounds, although not as good as the results obtained for Cases I and II. Angular errors for experimental axes are similar to those of Figure 44 (although somewhat larger), so are not plotted. Other parameter values are:

$$\epsilon_1 = -.0031 \text{ deg}$$

$$\epsilon_2 = -.0015 \text{ deg}$$

$$A = .83296$$

$$C = .83363$$

$$M_x = -1.56 \times 10^{-5} \text{ ft-lb/gauss}$$

$$M_y = 4.95 \times 10^{-5} \text{ ft-lb/gauss}$$

$$M_z = 1.46 \times 10^{-4} \text{ ft-lb/gauss}$$

$$K = 2.96 \times 10^{-5} \text{ ft-lb-sec/gauss}^2$$

The offset angles are somewhat larger than those for Case I, and ϵ_1 is better than that for Case II. The moment of inertia ratios are still good. The magnetic moment coefficients are somewhat closer to their actual values, but still do not represent reasonable estimates of those used to generate the data.

Case V. - This is the same as Case IV, except that the perturbations of the earth's magnetic field are reversed. Thus,

$$a_1 = a_2 = a_3 = -.05$$

Results for this case are shown in Table 7. The errors show a little larger spread than those of Case IV, but are within bounds. Other parameters obtained are:

$$\epsilon_1 = -.0031 \text{ deg}$$

$$\epsilon_2 = -.0016 \text{ deg}$$

$$A = .83291$$

$$C = .83368$$

$$M_x = -3.06 \times 10^{-5} \text{ ft-lb/gauss}$$

$$M_y = 4.74 \times 10^{-5} \text{ ft-lb/gauss}$$

$$M_z = 1.07 \times 10^{-4} \text{ ft-lb/gauss}$$

$$K = 2.75 \times 10^{-5} \text{ ft-lb-sec/gauss}^2$$

These compare favorably with those obtained in Case IV, and show how sensitive M_x, M_y, M_z and K are to the magnetic field perturbations.

From the results of Cases IV and V, it is concluded that a wide range of parameter variations can be tolerated in the vehicle and model with little effect on the accuracy of the attitude determination (at least at star sighting instants).

Summary of Results

The pitch angle, in all cases, was determined better than the ψ and ϕ angles. This is due primarily to the greater sensitivity of the starmapper about the spin axis. The results also showed that the two-star configuration does not appear to be adequate for the required estimation accuracies. The four star configuration does provide an adequate estimate. The six-star configuration provides yet a better estimate of the vehicle state. This is due to the greater number of data points collected per revolution of the spacecraft.

Conclusions

- Feasibility of attitude determination by the method of least squares is established.
- Four stars per revolution give adequate results, whereas two stars per revolution are not enough.
- Large parameter variations can be tolerated.
- Numerical integration of the differential equations is too slow.

Additional Work to be Accomplished

- A method for speeding integrations must be found.
- Computer runs to date should be repeated with different noise spans to determine variance of the results.
- Maximum errors between star sighting intervals should be determined.
- Effects of other model perturbations should be ascertained.

Sun Sighting Results

General. - The first problem to be solved is that of determining which of the 15 parameters in (34) can be found from observations of the sun. The approach to this problem is to apply the implicit function theorem to the normal equations (49), where more than one variable may be made an independent variable. According to the implicit function theorem, the matrix of partial derivatives must be examined for singularity, and individual elements of this matrix are expressed as

$$\sum_{k=1}^{N} H(t_k, y) \frac{\partial^2 H(t_k, y)}{\partial y_i \, \partial y_j} + \sum_{k=1}^{N} \frac{\partial H(t_k, y)}{\partial y_i} \frac{\partial H(t_k, y)}{\partial y_j}, \quad i, j = 1, \ldots, m \leq n.$$

If the model and the transit times are perfect, then each $H(t_k, y)$, $k = 1, \ldots, N$ is zero. The matrix then reduces to the product G'G, where G is defined in (42), and where selected columns of G have been omitted since they correspond to the independent variables. If the matrix is nonsingular, then the normal equations can be solved for the dependent variables in terms of the set of independent, or omitted, variables.

The matrix can be examined for singularity in only the simplest of analytic problems. For the torqued case of interest, the matrix must be examined numerically. Consequently, a computer program was constructed for this purpose.

The program starts with the complete 15 x 15 matrix. The vector G'H of equation (41) is also in memory. An input card specifies the rows and columns to be deleted. After the matrix and vector have been condensed, the program performs the four tests described below.

1. The solution to equation (41) is computed. The pivot elements are output during the Gauss-Jordan reduction as an aid in estimating which rows (or columns) are dependent.

2. The solution is multiplied by the condensed matrix and compared with the condensed G'H vector. This indicates the quality of the solution.

3. The minimum rank of the condensed matrix is determined.

For each numerical operation performed in the Gauss-Jordan reduction, a parallel calculation of the maximum error in that computation is made and stored. When the errors in the elements of the working matrix become greater than or equal to the elements yet to be processed, the reduction is halted, and the rank is said to be equal to the number of rows (and columns) processed. The original matrix is assumed to be perfect. A number equivalent to 1/2 of the least significant bit in the computer is required for the estimate of roundoff error.

4. The eigenvalues of the symmetric matrix are computed. The method is a highly accurate one developed by Householder. The eigenvalues are examined to see if there are any close to zero, and to see if they are all positive.

A listing of this program is included as Appendix M.

The above program was used at various stages of the development to determine sets of parameters for the solution. The approach was to generate the least squares equations for a given slit geometry, and then to examine the system for several likely cases. The parameter sets were selected from the results.

Conclusions from these studies are:

- A single, two-slit sun sensor produces a least squares matrix with a maximum rank of 12. Thus, 12 variable solutions are possible.
- Two, two-slit sun sensors (4 slits total) produce a least squares matrix with rank 13. Thus, 13 variable solutions are possible.
- One of the initial angles (ψ_o, ϕ_o or θ_o) can always be deleted without reducing the rank of the matrix.

The slit parameters were taken as those of slits 1 and 3 (Table 5) of the starmapper during runs of the data generating program and the least squares attitude determination program.

This slit configuration is illustrated in Figure 53, where the vehicle is pictured as a spherical body.

In Figure 53, the j_E axis is the outward normal.

The slits join together on the k_E axis. As the vehicle spins about the j_E axis, the sun-line traces the dotted line on the spherical skin of the vehicle. For the single sun sensor, the field of view is blocked off to the left of the i_E - j_E plane. In the four-slit design, the field of view was widened out to 180° so that the sun would cross each slit twice per revolution.

It is recognized that other sun sensor designs may be more practical. The objective of the studies was to draw conclusions about a geometry that would carry over to other slit configrations, without necessitating a major re-programming effort on the data generating program.

Several of the computer experiments performed are described below.

Six variable solutions. - Solutions for six variables were obtained for three different runs. The initial conditions for these were taken as the terminal conditions for cases IV, V, and II above, respectively. The variables were (ω_{x_o}, ω_{y_o}, ω_{z_o}, θ_o, M'_y, M'_z) and the constants (not changed) were (ψ_o, ϕ_o, A, C, M'_x, K', ϵ_1, ϵ_2). Runs extended over 1/2 of the sunlit part of the half-orbit (see Figure 49), since computer time for the total light portion would have been excessive.

Table 9 summarizes the extreme differences in principle coordinate angles for these runs.

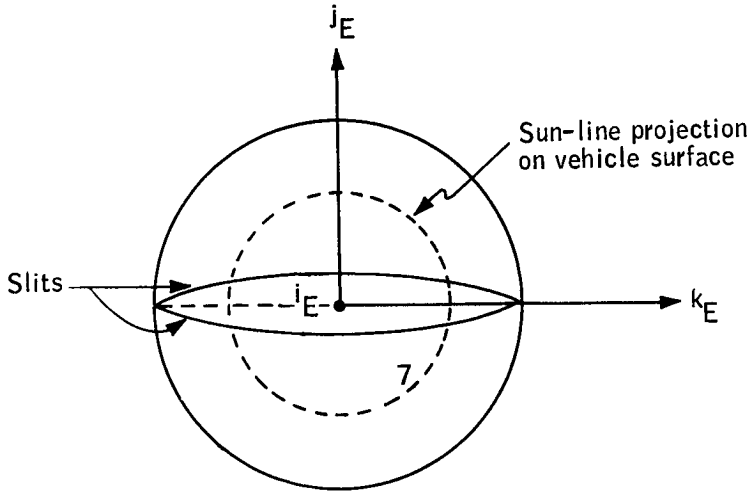


Figure 53. Slit Configuration for the Sun Sensor Studies

TABLE 9. - EXTREME ERRORS IN ANGLES RELATING EXPERIMENTAL AXES TO INERTIAL SPACE FOR 6 VARIABLE SOLUTIONS

Star case	$\Delta\psi$, arc sec		$\Delta\phi$, arc sec		$\Delta\theta$, arc sec	
	Max.	Min.	Max.	Min.	Max.	Min.
IV	2.44	-43.64	-8.33	-56.46	-11.54	-31.65
V	12.7	-32.99	12.61	-12.93	17.75	- 1.24
II	45.83	-41.55	2.04	-41.59	6.99	-37.94

Two slits were used in Cases IV and V, whereas four slits were assumed for Case II. It is seen that six variables do not give sufficient freedom to shape the path to the data, even when four slits are used. It is also significant that the magnetic moment coefficients, the eddy current coefficient, and the magnetic field perturbations are smaller for Case II than they are for either of Case IV or V.

Twelve and thirteen variable solutions. - Several runs were made assuming the star Case II terminal values to be the starting initial conditions. Four slits were used, which allowed solutions in terms of 13 variables. The results are summarized in Table 10 in terms of angular errors in principle coordinates. All runs except the last one are for 1/2 the sunlit part of the half orbit.

TABLE 10. - EXTREME ERRORS IN ANGLES RELATING EXPERIMENTAL AXES TO INERTIAL SPACE FOR 12 AND 13 VARIABLE SOLUTIONS

Run	Variables held fixed	$\Delta\psi$, arc sec		$\Delta\phi$, arc sec		$\Delta\theta$, arc sec	
		Max.	Min.	Max.	Min.	Max.	Min.
I	ψ_o	0.40	- 0.41	0.41	-0.41	0.08	-0.08
II	ψ_o	10.21	8.88	55.66	54.47	55.88	53.36
III	ψ_o	21.39	- 8.05	49.47	29.76	48.04	31.30
IV	ψ_o, ϕ_o	21.52	-15.11	28.07	4.94	27.37	6.82
V	θ_o	15.06	-15.05	11.17	-9.19	9.53	-7.26
VI	θ_o	5.38	- 7.46	-1.79	-9.84	0.40	-11.58

Run I assumes a perfect model and no noise. It was included to show that a thirteen variable solution is obtained. Run II is the same run, except that

the model is no longer perfect. The angular errors have biases, although the spreads are very small. No explanation for the bias was found. Errors in angular rates are measured in terms of hundredths of arc second per second. Run III adds noise to the sun transit times. It is seen that the angular bias becomes less and that the spread in extremes becomes larger.

In Run IV, angles ψ_o and ϕ_o are held fixed. A somewhat better bias is obtained, but a bigger spread is found. Evidently it is best to allow as much freedom as possible to the least squares process.

Angle ψ_o was held fixed in the above runs because an error in this quantity does not affect the solution for θ significantly (i. e., is a second-order error source). In fact, in the no torque case, the effect is to cause a bias in ψ alone, without changing the rest of the solution. However, the constraint equation H is sensitive to ψ, so that poor results are obtained, even though the analytic solution to the no-torque case does not show this effect.

However, the value of θ_o is accurately determined from star observations. Holding this constant should result in more accurate results. Runs V and VI demonstrate that this is so. Run V extends half way through the daylight part of the trajectory, whereas Run VI extends all the way. It is seen from Table 10 that the errors and the spreads in ψ and ϕ are smaller for the longer run. Although the spread in the θ error is less, the bias is larger in this case. A further comparison of the two runs is made in Table 11. Without exception, the parameter values are better for the longer run. The reason for the better accuracy may well be that twice as much data is processed to find the solution, resulting in better smoothing characteristics.

TABLE 11. - ADDITIONAL RESULTS FOR RUNS V AND VI

Run	ε_1	ε_2	A	C	M_x	M_y	M_z	K
V	.0012°	.0033°	.83345	.83311	1.01×10^{-4}	4.48×10^{-6}	6.26×10^{-4}	1.46×10^{-5}
VI	.0004	.0006	.83323	.83334	4.51×10^{-5}	4.83×10^{-5}	2.50×10^{-4}	1.44×10^{-5}

Figure 54 shows the pitch angle error for the experimental frame over a selected time period for Run VI. Data points are given and the dashed line represents the limiting values obtained. The data appears to be fairly well bounded by these curves, as examination of the slopes of the connecting line segments yields flat slopes (maxima and minima) for at least one set of data.

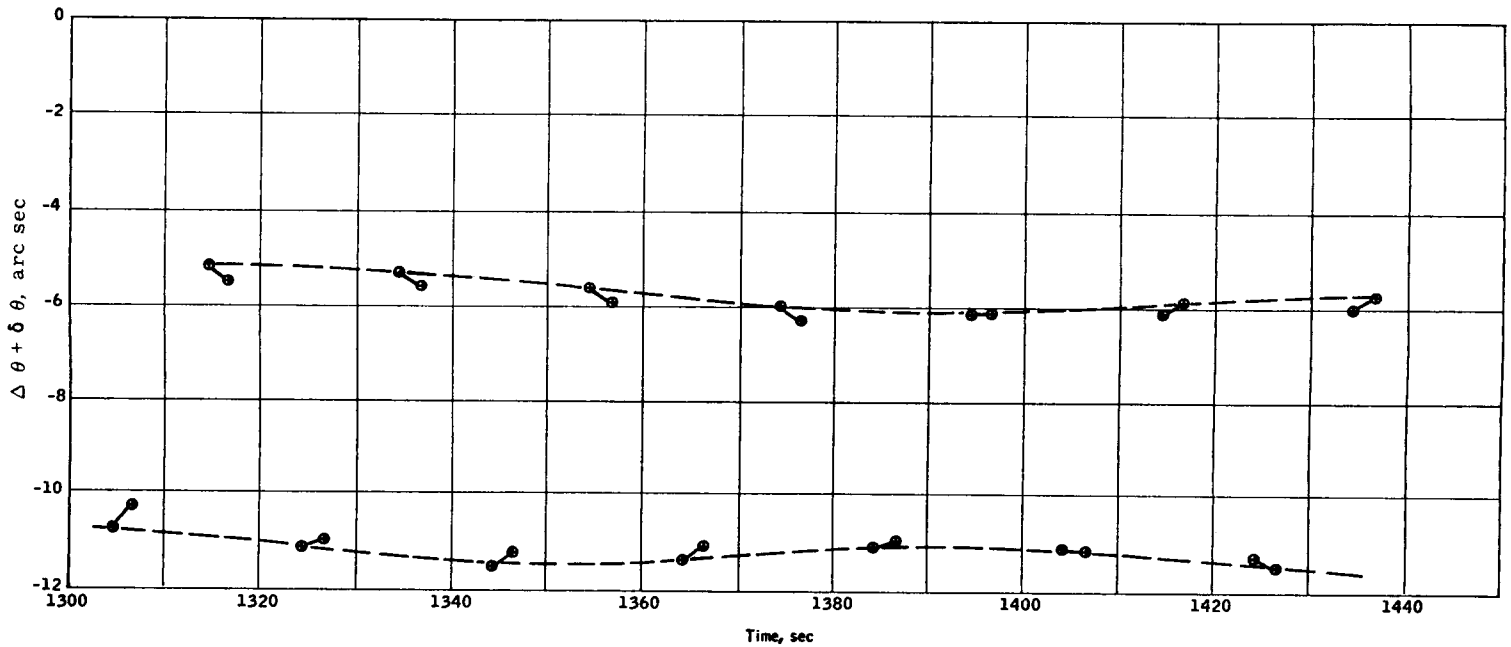


Figure 54. Experimental Frame Pitch Angle Error for Sun Sensor Run VI

CONCLUSIONS

Feasibility is indicated for the sun sensor, from the standpoint of a 13-variable solution. However, further effort is required to:

- Optimize the sun sensor design
- Establish confidence in the results through additional computer runs
- Determine effect on accuracy of more slits
- Determine effect of different noise spans on accuracy
- Determine effects of larger model perturbations on accuracy
- Determine effects of other model perturbations on accuracy

OVERALL CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The problem of estimating vehicle attitude from starmapper and sun sensor instrument time pulse measurements was considered. An a posteriori data processing algorithm was postulated for the solution of this problem, since real-time knowledge of precise vehicle attitude is not required. It was also noted that the interpretation of the instrument measurements in terms of attitude requires a model for the vehicle motion.

The approach chosen for solution of the attitude determination problem was the method of least squares. The solution of the model equations of motion can be expressed in terms of time, the initial conditions, and the model parameters. The least-squares problem was posed as that of determining those initial conditions and parameters that best explain the observed sequence of starmapper and sun sensor time pulses. An algorithm for the solution of the problem was derived and programmed for the digital computer. This algorithm has the advantage over other algorithms considered of being conceptually simple and readily implemented.

Simulation results show that the least-squares data reduction algorithm is entirely satisfactory for starmapper observations. It also appears to be satisfactory for use with the sun sensor data usage concept considered. Computer results for this case are sparse, at present, and more work on the definition of the sun sensor instrument and data requirements are necessary to verify this conjecture. In any event, there is no evidence at this time to justify the use of a more sophisticated algorithm. Thus, retention of the least-squares data reduction algorithm is recommended for future studies.

The model differential equations of motion cannot be integrated in closed form, so the Runge-Kutta method was used in the simulation to generate the solution. The numerical integration process was found to be satisfactory from the standpoint of accuracy, but it was exceedingly slow. The simulation program ran about three times real time on the H-1800 computer and a little faster than real time on the CDC6500 computer. It is evident that some method must be found to speed the integration of the model equations, or to approximate the solution with speed and accuracy, before further work is done.

The available methods for speeding integrations in this problem are closely tied to the choice of state variables. The coordinate system used in the simulation was chosen so that the singular point of the differential equations could be avoided. No simple closed-form solution for the torque-free problem (surely to be used in the approximation of the solution) is available, so this coordinate frame and choice of state variables do not lend themselves to the ready approximation of the solution. On the other hand, the equations of motion in the usual coordinate frame (in which the inertial z axis is aligned with the angular momentum vector) have a nice closed-form solution.

CONCLUSIONS AND RECOMMENDATIONS

Documented in this report are the HDS orbital characteristics and operations analyses. These studies include mission profile analysis, vehicle position determination, data acquisition, and attitude determination. The objectives of the studies were to evaluate parameters pertinent to each study area and to relate them to the overall system objectives and thereby, evolve the conceptual design and operational aspects associated with these areas of the measurement system.

The mission profile analysis results indicate that a nominally circular, 500-km altitude, sun-synchronous orbit (97.30 degrees inclination) with initial ascending node at 3:00 p.m. local time and launch date of 28 October meets the experiment and system requirements. The WTR is recommended for the launch site, and a 2-stage Improved Delta (DSV-3N) vehicle was selected as the booster.

In the position determination studies, it was determined that the propagation and basic tracking measurement errors using the Minitrack system or the vhf range/rate tracking system were too large to meet the position accuracy requirements of this program. Based on extrapolations from past experience, the S-band Range/Range-Rate system should be capable of providing sufficient data to give orbit arcs with 3-sigma equivalent tangent height errors under 100 m exclusive of drag uncertainty. The results of this study lead to the recommendation that the Range/Range-Rate S-band tracking system should be used to provide the tracking function for this program.

The data acquisition study determined that the vhf (136 MHz) STADAN telemetry link should be used as the primary telemetry link because it provides the best ground telemetry coverage and satisfies the data bandwidth requirements. The tone-digital command system is recommended to provide the command function. The Range/Range-Rate system is recommended for a back-up telemetry link since it is used as the primary tracking system and is therefore, available for telemetry with minor modifications and additions. Primary stations recommended for telemetry contacts are College, Rosman, St. Johns, and Winkfield since they provide adequate telemetry coverage and will permit transmission of the data to GSFC in the least amount of time.

The approach chosen for solution of the attitude determination problem was the method of least squares for determining those initial conditions and parameters that best explain the observed sequence of starmapper and sun sensor time pulses. An algorithm for the solution of the problem was derived and programmed for the digital computer. Simulation results show the least-squares data reduction algorithm is entirely satisfactory for starmapper observations. It also appears satisfactory for the sun sensor data usage concept considered. Computer results for this case are sparse and further effort on the definition of the sun sensor instrument and data requirements are necessary for verification.

An approximate solution to the torqued problem is readily obtained. The difficulty here, however, is that the vehicle operates very close to the singular point of the differential equations, so that the validity of the approximation is questionable. It may be that other choices of variables may be necessary to resolve the approximation problem. Possibilities include direction cosines, quaternions, and Cayley-Klein parameters.

RECOMMENDATIONS

The torques used in the simulation program, for the purpose of demonstrating feasibility, included magnetic moment and eddy current torques. These were found to be the most significant torquing terms acting on the vehicle. Their forms do not necessarily represent the actual torques acting on the vehicle, and more work is necessary in this area to refine the vehicle model. Also, the effects of flexure on the motion of the vehicle must be ascertained to determine if this must be considered in the vehicle model. The vehicle was assumed to be a rigid body in the simulation.

Finally, it was assumed during the study that starmapper time pulses were matched with stars. In the actual flight this is not so, and some means of matching the time pulses with the stars must be provided. This is the star identification problem (also the pattern recognition problem).

On the basis of the above discussion, it is clear that any program leading to an operational least-squares data reduction algorithm must contain the following items:

- A method for speeding the integration of the equations of motion must first be found.
- The design of the sun sensor should be established and verified.
- A study of the environmental torques acting on the vehicle should be made to refine the model differential equations of motion. The effects of flexure should also be ascertained.
- A pattern recognition computer program should be developed.
- The operational program should be developed and extensively tested.

The following recommendations for further study are made:

- Further investigate the position determination accuracy and the horizon resolution degradation as a function of orbit altitude. The element of concern here is the drag uncertainty at orbits less than roughly 900 km and the increased sensitivity to angular errors at higher altitudes.

- Refine and update the tracking and data acquisition plans as required when more definitive design specifications become available.

It is recognized that the first recommendation for further study can be realized only through the efforts at the GSFC. This improvement in orbit position accuracy will evolve as work on the total orbit determination process is carried out at GSFC.

APPENDIX A
ORBITAL ANALYSIS COMPUTER PROGRAMS

APPENDIX A

ORBITAL ANALYSIS COMPUTER PROGRAMS

This appendix contains the computer program descriptions, listings, and test outputs for the programs used in the orbital analysis section of this report. Included are programs: 1) SHASTA, which evaluates solar illumination and sun-angle profiles; 2) TECO, SICO and PICO, which simulate tracking and telemetry coverage for the STADAN stations.

PROGRAM SHASTA

Purpose

SHASTA computes the angle between the normal-to-orbit-plane vector and the vector toward the sun, the fraction of time per orbit spent within the earth's shadow, the local true sun time at ascending node, and the angles between the normal-to-orbit-plane vector and the vectors toward selected stars, all as a function of time. Circular orbits and a cylindrical earth shadow are assumed.

Method

Once a near circular orbit of moderate or low altitude is established about the earth, it tends to remain stationary, with constant inclination relative to the equator, constant altitude, and constant equatorial crossing point with respect to the stellar frame of reference. The primary disturbing influences which alter this tendency at altitudes below about 30 000 km are molecular drag and earth oblateness. At altitudes above 400 to 500 km, molecular drag becomes almost insignificant, and it is this range which will be considered.

The rate at which the node (equatorial crossing point) of a circular earth orbit secularly progresses eastward due to earth oblateness can be expressed to first-order as:

$$\dot{\Omega} = -9.9958 \cos i (1 + h/R_E)^{-3.5} \text{°/day} \qquad \text{(A1)}$$

where i is orbit inclination ($0 \leq i \leq 180°$), h is orbit altitude, and R_E is the earth's radius. The node, measured from a reference axis in the equator, is then $\Omega = \Omega_o + \dot{\Omega} t$ where Ω_o is the value of time $t = 0$.

The unit normal to the orbit plane, $\hat{n}$, can be expressed in terms of x, y, and z components as (see Figure A1):

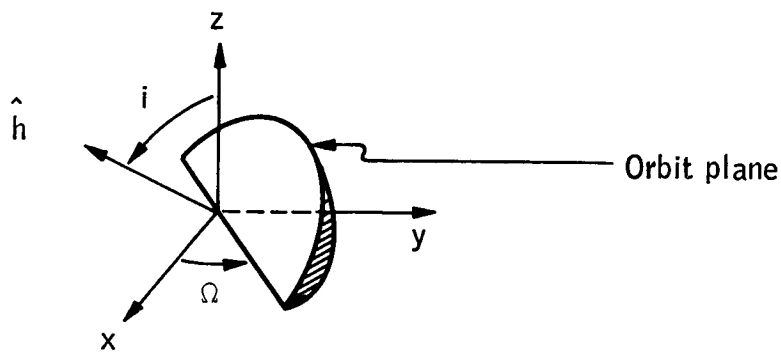


Figure A1. Normal-to-Orbit Vector Geometry

$$h_x = \sin i \sin \Omega$$

$$h_y = -\sin i \cos \Omega \qquad \text{(A2)}$$

$$h_z = \cos i$$

The unit vector toward the sun, $\hat{s}$, can be expressed as:

$$S_x = \cos \theta_s$$

$$S_y = \sin \theta_s \cos i_s \qquad \text{(A3)}$$

$$S_z = \sin \theta_s \sin i_s$$

Where θ_s is the angle from the x-axis to the sun, and i_s is the inclination of the ecliptic to the equator (about 23.5°). The angle between the orbit normal and the sun vector, $\hat{s}$, is then:

$$\beta = \cos^{-1} |\hat{h} \cdot \hat{s}|$$

The angle θ_s can be evaluated from:

$$\theta_s = M_s + 2e_s \sin M_s + \frac{5}{4} e_s^2 \sin 2 M_s - \theta_{so} \qquad \text{(A4)}$$

where:

M_s = true anomaly of sun

= (Day of year -2) · (2π /365)

e_s = eccentricity of sun's orbit (earth's orbit)

= 0.01675104

θ_{so} = Value of θ_s expression at time of vernal equinox (0737 hrs. 21 March in 1967)

Similarly, for any star in a direction given by a unit vector $\hat{e}$, the angle between e and the orbit normal is:

$$\beta st = \cos^{-1} |\hat{h} \cdot \hat{e}|$$

The calculation of shadow time is made by assuming that the earth's shadow is cylindrical, i.e., no umbra or penumbra distinction. This assumption is valid for low or moderate altitudes. The projection of the shadow in the orbit plane is then, in general, an ellipse. The major axis of this ellipse is $a = R_E / \sin \eta$ (see Figure A2).

The geocentric angle from shadow entry to mid-shadow point, ψ, can be found by solving for the intersection of the orbit circle with the shadow projection ellipse, yielding

$$\sin \psi = \frac{Y}{R_E + h} = \frac{R_E^2 - (R_E + h)^2 \sin^2 \eta}{(R_E + h)(1 - \sin^2 \eta)} \tag{A5}$$

The shadow fraction is:

$$f_{sh} = \psi / \pi$$

The local sun time at ascending node is given by

$$t_{AN} = \left[\tan^{-1} (h_y / h_x) - \pi/2 - \tan^{-1} (s_y / s_x) \right] \cdot \frac{24 \text{ hr}}{2 \pi}$$

where the expression in brackets is placed in the range $(0, 2\pi)$.

Input

The sequence of input data cards for SHASTA is as follows. The first card is a title card and may contain anything in columns 1 - 80. A case description is best used since this data is printed at the top of the first output sheet. The second card is an orbit, NST card, with data as follows:

Columns	1 - 3	First three letters of initial month, e.g., MAR for March
	4 - 8	Day of initial month (with decimal)
	9 - 16	Initial orbit ascending node on the equator, degrees, (with decimal) with respect to vernal equinox, or with respect to sun's longitude.
	22 - 24	Letters SUN if orbit ascending node is with respect to sun's longitude, blank otherwise.
	25 - 32	Orbit altitude, n.mi. or km (with decimal).
	33 - 40	Orbit inclination, deg (with decimal).

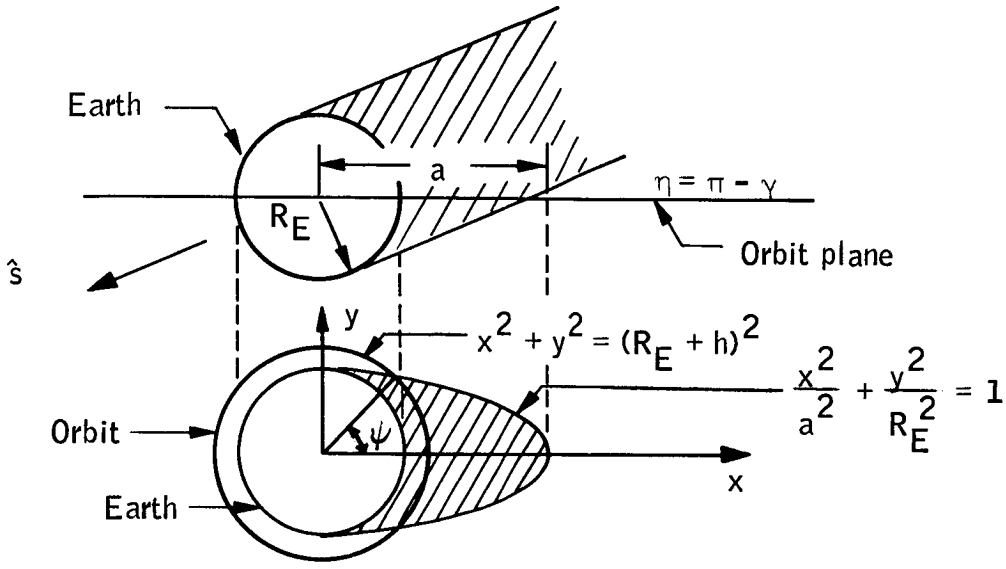


Figure A2. Shadow Geometry

41-48 Time increment of output, days (with decimal).

49-56 Total length of time, days (with decimal).

57-62 Letters METRIC if altitude is in km., blank if altitude is in n.mi. (any characters other than blanks are equivalent to METRIC).

79-80 Number of star cards which follow (maximum of 10) (no decimal), e.g. if three star cards follow, 03 is punched in 79-80. May be blank if no star cards follow.

The third card will be a star card if columns 79-80 are not blank or zero in card 2. The format of each star card is as follows:

Columns 1 -12 Name or description.

17-24 Star right ascension, deg (with decimal).

25-32 Star declination, deg (with decimal).

After the appropriate number of star cards (zero to ten possible), a new title card may follow, etc. Any number of such new cases may be run sequentially. The last two cards, after all data, should be blank, terminating the run by sensing an orbit altitude less than 1.0 units.

The time increment in days determines the resolution of the output data. For orbits which are near polar, a 5-day step may be appropriate; for moderate inclinations, a smaller step size should be used, since orbit precession, Equation (A1), approaches 10°/day for low inclinations. The total time may be any value; generally a year (365.0 days) is adequate.

Output

The program output is shown in Table A1 for a sample case. The top of the first page lists the input data plus some auxiliary parameters. "HORIZON DIP" is the angle between local horizontal at the satellite and the earth's horizon. The output tables are virtually self-explanatory. The "DAYS" are measured from the initial date, angles are given in degrees.

Computer Requirements

1. Compiler language: Fortran IV

2. Memory requirement: 2245 words

3. Tape units: Common input 5
   Common output 9

TABLE A1. - SHASTA TEST CASE

* * * S H A S T A * * *

SHASTA TEST CASE

INITIAL DATE = OCT 28.0
INITIAL ASC. NODE = 45.0 DEG REL TO SUN POS.
ORBIT ALTITUDE = 500.0 KM.
ORBIT INCLINATION = 97.38 DEG
TIME INCREMENT = 5.00 DAYS

HORIZON DIP = 22.0 DEG
NODAL PRECESSION = .99 DEG/DAY
PERIOD = 94.6 MIN

STAR 1 TWINKLE RT. ASC. = 270.0 DEG DECL. = -48.0 DEG
STAR 2 LITTLE STAR RT. ASC. = 93.0 DEG DECL. = 25.0 DEG

DAYS	SHADOW FRACTION	ASC NODE LOC TIME	ANGLE FROM ORBIT NORMAL TO: SUN	ST 1	ST 2
.0	.3210	14:59	44.6	93.3	78.5
5.0	.3210	15: 0	44.6	90.1	82.9
10.0	.3216	15: 0	44.7	86.9	87.3
15.0	.3224	14:59	45.0	83.6	91.7
20.0	.3236	14:59	45.4	80.3	96.1
25.0	.3251	14:58	45.8	77.0	100.6
30.0	.3267	14:56	46.3	73.7	105.1
35.0	.3285	14:54	46.8	70.4	109.5
40.0	.3303	14:52	47.4	67.2	114.0
45.0	.3320	14:50	48.0	64.1	118.5
50.0	.3337	14:48	48.6	61.0	122.9
55.0	.3353	14:45	49.2	58.0	127.3
60.0	.3368	14:43	49.7	55.2	131.7
65.0	.3381	14:40	50.2	52.5	136.0
70.0	.3392	14:38	50.7	49.9	140.3
75.0	.3402	14:36	51.1	47.7	144.4
80.0	.3410	14:34	51.4	45.6	148.3
85.0	.3416	14:33	51.6	43.9	152.2
90.0	.3420	14:31	51.8	42.5	155.6
95.0	.3423	14:30	51.9	41.4	158.6
100.0	.3424	14:30	52.0	40.8	160.9
105.0	.3424	14:29	52.0	40.6	162.2
110.0	.3422	14:29	51.9	40.8	162.3
115.0	.3420	14:30	51.8	41.5	161.1
120.0	.3417	14:30	51.7	42.6	159.0
125.0	.3414	14:31	51.6	44.0	156.1
130.0	.3411	14:32	51.4	45.8	152.7
135.0	.3408	14:34	51.3	47.8	148.9
140.0	.3406	14:35	51.2	50.1	145.0
145.0	.3404	14:37	51.1	52.7	140.8

TABLE A1. - SHASTA TEST CASE - Concluded

DAYS	SHADOW FRACTION	ASC NODE LOC TIME	ANGLE FROM ORBIT NORMAL TO: SUN	ST 1	ST 2
150.0	.3404	14:38	51.1	55.4	136.6
155.0	.3404	14:40	51.2	58.2	132.3
160.0	.3406	14:41	51.2	61.2	127.9
165.0	.3410	14:43	51.4	64.3	123.5
170.0	.3415	14:44	51.6	67.5	119.1
175.0	.3422	14:45	51.9	70.7	114.6
180.0	.3429	14:46	52.2	74.0	110.1
185.0	.3438	14:47	52.6	77.2	105.7
190.0	.3448	14:48	53.0	80.5	101.2
195.0	.3458	14:48	53.5	83.8	96.7
200.0	.3468	14:48	54.0	87.1	92.3
205.0	.3479	14:48	54.5	90.4	87.9
210.0	.3489	14:48	55.0	93.6	83.5
215.0	.3498	14:47	55.4	96.7	79.1
220.0	.3507	14:46	55.9	99.8	74.8
225.0	.3515	14:45	56.3	102.8	70.5
230.0	.3521	14:44	56.7	105.7	66.3
235.0	.3527	14:43	57.0	108.5	62.2
240.0	.3530	14:42	57.2	111.1	58.1
245.0	.3533	14:41	57.3	113.6	54.2
250.0	.3534	14:40	57.3	115.9	50.5
255.0	.3533	14:39	57.3	117.9	46.9
260.0	.3530	14:39	57.1	119.8	43.5
265.0	.3525	14:38	56.9	121.3	40.5
270.0	.3519	14:38	56.5	122.6	37.8
275.0	.3511	14:38	56.1	123.6	35.6
280.0	.3500	14:38	55.6	124.3	33.9
285.0	.3488	14:39	54.9	124.6	32.8
290.0	.3474	14:40	54.2	124.6	32.4
295.0	.3458	14:41	53.5	124.2	32.7
300.0	.3439	14:42	52.6	123.5	33.7
305.0	.3419	14:43	51.8	122.5	35.3
310.0	.3398	14:45	50.9	121.2	37.5
315.0	.3375	14:46	50.0	119.6	40.1
320.0	.3351	14:48	49.1	117.7	43.1
325.0	.3327	14:50	48.3	115.7	46.5
330.0	.3303	14:52	47.4	113.4	50.0
335.0	.3280	14:54	46.7	110.9	53.7
340.0	.3259	14:55	46.0	108.2	57.6
345.0	.3240	14:57	45.4	105.5	61.7
350.0	.3224	14:58	45.0	102.6	65.8
355.0	.3211	14:59	44.6	99.5	70.0
360.0	.3203	15: 0	44.4	96.5	74.2
365.0	.3199	15: 1	44.3	93.3	78.6
370.0	.3200	15: 1	44.3	90.1	82.9

THE CLOCK SEZ 40755 AT FILTER LOAD TIME.

4. Subroutines: None

5. Library:

ALOG	logarithm to base e
EXP	exponential
COS	cosine
SIN	sine
ABS	absolute value
ATAN	arctangent
SQRT	square root
AMOD	remaindering

Definition of Variables

Fixed-point single variables. --

I	loop counter
IHR	integer number of hours local time at ascending node
IM	month of year (1-12) in which launch occurs
IUNIT	indicator for metric or British units (IUNIT - 1 implies British, IUNIT = 2 implies metric).
JC	loop counter
MINS	fractional part of ascending node local time in minutes
NLN	line counter for page output
NST	number of stars in present case
NSTP	total number of days for which output is to be generated
NTS	NST + 1

Floating-point single variables. --

BLANK	five blank alphanumeric characters
SAN	three alphanumeric characters: SUN
DTR	degrees-to-radian conversion
RTD	radians-to-degree conversion

PI	3.1415926536
AM	three alphanumeric characters specifying launch month (e.g. JAN: January)
DA	day of month in which launch occurs
OMED	launch ascending node with respect to vernal equinox, or with respect to sun's longitude, degrees
REF	three alphanumeric characters specifying reference for launch ascending node
H	orbit altitude, n.mi. or km
AD	orbit inclination, deg
STEP	output time step, days
SPAN	total length of time, launch-to-end, days
UNIT	indicator which specifies metric units for distances if not blank on input
RE	radius of earth, n.mi. or km
OMEG	ascending node at launch, radians
AI	orbit inclination, radians
XAB	cumulative day counter, integral number of months, in determining day of year
D	day of year (from 0 Jan.) on which launch occurs
SM	orbital mean anomaly of sun
STH	sun's in-ecliptic angle from vernal equinox, radians
SX	X-component of sun's position
SY	Y-component of sun's position
SZ	Z-component of sun's position
SMEG	sun's right ascension, radians
VND	orbit ascending node, radians
DY	day of year (from 0 Jan.)

P	orbit period, minutes
ODOT	eastward orbit nodal precession, degrees/day
ODOTR	eastward orbit nodal precession, radians/day
DVND	eastward orbit nodal precession, radians/time-step
DIP	angle from local horizontal at satellite to earth horizon, deg
TEE	temporary output variable, star declination, deg
TEA	temporary output variable, star right ascension, deg
SNAI	sine of orbit inclination
HZ	cosine of orbit inclination = Z-component of orbit-normal
HX	X-component of orbit-normal
HY	Y-component of orbit-normal
AHSR	$\hat{h} \cdot \hat{s}$ = cosine of orbit-normal/sun-line angle
AHS	absolute value of AHSR
FRSH	shadow fraction
Y	X-component of shadow/orbit intersection point
X	Y-component of shadow/orbit intersection point
PSI	arctangent (Y/X)
TIAN	right ascension of orbit-normal, deg
SRE	sun's right ascension, deg
D2	DY-D = days after launch

Arrays.--

SRA(10)	star right ascension
SDE(10)	star declinations
STX(10)	X-component of star
STY(10)	Y-component of star
STZ(10)	Z-component of star

TAB(12)	code names for months [e.g. JAN for TAB(1)]
DAB(12)	number of days in month [31.0 for DAB(1)]
TTL(20)	alphanumeric title information for output header
HDR(11)	alphanumeric column header for output
SH(10)	currently unused
BEGA(11)	angles between orbit-normal and star-line (BETA(1) corresponds to sun)
ZS(10)	absolute value of ZSR
ZSR(10)	$\hat{h} \cdot \hat{e}$ = cosine of orbit-normal/star-line angle
SNMI(10)	first part of alphanumeric star name
SNMZ(10)	second part of alphanumeric star name
UN(2)	alphanumeric constants, n.mi. and km
RET(2)	earth radius values, 3443.9 and 6378.2

Program Listing

See Table A2.

PROGRAM TECO

Purpose

TECO computes the visibility time periods, above specified minimum elevation, at each of up to 15 ground stations as a function of orbit ascending node longitude for a spacecraft in a circular orbit. The maximum single station time and total of times for all stations is printed for each nodal longitude. The average visibility time, over all the nodal longitudes used, is computed for each station after nodal longitudes from 0° to 360° have been covered.

Method

The TECO model is based on the following simplifying assumptions:

TABLE A2. - AUTOMATH 1800 SOURCE PROGRAM LISTING - SHASTA

```
                                AUTOMATH  1800  SOURCE  PROGRAM  LISTING

IFN        EFN              PROGRAM:  SHASTA                    JOB:    BALTES

0001            DIMENSION SRA(10),SDE(10),STX(10),STY(10),STZ(10),TAB(12),DAB(12),
               2 TTL(20),HDR(11),SH(10),BETA(11),ZS(10),SNM1(10),SNM2(10)
0002            DIMENSION UN(2),RET(2),ZSR(10)
0003          9 FORMAT (20A4)
0004         10 FORMAT (A3,F5.0,E8.1,5X,A3,4E8.1,A5,17X,I2)
0005         12 FORMAT (2A6,4X,2E8.1)
0006         18 FORMAT (43H ILLEGAL,MISSING,OR MISPLACED INITIAL MONTH  )
0007         20 FORMAT(1H1,30X,28H* * *   S H A S T A   * * *   /  20A4 // )
0010         21 FORMAT (1X,21HINITIAL DATE        = ,A3, F5.1 )
0011         23 FORMAT (1X,20HINITIAL ASC. NODE  = ,F6.1,21H DEG REL TO VERNAL EQ)
0012         25 FORMAT (1X,20HINITIAL ASC. NODE  = ,F6.1,20H DEG REL TO SUN POS.)
0013         26 FORMAT (1X,20HORBIT ALTITUDE     = ,F8.1,1X,A5          /1X,20HORBI
               1T INCLINATION  = ,F6.2,4H DEG / 1X, 20HTIME INCREMENT      = ,F6.2,
               2 5H DAYS // 1X,11HHORIZON DIP,8X,1H=,F5.1,4H DEG/1X,20HNODAL PRECE
               3SSION   = ,F6.2,8H DEG/DAY/1X,6HPERIOD,13X,1H=,F7.1,4H MIN // )
0014         28 FORMAT(1X,5HSTAR ,I2,2X,2A6,4X,11H RT. ASC. = ,F7.1,
               1 14H DEG   DECL. = ,F6.1,4H DEG)
0015         31 FORMAT (1H1,9X,47HSHADOW   ASC NODE   ANGLE FROM ORBIT NORMAL TO:
               1 /26H  DAYS  FRACTION  LOC TIME , 3X,11A6)
0016         40 FORMAT (F6.1,F9.4,I6,1H:,I2,4X,11F6.1)
0017         55 FORMAT (1H0)
0020         56 FORMAT (1H5,9X,47HSHADOW   ASC NODE   ANGLE FROM ORBIT NORMAL TO:
               1 /26H  DAYS  FRACTION  LOC TIME , 3X,11A6)
0021            DATA (TAB(I),DAB(I),I = 1,12) / 3HJAN,31.0,3HFEB,28.0,3HMAR,31.0,
               1  3HAPR,30.0,3HMAY,31.0,3HJUN,30.0,3HJUL,31.0,3HAUG,31.0,3HSEP,
               2  30.0,3HOCT,31.0,3HNOV,30.0,3HDEC,31.0 /
0022            DATA (HDR(I), I= 1,11) / 6H  SUN ,6H ST 1 ,6H ST 2 ,6H ST 3 ,6H ST
               1 4 ,6H ST 5 ,6H ST 6 ,6H ST 7 ,6H ST 8 ,6H ST 9 ,6H ST 10 /
0023            BLANK = 5H
0024            SAN = 3HSUN
0025            DTR = 0.0174532925
0026            RTD = 57.295779513
0027            UN(1) = 5HN.MI.
0030            UN(2) = 5HKM.
0031            RET(1) = 3443.9
0032            RET(2) = 6378.2
0033            PI  = 3.1415926536
0034         45 READ (5,9)(TTL(I),I = 1,20)
0035            IUNIT = 2
0036            READ (5,10) AMN,DA,OMED,REF,H,AD,STEP,SPAN,UNIT,NST
0037            IF (UNIT .EQ. BLANK) IUNIT = 1
0040            RE = RET(IUNIT)
0041            IF (H .GT. 1.0) GO TO 13
0042            STOP 1
0043         13 IF (NST .EQ. 0) GO TO 11
0044            READ (5,12) (SNM1(I),SNM2(I),SRA(I),SDE(I), I = 1,NST)
0045            DO 14 I = 1,NST
0046            SDE(I) = SDE(I) * DTR
0047            SRA(I) = SRA(I) * DTR
0050            STX(I)= COS(SDE(I)) * COS(SRA(I))
0051            STY(I)= COS(SDE(I)) * SIN(SRA(I))
```

TABLE A2. - AUTOMATH 1800 SOURCE PROGRAM LISTING - SHASTA - Continued

```
                                    AUTOMATH  1800  SOURCE  PROGRAM  LISTING

IFN                          PROGRAM:  SHASTA                    JOB:    BALTES

0052              STZ(I)= SIN(SDE(I))
0053           14 CONTINUE
0054           11 OMEG = OMED * DTR
0055              AI = AD * DTR
0056              XAB = 0.0
0057              DO 15 I = 1,12
0060              IF (AMN .NE. TAB(I)) GO TO 16
0061              D = XAB + DA
0062              IM= I
0063              GO TO 17
0064           16 XAB = XAB + DAB(I)
0065           15 CONTINUE
0066              WRITE (9,18)
0067              STOP 13
0070           17 SM = (D - 2.0) * 0.017202
0071              STH = SM+0.0335021*SIN(SM)+3.5074668E-4*SIN(2.0*SM)-1.3800116
0072              SX = COS(STH)
0073              SY = SIN(STH) * 0.91744
0074              SZ = SY * 0.43367
0075              IF (ABS(SX) .LT.  1.0E-8) SX = 1.0E-8
0076              SMEG = ATAN(SY/SX)
0077              IF (SX .GE. 0.0) GO TO 50
0100              SMEG = SMEG + PI
0101           50 IF (REF .NE. SAN) GO TO 19
0102              OMEG = OMEG + SMEG
0103           19 NSTP = SPAN/STEP +1.0
0104              VND = OMEG
0105              DY = D
0106              P = 84.49 *((H + RE)/RE)**1.5
0107              ODOT = - 9.9958 * COS(AI) / (1.0 + H/RE) ** 3.5
0110              ODOTR = ODOT * DTR
0111              DVND = ODOTR* STEP
0112              DIP = ATAN (SQRT(1.0 - (RE/(RE + H))**2) /(RE/(RE+H))) *RTD
0113              WRITE (9,20) (TTL(I), I= 1,20)
0114              WRITE (9,21) AMN,DA
0115              IF (REF .EQ. SAN) GO TO 22
0116              WRITE (9,23) OMED
0117              GO TO 24
0120           22 WRITE (9,25) OMED
0121           24 WRITE (9,26) H,UN(IUNIT),AD.STEP,DIP,ODOT,P
0122              IF (NST .EQ. 0) GO TO 27
0123              DO 51 I = 1,NST
0124              TEE = SDE(I) * RTD
0125              TEA = SRA(I) * RTD
0126              WRITE (9,28) I,SNM1(I),SNM2(I),TEA,TEE
0127           51 CONTINUE
0130           27 NTS = NST + 1
0131              SNAI = SIN(AI)
0132              HZ   = COS(AI)
0133              WRITE(9,56) (HDR(I), I = 1,NTS)
0134              WRITE(9,55)
```

TABLE A2. - AUTOMATH 1800 SOURCE PROGRAM LISTING - SHASTA - Concluded

```
                                AUTOMATH  1800  SOURCE  PROGRAM  LISTING
IFN                      PROGRAM:  SHASTA                    JOB:    BALTES

0135          NLN = 19 + NST
0136          DO 30 JC= 1,NSTP
0137          SM = (DY - 2.0) * 0.017202
0140          STH = SM+0.0335021*SIN(SM)+3.5074668E-4*SIN(2.0*SM)-1.3800116
0141          SX = COS(STH)
0142          SY = SIN(STH) * 0.91744
0143          SZ = SY * 0.43367
0144          HX =SNAI*SIN(VND)
0145          HY =-SNAI*COS(VND)
0146          AHSR = (HX*SX+HY*SY+HZ*SZ)
0147          AHS = ABS(AHSR)
0150          FRSH = 0.0
0151          IF (AHS .GE.(RE/(RE+H))) GO TO 33
0152          Y =SQRT((RE*RE -AHS*AHS*(RE+H)*(RE+H))/(1.0 - AHS*AHS))
0153          X =SQRT((RE+H)*(RE+H) -Y*Y)
0154          PSI = ATAN(Y/X)
0155          FRSH = PSI/PI
0156       33 TIAN = ATAN(HY/HX) * RTD
0157          IF (HX .LT. 0.0)TIAN = TIAN + 180.0
0160          SRE = ATAN(SY/SX) * RTD
0161          IF (SX .LT. 0.0)SRE = SRE + 180.0
0162          TIAN = (TIAN - SRE - 90.0) * 0.066666667
0163       61 IF ((TIAN .GE. 0.0) .AND. (TIAN .LE. 24.0)) GO TO 60
0164          IF (TIAN .LT. 0.0) TIAN = TIAN + 24.0
0165          IF (TIAN .GT. 24.0) TIAN = TIAN - 24.0
0166          GO TO 61
0167       60 IHR = TIAN
0170          MINS = AMOD(TIAN,1.0) * 60.0
0171          BETA(1) = 90.0
0172          IF (AHS . LT. 0.0000001) GO TO 34
0173          BETA(1) = ATAN(SQRT(1.0 - AHS*AHS)/AHS) * RTD
0174          IF (AHSR .LT. 0.0) BETA(1) = 180.0 - BETA(1)
0175       34 DO 35 I = 1,NST
0176          ZSR(I) = (HX*STX(I)+HY*STY(I)+HZ*STZ(I))
0177          ZS(I) = ABS(ZSR(I))
0200          BETA(I+1) = 90.0
0201          IF (ZS(I) .LT. 0.0000001) GO TO 35
0202          BETA(I+1) = ATAN(SQRT(1.0 - ZS(I)*ZS(I))/ZS(I)) * RTD
0203          IF (ZSR(I) .LT. 0.0) BETA(I+1) = 180.0 - BETA(I+1)
0204       35 CONTINUE
0205          D2 = DY - D
0206          WRITE (9,40) D2,FRSH,IHR, MINS, (BETA(I), I = 1,NTS)
0207          NLN = NLN + 1
0210          VND = VND + DVND
0211          DY = DY + STEP
0212          IF (NLN .LE. 50) GO TO 30
0213          WRITE (9,31) (HDR(I), I = 1,NTS)
0214          WRITE(9,55)
0215          NLN =1
0216       30 CONTINUE
0217          GO TO 45
0220          END
```

- Orbits are circular and a spherical earth model is used.
- Earth rotation during a station pass is neglected.
- Coverage at any station is independent of azimuth and exists whenever the spacecraft line-of-sight exceeds the minimum value.

To establish the geometry of station coverage, a coordinate system is defined with the x-y plane in the equator and the x-axis toward the orbit ascending node (see Figure A3).

The unit vector along the orbital angular momentum vector is $\hat{h}$, the unit vector toward the station is $\hat{s}$. If the station north latitude is denoted as λ_s and cast longitude as ϕ_s, and the east longitude of the x-axis as ϕ (the x-axis is fixed in the earth and at the location where the sattelite crosses the equator going north) then

$$\left.\begin{aligned} h_x &= 0 & s_x &= \cos\lambda_s \cos(\phi_s - \phi) \\ h_y &= -\sin i & s_y &= \cos\lambda_s \sin(\phi_s - \phi) \\ h_z &= \cos i & s_z &= \sin\lambda_s \end{aligned}\right\} \qquad \text{(A6)}$$

where i is the orbit inclination, $0 \le i \le 180$ deg

If the angle between the orbit plane (defined at time of equatorial crossing) and the $\hat{s}$ vector is denoted as δ, then

$$\begin{aligned} \delta &= |\mathrm{Sin}^{-1}(\hat{h} \cdot \hat{s})| \\ \delta &= |\mathrm{Sin}^{-1} \sin\lambda_s \cos i - \cos\lambda_s \sin i \sin(\phi_s - \phi)| \end{aligned} \qquad \text{(A7)}$$

The angle δ determines the visibility time for the station. However, it must be remembered that the xyz frame rotates with the earth and, thus, the $\hat{h}$ vector has moved slightly by the time the satellite approaches the station. This means that the angle ϕ has increased. In order to correct for this, find the projection of the $\hat{s}$ vector in the orbit plane (defined at time of equatorial crossing) and denote the unit vector along the projection as $\hat{t}$:

$$\hat{t} = \frac{(\hat{h} \times \hat{s}) \times \hat{h}}{|(\hat{h} \times \hat{s}) \times \hat{h}|} \qquad \text{(A8)}$$

The angle from equatorial crossing to closest approach to the station in the original orbit plane, θ, is found from

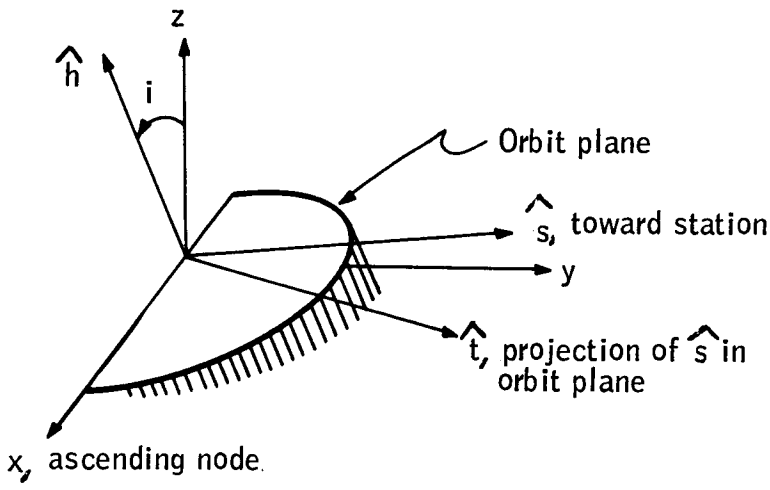


Figure A3. Station/Orbit Plane Geometry

$$\cos\theta = t \cdot i = t_x \qquad (0 \le \theta \le \pi)$$

$$[\text{if } t \cdot k < 0, \text{ set } \theta \text{ to } (2\pi - \theta)] \tag{A9}$$

The time required to traverse this angle is

$$\tau = \frac{\theta}{2\pi} \cdot P \tag{A10}$$

where P is the orbit period. The angle ϕ changes to a corrected value ϕ_c in this time where

$$\phi_c = \phi + \frac{2\pi(\tau)}{1 \text{ sidereal day}} \tag{A11}$$

If we replace the original nodal longitude; ϕ, by ϕ_c in equation (A7), a much closer approximation to the actual pass distance results.

The maximum value of σ at which the satellite is visible is σ_m, which can be shown to be

$$\sigma_m = \pi/2 - e - \sin^{-1}\left[\frac{R_E}{R_E + h} \cos e\right]$$

where e is the minimum elevation angle at the station, R_E is the earth radius, and h is satellite altitude. It can also be shown that the visibility time is then:

$$T = \begin{cases} \frac{P}{\pi} \cos^{-1}(\cos\sigma_m / \cos\sigma) & \text{if } \sigma < \sigma_m \\ 0 & \text{if } \sigma \ge \sigma_m \end{cases}$$

The orbit period, P, is given by

$$P = 84.49\,(1 + h/R_E)^{3/2} \text{ minutes}$$

Input

The sequence of input data (cards) for TECO is as follows. The first card must be a NAME card (letters NAME in columns 1 - 4). The second card may have any descriptive material punched in columns 1 - 80 which will be used as a title on output. The third card has the number of stations (NST) in the current case (maximum 15) punched in columns 1 - 2 (e.g., six stations would be 06 in columns 1 - 2). Following this card should be NST station cards, each punched as follows:

Columns	1 - 12	Station name
	17 - 24	North latitude, degree (with decimal)
	25 - 32	East longitude, degree (with decimal)
	33 - 40	Minimum elevation for station, degree (with decimal)

The next card must be an ORBT card (letters ORBT in columns 1 - 4). Following this is a card describing the orbit parameters as follows:

Columns	1 - 8	Orbit altitude, nautical mi. <u>or</u> km (with decimal)
	9 - 16	Orbit inclination, degree (with decimal)
	17 - 24	Nodal longitude step size, degree (with decimal)
	25 - 32	Minimum elevation for all stations, degree (with decimal)
	33 - 38	Letters METRIC if altitude was given in km, <u>blank</u> if in nautical miles (any characters other than blanks are equivalent to METRIC).
	41 - 48	Fractional increase in earth radius for refraction correction (with decimal).

The refraction correction can be left blank; this amounts to no correction. On the other hand, if the "4/3 earth radius" rule-of-thumb correction is applied, then the fractional increase (0.3333) should be punched in the col. 41 - 48 field. The effect of this correction is to "flatten" the earth and increase the visibility range of a station. It does not affect orbit computations.

Minimum elevation data can be supplied with each station and/or with orbit data. For each station, the largest minimum elevation (of those supplied by station card and by orbit data card) is used.

Following this card, there may be another ORBT card and a card with more orbit data which is applied to the same set of station data. There may be any number of such (ORBT, orbit data) card pairs. Occurrence of another NAME card indicates that prior data will no longer be used, and the foregoing sequence of cards is repeated for a new case. Occurrence of a STOP card (letters STOP in columns 1 - 4) after an orbit data card indicates end-of-data and causes the program to stop.

The nodal longitude step size determines the amount of tabular output. A 10° step size means that nodal longitudes of 0, 10, 20, ..., 360° will be evaluated. For best resolution, it is recommended that a step size of 5° or less be used.

Output

The program output format is shown in Table A3 for a sample case. The first page essentially lists the input data plus some auxiliary parameters. "MAX. ARC RANGE VISIBLE (DEG)" is just the angle σ_m and "MAX. DIST (KM) is the slant range to the satellite at the limiting case ($\sigma = \sigma_m$).

The second (and following pages if necessary) list the visibility times at each station for each nodal longitude. The "MAX" and "TOTAL" columns list the maximum visibility time and sum of visibility times, respectively, over all stations for the given nodal longitude. The "AVERAGES" row at the bottom of the last page is just that, namely, the averages for each of the columns above.

Computer Requirements

1. Compiler language: Fortran IV
2. Memory requirement: 1796 words
3. Tape units: common input 5
   common output 9
4. Subroutines: none
5. Library:

ALOG	logarithm to the base e
EXP	exponential
COS	cosine
SIN	sine
SQRT	square root
ATAN	arctangent
ABS	absolute value

Definition of Variables

Fixed-point single variables.--

J	loop counter
I	loop counter
IUNIT	indicator which specifies units for distance (IUNIT = 1 implies n. mi., IUNIT = 2 implies km)

TABLE A3. - TECO TEST CASE

TECO TEST CASE

STATION	1	COLLEGE	NORTH LAT=	64.90	DEG	EAST LONG.=	212.10	DEG	MIN ELEV=	5.00	DEG
STATION	2	FT. MYERS	NORTH LAT=	26.50	DEG	EAST LONG.=	278.10	DEG	MIN ELEV=	5.00	DEG
STATION	3	JOHANNESBURG	NORTH LAT=	-25.90	DEG	EAST LONG.=	27.70	DEG	MIN ELEV=	5.00	DEG
STATION	4	LIMA	NORTH LAT=	-11.80	DEG	EAST LONG.=	282.80	DEG	MIN ELEV=	5.00	DEG
STATION	5	ORRORAL	NORTH LAT=	-35.60	DEG	EAST LONG.=	148.90	DEG	MIN ELEV=	5.00	DEG
STATION	6	QUITO	NORTH LAT=	-.60	DEG	EAST LONG.=	281.40	DEG	MIN ELEV=	5.00	DEG
STATION	7	ST. JOHNS	NORTH LAT=	47.70	DEG	EAST LONG.=	307.30	DEG	MIN ELEV=	5.00	DEG
STATION	8	SANTIAGO	NORTH LAT=	-33.20	DEG	EAST LONG.=	289.30	DEG	MIN ELEV=	5.00	DEG
STATION	9	WINKFIELD	NORTH LAT=	51.50	DEG	EAST LONG.=	359.30	DEG	MIN ELEV=	5.00	DEG

ORBIT ALT= 500.0 KM.
ORBIT INCL= 97.38 DEG.
NODAL LONGITUDE STEP SIZE= 5.00 DEG.
ORBIT PERIOD= 94.62 MINUTES
EARTH RADIUS= 33.3 PERCENT OVER ACTUAL (REFRACTION CORRECTION)

STATION	MAX. ARC RANGE VISIBLE(DEG)	MAX. DIST.KM.
1	19.73	2331.3
2	19.73	2331.3
3	19.73	2331.3
4	19.73	2331.3
5	19.73	2331.3
6	19.73	2331.3
7	19.73	2331.3
8	19.73	2331.3
9	19.73	2331.3

TABLE A3. - TECO TEST CASE - Continued

E.LONG OF ASC. NODE	TIME ABOVE MIN ELEVATION IN MINUTES 1	2	3	4	5	6	7	8	9	MAX	TOTAL
.00	10.22	.00	10.31	.00	.00	.00	.00	.00	10.24	10.31	30.77
5.00	10.35	.00	10.30	.00	.00	.00	.00	.00	10.37	10.37	31.02
10.00	10.37	.00	9.74	.00	.00	.00	.00	.00	10.27	10.37	30.37
15.00	10.28	.00	8.50	.00	.00	.00	.00	.00	9.92	10.28	28.70
20.00	10.08	.00	6.14	.00	.00	.00	.00	.00	9.32	10.08	25.54
25.00	9.75	.00	.00	.00	.00	.00	.00	.00	8.43	9.75	18.18
30.00	9.27	.00	.00	.00	.00	.00	.00	.00	7.17	9.27	16.44
35.00	8.62	.00	.00	.00	.00	.00	.00	.00	5.34	8.62	13.96
40.00	7.77	.00	.00	.00	.00	.00	.00	.00	1.68	7.77	9.45
45.00	6.65	.00	.00	.00	.00	.00	.00	.00	.00	6.65	6.65
50.00	5.08	.00	.00	.00	.00	.00	.00	.00	.00	5.08	5.08
55.00	2.39	.00	.00	.00	.00	.00	.00	.00	.00	2.39	2.39
60.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
65.00	.00	5.13	.00	.00	.00	.00	.00	.00	.00	5.13	5.13
70.00	.00	7.94	.00	.00	.00	.62	.00	.00	.00	7.94	8.56
75.00	.00	9.42	.00	5.83	.00	7.00	.00	.00	.00	9.42	22.26
80.00	.00	10.17	.00	8.48	.00	9.08	2.47	5.58	.00	10.17	35.77
85.00	.00	10.37	.00	9.79	.00	10.09	5.93	8.05	.00	10.37	44.23
90.00	.00	10.04	.00	10.33	.00	10.37	7.74	9.41	.00	10.37	47.90
95.00	.00	9.13	.00	10.25	.00	10.00	8.94	10.14	.00	10.25	48.45
100.00	.00	7.17	.00	9.51	4.23	8.89	9.73	10.37	.00	10.37	50.11
105.00	.00	3.64	.00	7.94	7.30	6.62	10.20	10.17	.00	10.20	45.86
110.00	.00	.00	.00	4.66	8.93	.00	10.37	9.49	.00	10.37	33.46
115.00	.00	.00	.00	.00	9.88	.00	10.26	8.24	.00	10.26	28.37
120.00	.00	.00	.00	.00	10.32	.00	9.84	6.05	.00	10.32	26.20
125.00	.00	.00	.00	.00	10.32	.00	9.06	.00	.00	10.32	19.38
130.00	.00	.00	.00	.00	9.88	.00	7.81	.00	4.26	9.88	21.95
135.00	.00	.00	.00	.00	8.91	.00	5.77	.00	6.52	8.91	21.20
140.00	.00	.00	.00	.00	7.19	.00	.00	.00	7.98	7.98	15.16
145.00	.00	.00	.00	.00	3.72	.00	.00	.00	9.01	9.01	12.73
150.00	.00	.00	.00	.00	.00	.00	.00	.00	9.72	9.72	9.72
155.00	.00	.00	.00	.00	.00	.00	.00	.00	10.16	10.16	10.16
160.00	.00	.00	.00	.00	.00	.00	.00	.00	10.36	10.36	10.36
165.00	.00	.00	.00	.00	.00	.00	.00	.00	10.32	10.32	10.32
170.00	.00	.00	.00	.00	.00	.00	.00	.00	10.02	10.02	10.02
175.00	.00	.00	.00	.00	.00	.00	.00	.00	9.43	9.43	9.43
180.00	4.14	.00	6.21	.00	.00	.00	.00	.00	8.49	8.49	18.84
185.00	6.02	.00	8.51	.00	.00	.00	.00	.00	7.06	8.51	21.58
190.00	7.30	.00	9.73	.00	.00	.00	.00	.00	4.70	9.73	21.73
195.00	8.26	.00	10.29	.00	.00	.00	.00	.00	.00	10.29	18.55
200.00	8.99	.00	10.32	.00	.00	.00	.00	.00	.00	10.32	19.31
205.00	9.54	.00	9.83	.00	.00	.00	.00	.00	.00	9.83	19.37
210.00	9.94	.00	8.72	.00	.00	.00	.00	.00	.00	9.94	18.66
215.00	10.20	.00	6.69	.00	.00	.00	.00	.00	.00	10.20	16.89
220.00	10.34	.00	1.45	.00	.00	.00	.00	.00	.00	10.34	11.80

TABLE A3. - TECO TEST CASE - Concluded

E.LONG OF ASC. NODE	TIME ABOVE MIN ELEVATION IN MINUTES 1	2	3	4	5	6	7	8	9	MAX	TOTAL
225.00	10.37	.00	.00	.00	.00	.00	.00	.00	.00	10.37	10.37
230.00	10.30	.00	.00	.00	.00	.00	.00	.00	.00	10.30	10.30
235.00	10.12	.00	.00	.00	.00	.00	.00	.00	.00	10.12	10.12
240.00	9.86	.00	.00	3.95	.00	4.42	.00	2.36	.00	9.86	20.59
245.00	9.51	.00	.00	7.70	.00	7.92	.00	6.70	.00	9.51	31.83
250.00	9.08	.00	.00	9.41	.00	9.54	.00	8.64	.00	9.54	36.67
255.00	8.59	.00	.00	10.21	.00	10.27	.00	9.74	.00	10.27	38.81
260.00	8.04	4.39	.00	10.35	.00	10.31	.00	10.28	.00	10.35	43.37
265.00	7.45	7.65	.00	9.85	.00	9.69	.00	10.34	.00	10.34	44.98
270.00	6.84	9.27	.00	8.58	.00	8.23	.00	9.94	.00	9.94	42.86
275.00	6.23	10.11	.00	6.01	.00	5.20	.00	9.00	.00	10.11	36.55
280.00	5.65	10.37	.00	.00	.00	.00	.00	7.28	.00	10.37	23.31
285.00	5.17	10.12	.00	.00	.00	.00	3.99	3.79	.00	10.12	23.06
290.00	4.81	9.31	.00	.00	.00	9.36	6.84	.00	.00	9.36	30.33
295.00	4.65	7.76	.00	.00	.00	7.57	8.44	.00	.00	8.44	28.42
300.00	4.70	4.78	.00	.00	6.03	3.47	9.45	.00	.00	9.45	28.42
305.00	4.96	.00	.00	.00	8.24	.00	10.06	.00	.00	10.06	23.25
310.00	5.38	.00	.00	.00	9.49	.00	10.34	.00	.00	10.34	25.21
315.00	5.92	.00	.00	.00	10.16	.00	10.33	.00	.00	10.33	26.41
320.00	6.51	.00	.00	.00	10.37	.00	10.04	.00	.00	10.37	26.93
325.00	7.13	.00	.00	.00	10.17	.00	9.45	.00	.00	10.17	26.75
330.00	7.74	.00	.00	.00	9.53	.00	8.51	.00	.00	9.53	25.78
335.00	8.31	.00	.00	.00	8.35	.00	7.12	.00	3.43	8.35	27.21
340.00	8.84	.00	.00	.00	6.35	.00	4.93	.00	6.41	8.84	26.53
345.00	9.30	.00	6.37	.00	1.61	.00	.00	.00	8.07	9.30	25.35
350.00	9.69	.00	8.59	.00	.00	.00	.00	.00	9.15	9.69	27.43
355.00	10.00	.00	9.78	.00	.00	.00	.00	.00	9.84	10.00	29.62
360.00	10.22	.00	10.31	.00	.00	.00	.00	.00	10.24	10.31	30.77
365.00	10.35	.00	10.30	.00	.00	.00	.00	.00	10.37	10.37	31.02
AVERAGES	5.28	1.99	2.05	1.80	2.18	2.01	2.67	2.10	3.08	9.27	23.15

THE CLOCK SEZ 40702 AT FILTER LOAD TIME.

NM	indicator which specifies that NAME card has been read (if NM> 2)
NST	number of stations in current case (maximum 15)
K	line counter for page output

Floating-point single variables.--

ENM	alphanumeric characters NAME
EBT	alphanumeric characters ORBT
ESP	alphanumeric characters STOP
EBTE	alphanumeric characters ORBT (zero in place of letter O; used in case of erroneous punch)
ESPE	alphanumeric characters STOP (zero in place of letter O; used in case of erroneous punch)
HMX	alphanumeric characters MAX
HSM	alphanumeric characters TOTAL
BLANK	five blank alphanumeric characters
DTR	degrees-to-radian conversion
RTD	radian-to-degrees conversion
PI2	0.5 times PI
PI	3.141592652
CRT	earth rotation rate, radians/minute
ALAB	alphanumeric indicator variable read from card (should be equal to ENM, EBT, or ESP
H	orbit altitude, n. mi. or km
AI	orbit inclination
DFEE	nodal longitude step size
ELEV	minimum elevation angle applicable to all stations
UNIT	indicator which specifies units of distance (n. mi. if blank, km otherwise)

CORR	fractional increase in earth radius for refraction correction
RE	actual earth radius, n. mi. or km
REC	RE · (1.0 + CORR)
HY	y-component of orbit normal
HZ	z-component of orbit normal
P	orbit period, minutes
SEMP	temporary variable used in computing maximum geocentric angle to spacecraft
TSTLA	temporary variable used in writing station latitudes, deg
TSTLO	temporary variable used in writing station longitudes, deg
TEL	temporary variable used in writing minimum elevations, deg
TAI	temporary variable used in writing orbit inclination, deg
TDFE	temporary variable used in writing nodal longitude, step-size, deg
DIST	maximum slant-range to satellite, n. mi or km
TSM	temporary variable used in writing maximum geocentric angle to satellite, deg
FEE	actual ascending node longitude, radians
CTR	counter to keep track of number of nodal longitude cases computed
SX	x-coordinate of station
SY	y-coordinate of station
SZ	z-coordinate of station
HDTS	$\hat{h} \cdot \hat{s}$ = cosine of geocentric-station-vector/orbit-normal angle
TX	x-component of projection of station-vector on orbit plane at ascending node

TY	y-component of projection of station-vector on orbit plane at ascending node
TZ	z-component of projection of station-vector on orbit plane at ascending node
TM	magnitude of station vector projection on orbit plane
TX1	TX/TM
THP	in-orbit angle from ascending node to projection of station vector on orbit plane
TAU	time from ascending node to projection of station vector in orbit plane
FEEC	orbit ascending node, corrected for earth/orbit plane rotation during time TAU
SA	minimum geocentric angle to satellite for current nodal longitude case, radians
TEM	in-orbit incremental angle within station visibility, radians
TMAX	maximum single-station visibility time for current nodal longitude case
SUMT	total of visibility times for all stations for current nodal longitude case
TFEE	temporary variable for writing nodal longitude, deg

Arrays.--

TTL(20)	alphanumeric title information for output header
STA1(15)	first four alphanumeric characters of station name
STA2(15)	second four alphanumeric characters of station name
STA3(15)	third four alphanumeric characters of station name
STLA(15)	station latitude
STLO(15)	station longitude
EL(15)	minimum elevation angle at station or minimum elevation angle supplied by orbit data card, whichever is greater

C(15)	cosine of station latitude
S(15)	sine of station latitude
CE(15)	CE(I) = cosine of EL(I)
SM(15)	maximum geocentric angle to satellite, radians
HDR(15)	alphanumeric data for output column headers
T(15)	visibility time at station for current nodal longitude case
EL2(15)	minimum elevation angle for particular station, currently not used
AVG(17)	average visibility time for station, max., or total
UN(2)	alphanumeric constants, n. mi., and km
RET(2)	earth radius values, 3443.9 and 6378.2

Program Listing

See Table A4

PROGRAM SICO

Purpose

SICO computes the time sequence of ground station passes for up to 30 ground stations, including time of acquisition, visibility time, time since last contact of a station, and last ascending node longitudes for each of several typical days in the long-life mission of a satellite in a circular orbit. By generating virtually all possible daily nodal sequences, the output gives a good indication of what can be expected during the lifetime of such a mission.

Method

SICO (SImulated COverage) makes use of the same basic computational model as TECO. However, the output format is greatly different, and consequently the data must be edited and sorted prior to output. After each orbit (ascending-node to ascending-node), a list of stations visible during that orbit is generated and sorted into chronological order. The times of contact, station names, visibility times, times since last contact, and east longitude of the last ascending-node are then printed out. Time remaining to end-of-orbit is stored for the computation of the "time-since-last-contact" for the first station visible on the next orbit. Each succeeding orbit is contiguous, i.e.,

TABLE A4. - AUTOMATH 1800 SOURCE PROGRAM LISTING - TECO

```
                                    AUTOMATH  1800  SOURCE  PROGRAM  LISTING

IFN          EFN              PROGRAM:  TECO                    JOB:    BALTES

0001              DIMENSION TTL(20),STA1(15),STA2(15),STA3(15),STLA(15),STLO(15),
                 1 EL(15),C(15),S(15),CE(15),SM(15),HDR(15),T(15),EL2(15),AVG(17)
0002              DIMENSION UN(2),RET(2)
0003           30 FORMAT(A4)
0004           31 FORMAT(1H1,37H ILLEGAL OR MISSING DATA HEADER CARD  )
0005           32 FORMAT (20A4)
0006           33 FORMAT (I2)
0007           35 FORMAT (3A4,4X,3E8.1)
0010           37 FORMAT (1H1,33H NO NAME CARD PRIOR TO ORBT CARD )
0011           38 FORMAT(4F8.1,A5,3X,E8.1)
0012           42 FORMAT(1H1,40X,23H* * *   T E C O   * * * //10X,20A4///)
0013           44 FORMAT ( 8H STATION ,I3,2X,3A4,13H   NORTH LAT= ,F6.2,6H DEG   .
                 1 11HEAST LONG.= ,F7.2,6H DEG  ,9HMIN ELEV= ,F6.2, 4H DEG )
0014           45 FORMAT (// 11H ORBIT ALT= , F8.1,1X,A5   /12H ORBIT INCL= ,F7.2,
                 1  5H DEG./ 27H NODAL LONGITUDE STEP SIZE= ,F6.2, 5H DEG./14H ORBIT
                 2 PERIOD=  ,F8.2,8H MINUTES/14H EARTH RADIUS= ,2PF5.1,44H PERCENT O
                 3VER ACTUAL (REFRACTION CORRECTION)  // )
0015           46 FORMAT( 52H STATION   MAX. ARC RANGE VISIBLE(DEG)    MAX. DIST, ,
                 1  A5 / )
0016           48 FORMAT(3X,I2,14X,F7.2,19X,F8.1)
0017           49 FORMAT (1H1,50H E.LONG OF      TIME ABOVE MIN ELEVATION IN MINUTES
                 1  /10H ASC. NODE , 4X, 17A6    )
0020           55 FORMAT ( F9.2,4X,17F6.2 )
0021           62 FORMAT (//9H AVERAGES , 4X, 17F6.2)
0022           64 FORMAT (1H0)
0023              DATA (HDR(J),J = 1,15) / 6H   1  ,6H   2  ,6H   3  ,6H   4  ,6H
                 15  ,6H   6  ,6H   7  ,6H   8  ,6H   9  ,6H   10 ,6H   11 ,6H   12
                 2,6H   13 ,6H   14 ,6H   15  /
0024              ENM = 4HNAME
0025              EBT = 4HORBT
0026              ESP = 4HSTOP
0027              EBTE = 4HORBT
0030              ESPE = 4HSTOP
0031              HMX = 6H MAX
0032              HSM = 6H TOTAL
0033              UN(1) = 5HN.MI.
0034              UN(2) = 5HKM.
0035              RET(1) = 3443.9
0036              RET(2) = 6378.2
0037              BLANK = 5H
0040              NM = 0
0041              DTR = 0.0174532925
0042              RTD = 57.2957795
0043              PI2 =1.570796326
0044              PI = 3.141592652
0045              CRT = 4.3752639E-3
0046           15 READ(5,30) ALAB
0047              IF(ALAB .EQ. ENM) GO TO 10
0050              IF(ALAB .EQ. EBT .OR. ALAB .EQ. EBTE) GO TO 11
0051              IF(ALAB .EQ. ESP .OR. ALAB .EQ. ESPE) GO TO 1
0052              WRITE(9,31)
```

TABLE A4. - AUTOMATH 1800 SOURCE PROGRAM LISTING - TECO - Continued

```
                                    AUTOMATH  1800  SOURCE  PROGRAM  LISTING

IFN          FFN              PROGRAM:  TECO                    JOB:    BALTES

0053          13 STOP 13
0054           1 STOP 1
0055          10 NM = 99
0056             READ (5,32)(TTL(I),I = 1,20)
0057             READ (5,33) NST
0060             DO 34 I = 1,NST
0061             READ (5,35)  STA1(I),STA2(I),STA3(I),STLA(I),STLO(I),EL(I)
0062             STLA(I) = STLA(I) * DTR
0063             STLO(I) = STLO(I) * DTR
0064             EL(I) = EL(I) * DTR
0065             C(I) = COS(STLA(I))
0066             EL2(I) = EL(I)
0067             S(I) = SIN(STLA(I))
0070             CE(I) = COS(EL(I))
0071          34 CONTINUE
0072             GO TO 15
0073          11 IF (NM .GT. 2) GO TO 36
0074             WRITE (9,37)
0075             GO TO 13
0076          36 READ(5,38) H,AI,DFEE,ELEV,UNIT,CORR
0077             IUNIT = 2
0100             IF (UNIT .EQ. BLANK) IUNIT = 1
0101             RE = RET(IUNIT)
0102             REC = RE * (1.0 + CORR)
0103             AI = AI * DTR
0104             DFEE = DFEE * DTR
0105             ELEV = ELEV * DTR
0106             HY = -SIN(AI)
0107             HZ = COS(AI)
0110             DO 40 I=1,NST
0111             EL(I) = EL2(I)
0112             IF (ELEV .LE. EL(I)) GO TO 40
0113             EL(I) = ELEV
0114             CE(I) = COS(ELEV)
0115          40 CONTINUE
0116          39 P =84.49*(((H+RE)/RE) ** 1.5)
0117             DO 41 I = 1,NST
0120             SEMP = REC * CE(I)/ (REC + H)
0121             SEMP = SEMP / SQRT(1. - SEMP * SEMP)
0122             SEMP = ATAN (SEMP)
0123             SM(I) = PI2 - EL(I) - SEMP
0124             SM(I) = SM(I) * (1.0 + CORR)
0125          41 CONTINUE
0126             WRITE (9,42)(TTL(I), I =1,20)
0127             DO 43 I = 1,NST
0130             TSTLA = RTD * STLA(I)
0131             TSTLO = RTD * STLO(I)
0132             TEL = RTD * EL(I)
0133             WRITE (9,44) I,STA1(I),STA2(I),STA3(I),TSTLA,TSTLO,TEL
0134          43 CONTINUE
0135             TAI = AI * RTD
```

TABLE A4. - AUTOMATH 1800 SOURCE PROGRAM LISTING - TECO - Continued

```
                                    AUTOMATH  1800  SOURCE  PROGRAM  LISTING

IFN          FFN              PROGRAM:  TECO                    JOB:    BALTES

0136              TDFE = DFEE * RTD
0137              WRITE (9,45) H,UN(IUNIT),TAI,TDFE,P,CORR
0140              WRITE (9,46) UN(IUNIT)
0141              DO 47 I = 1,NST
0142              DIST = SIN(SM(I)) * (RE+H) / SIN(PI2+EL(I))
0143              TSM = SM(I) * RTD
0144              WRITE (9,48) I,TSM,DIST
0145           47 CONTINUE
0146              FEE = 0.0
0147              CTR = 1.0
0150              DO 60 I = 1,17
0151           60 AVG(I) = 0.0
0152            3 WRITE(9,49) (HDR(J),J = 1,NST),HMX,HSM
0153              WRITE (9,64)
0154              K = 1
0155            4 DO 50 I = 1,NST
0156              SX = C(I) * COS(STLO(I) -FEE)
0157              SY = C(I) * SIN(STLO(I) -FEE)
0160              SZ = S(I)
0161              HDTS = SY*HY + SZ*HZ
0162              TX = SX
0163              TY = SY - HY*HDTS
0164              TZ = SZ - HZ*HDTS
0165              TM = SQRT(TX*TX + TY*TY + TZ*TZ)
0166              TX1 = TX/TM
0167              THP =0.0
0170              IF (ABS(TX1) .GT. 0.000001) THP = ATAN(SQRT(1.-TX1*TX1)/TX1)
0171              IF (THP .GE. 0.0) GO TO 51
0172              IF (TZ .GE. 0.0) GO TO 52
0173              THP = PI - THP
0174              GO TO 53
0175           52 THP = PI + THP
0176              GO TO 53
0177           51 IF (TZ .LT. 0.0) THP = 2.0 * PI - THP
0200           53 TAU = P * THP /(2.0 * PI)
0201              FEEC = FEE + CRT * TAU
0202              SX = C(I) * COS(STLO(I) - FEEC)
0203              SY = C(I) * SIN(STLO(I) - FEEC)
0204              HDTS= SY*HY + SZ*HZ
0205              SA = PI2
0206              IF (ABS(HDTS) .LT. 0.999999) SA=ATAN(ABS(HDTS)/SQRT(1.-HDTS*HDTS))
0207              T(I) = 0.0
0210              IF (SA .GE. SM(I)) GO TO 50
0211              TEM = COS(SM(I)) / COS(SA)
0212              TEM = ATAN(SQRT(1.0 - TEM*TEM)/TEM)
0213              T(I) = P * TEM / PI
0214           50 CONTINUE
0215              TMAX= T(1)
0216              SUMT = T(1)
0217              DO 54 I = 2,NST
0220              IF(T(I) .GT. TMAX)TMAX= T(I)
```

TABLE A4. - AUTOMATH 1800 SOURCE PROGRAM LISTING - TECO - Concluded

```
                                    AUTOMATH  1800  SOURCE  PROGRAM  LISTING
IFN          FFN              PROGRAM:  TECO                    JOB:    BALTES

0221              SUMT = SUMT + T(I)
0222           54 CONTINUE
0223              TFEE = FEE * RTD
0224              WRITE (9,55) TFEE, (T(I) , I = 1,NST), TMAX, SUMT
0225              K = K + 1
0226              IF (FEE .GE.(2.0*PI)) GO TO 80
0227              DO 61 I = 1,NST
0230           61 AVG(I) = AVG(I) + T(I)
0231              AVG(16) = AVG(16) + TMAX
0232              AVG(17) = AVG(17) + SUMT
0233              CTR = CTR + 1.0
0234              FEE = FEE + DFEE
0235              IF ( K .GT. 45 ) GO TO 3
0236              GO TO 4
0237           80 DO 63 I = 1,17
0240           63 AVG(I) = AVG(I)/CTR
0241              WRITE (9,62) (AVG(I),I=1,NST),AVG(16),AVG(17)
0242              GO TO 15
0243              END
```

ascending nodes are spaced as they would actually occur for the given orbit. Allowance is made for earth rotation and for precession of the node due to earth oblateness in the form:

$$\Delta\Omega = -9.9958 \cos(i) \; (1 + h/R_E)^{-3.5} \; \Delta t \text{ deg} \qquad \text{(A12)}$$

where
i = orbit inclination
h = orbit altitude
R_E = earth radius (actual)
Δt = time increment involved (in days)

Computation starts with the ascending node at 0 degree longitude and proceeds through a time period of one day plus one orbit period, completing the first output table. The program is then re-initiated at a longitude slightly east of 0°, corresponding to the input parameter "nodal longitude step size" and another table is generated. Another increment in initial longitude is taken, another table generated, etc., until the initial longitude reaches a value greater than the difference in successive ascending node longitudes. The tables thus generated represent the variety of possible "orbiting days" which may occur in actual practice to the resolution given by the nodel longitude step size used. Over a long period of time, the coverage profiles corresponding to each table will become equally likely or equally "typical". Estimates of the probability of occurrence of "holes" can thus be based on the relative occurrence of tables corresponding to these holes, recognizing that this is only approximate.

Input

The sequence of input cards for SICO is identical to that of TECO. One additional parameter can be used; minimum visibility time in minutes, punched in columns 49-56 of the orbit data card (with decimal). This parameter has the effect of deleting any station passes which, although exceeding minimum elevation angle, do so for less than the specified minimum time. Also, up to 30 stations, rather than 15 as with TECO, can be handled by SICO.

The "nodal longitude step size" parameter controls the number of output "typical day" tables. In practice, this parameter should be kept down to one degree or less for best resolutions. A one degree step results in about 22 or 23 output tables for a typical orbit.

Output

Table A5 shows the first three pages of a typical SICO output. The first page essentially lists the input data plus some auxiliary parameters. The second, third, etc., pages are "orbit day" outputs, each for a specific initial ascending node longitude. The first column gives the time past the <u>initial</u> ascending

TABLE A5. - POLAR ORBIT STADAN COVERAGE

* * * S I C O * * *

POLAR ORBIT STADAN COVERAGE

		NORTH LAT. DEG	EAST LONG. DEG	MIN ELEV. DEG
STATION 1	COLLEGE	64.90	212.10	5.00
STATION 2	ROSMAN	35.20	277.10	5.00
STATION 3	FT. MYERS	26.50	278.10	5.00
STATION 4	JOHANNESBURG	-25.90	27.70	5.00
STATION 5	LIMA	-11.80	282.80	5.00
STATION 6	ORRORAL	-35.60	148.90	5.00
STATION 7	QUITO	-.60	281.40	5.00
STATION 8	ST. JOHNS	47.70	307.30	5.00
STATION 9	SANTIAGO	-33.20	289.30	5.00
STATION 10	WINKFIELD	51.50	359.30	5.00

ORBIT ALT= 500.0 KM.
ORBIT INCL= 90.00 DEG.
NODAL LONGITUDE STEP SIZE= 1.00 DEG.
ORBIT PERIOD= 94.62 MINUTES
EARTH RADIUS= 33.3 PERCENT OVER ACTUAL (REFRACTION CORRECTION)
MINIMUM TIME= 3.00 MIN
WESTWARD SHIFT OF ASC. NODE= 23.72 DEG./ORBIT

STATION	MAX. ARC RANGE VISIBLE(DEG)	MAX. DIST.KM.
1	19.73	2331.1
2	19.73	2331.1
3	19.73	2331.1
4	19.73	2331.1
5	19.73	2331.1
6	19.73	2331.1
7	19.73	2331.1
8	19.73	2331.1
9	19.73	2331.1
10	19.73	2331.1

TABLE A5. - POLAR ORBIT STADAN COVERAGE - Continued

LONGITUDE.ASC. NODE (TIME=0) = .00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.37	WINKFIELD	10.34		.00
26.14	COLLEGE	6.41	7.44	
53.96	ORRORAL	7.66	21.42	
105.43	ST. JOHNS	5.44	43.80	-23.72
105.74	WINKFIELD	6.03	.00	
146.36	ORRORAL	9.97	34.59	
196.63	ST. JOHNS	10.35	40.30	-47.44
269.36	SANTIAGO	10.34	62.39	
275.41	LIMA	9.76	.00	
278.86	QUITO	9.62	.00	
286.17	FT. MYERS	9.51	.00	-71.16
288.46	ROSMAN	9.59	.00	
293.20	ST. JOHNS	7.16	.00	
367.74	SANTIAGO	4.00	67.38	
372.48	LIMA	5.75	.73	
375.32	QUITO	5.98	.00	
381.70	FT. MYERS	7.79	.40	-94.88
383.67	ROSMAN	8.42	.00	
396.09	COLLEGE	3.79	4.00	
486.45	COLLEGE	8.91	86.56	-118.60
526.07	JOHANNESBURG	4.57	30.71	
579.60	COLLEGE	10.37	48.97	-142.31
597.80	WINKFIELD	3.90	7.83	
616.79	JOHANNESBURG	10.24	15.09	
675.08	COLLEGE	9.18	48.05	-166.03
690.76	WINKFIELD	10.18	6.51	
773.33	COLLEGE	4.41	72.39	-189.75
786.25	WINKFIELD	8.74	8.51	
836.50	ORRORAL	10.37	41.51	
881.05	ST. JOHNS	9.70	34.18	-213.47
907.70	SANTIAGO	3.04	16.96	
976.27	ST. JOHNS	9.31	65.52	-237.19
979.61	ROSMAN	7.73	.00	
982.02	FT. MYERS	7.80	.00	
989.08	QUITO	9.13	.00	
991.93	LIMA	9.69	.00	
997.22	SANTIAGO	10.37	.00	
1073.91	ROSMAN	9.87	66.32	-260.91
1076.39	FT. MYERS	9.48	.00	
1084.62	QUITO	7.27	.00	
1088.13	LIMA	6.16	.00	
1160.45	COLLEGE	7.13	66.16	-284.63
1254.92	COLLEGE	10.04	87.35	-308.35
1312.12	JOHANNESBURG	10.33	47.17	
1335.79	WINKFIELD	6.66	13.34	-332.07
1349.85	COLLEGE	10.05	7.40	
1427.64	WINKFIELD	10.36	67.74	-355.79
1445.18	COLLEGE	7.28	7.18	
1474.62	ORRORAL	5.58	22.16	
1524.03	WINKFIELD	7.56	43.83	-379.50
1565.53	ORRORAL	10.31	33.94	

TABLE A5. - POLAR ORBIT STADAN COVERAGE - Concluded

LONGITUDE,ASC. NODE (TIME=0) = 1.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.36	WINKFIELD	10.36		1.00
26.08	COLLEGE	6.63	7.37	
54.24	ORRORAL	7.26	21.53	
105.80	ST. JOHNS	4.85	44.29	-22.72
105.48	WINKFIELD	6.45	.00	
146.32	ORRORAL	10.08	34.39	
196.66	ST. JOHNS	10.32	40.26	-46.44
269.33	SANTIAGO	10.30	62.35	
275.48	LIMA	9.56	.00	
278.97	QUITO	9.40	.00	
286.30	FT. MYERS	9.29	.00	-70.16
288.58	ROSMAN	9.40	.00	
292.99	ST. JOHNS	7.51	.00	
367.28	SANTIAGO	4.93	66.78	
372.11	LIMA	6.47	.00	
374.97	QUITO	6.67	.00	
381.48	FT. MYERS	8.18	.00	-93.88
383.50	ROSMAN	8.71	.00	
396.40	COLLEGE	3.37	4.19	
486.56	COLLEGE	8.78	86.80	-117.60
526.71	JOHANNESBURG	3.44	31.36	
579.62	COLLEGE	10.36	49.47	-141.31
598.15	WINKFIELD	3.02	8.17	
616.78	JOHANNESBURG	10.30	15.61	
674.99	COLLEGE	9.29	47.91	-165.03
690.76	WINKFIELD	10.11	6.48	
773.09	COLLEGE	4.76	72.22	-188.75
786.17	WINKFIELD	8.93	8.33	
836.45	ORRORAL	10.36	41.35	
881.07	ST. JOHNS	9.56	34.26	-212.47
934.85	ORRORAL	3.92	44.22	
976.19	ST. JOHNS	9.47	37.42	-236.19
979.76	ROSMAN	7.32	.00	
982.20	FT. MYERS	7.35	.00	
989.24	QUITO	8.83	.00	
992.06	LIMA	9.48	.00	
997.25	SANTIAGO	10.37	.00	
1073.84	ROSMAN	10.00	66.22	-259.91
1076.29	FT. MYERS	9.67	.00	
1084.37	QUITO	7.78	.00	
1087.80	LIMA	6.81	.00	
1160.48	COLLEGE	6.92	65.87	-283.63
1254.91	COLLEGE	9.98	87.52	-307.35
1312.10	JOHANNESBURG	10.27	47.21	
1336.05	WINKFIELD	6.27	13.68	-331.07
1349.83	COLLEGE	10.10	7.51	
1410.69	JOHANNESBURG	3.51	50.76	
1427.66	WINKFIELD	10.34	13.46	-354.79
1445.14	COLLEGE	7.47	7.13	
1475.07	ORRORAL	4.86	22.47	
1523.85	WINKFIELD	7.84	43.91	-378.50
1565.54	ORRORAL	10.35	33.85	

node to station acquisition (station "rise") in minutes, the second column gives the station name, the third column gives the time for "rise" to "set" (at minimum elevation) in minutes, the fourth column gives the elapsed time since "set" at the previous station to "rise" at the current station in minutes, and the fifth column gives the east longitude of the last ascending node (negative values correspond to west longitude). Only passes which exceed the minimum time specified are considered. Note that each output table covers slightly more than one day; the time period is one day plus one orbit period.

Computer Requirements

1. Compiler language: Fortran IV
2. Memory requirement: 2245 words
3. Tape Units: common input 5
   common output 9
4. Subroutines: none
5. Library:

ALOG	logarithm to the base e
EXP	exponential
COS	cosine
SIN	sine
SQRT	square root
ATAN	arctangent
ABS	absolute value

Definition of Variables

a. Fixed-point single variables

NM	indicator which specifies that NAME card has been read (if NM > 2)
I	loop counter
NST	number of stations in current case (maximum 30)
IUNIT	indicator which specifies units for distance (IUNIT = 1 implies n. mi., IUNIT = 2 imples km)
INIT	flag which indicates whether first station pass of current day has been printed (if INIT < 0) (used to suppress "MINUTES SINCE LAST CONTACT" on first pass)
NVS	number of stations visible for more than minimum visibility time on current nodal longitude case

I1	loop counter
K1	loop counter
K2	index variable
K4	index variable
I2	index variable
K5	index variable

b. Floating-point single variables

ENM	alphanumeric characters NAME
EBT	alphanumeric characters ORBT
ESP	alphanumeric characters STOP
EBTE	alphanumeric characters ORBT (zero in place of letter O; used in case of erroneous punch)
ESPE	alphanumeric characters STOP (zero in place of letter O; used in case of erroneous punch)
HMX	alphanumeric characters MAX
HSM	alphanumeric characters TOTAL
BLANK	Five blank alphanumeric characters
DTR	degrees-to-radian conversion
RTD	radian-to-degrees conversion
PI2	0.5 times PI
PI	3.141592652
CRT	earth rotation rate, radians/minute
ALAB	alphanumeric indicator variable read from card (should be equal to ENM, EBT, or ESP)
H	orbit altitude, n. mi. <u>or</u> km
AI	orbit inclination
DFEE	nodal longitude step size

ELEV	minimum elevation angle applicable to all stations
UNIT	indicator which specifies units of distance (n. mi. if blank, km otherwise)
CORR	fractional increase in earth radius for refraction correction
TMIN	minimum allowable visibility time, minutes
RE	actual earth radius, n. mi. <u>or</u> km
REC	RE · (1.0 + CORR)
HY	y-component of orbit normal
HZ	z-component of orbit normal
P	orbit period, minutes
ODOT	eastward nodal orbit precession, radians/minute
DFEL	eastward shift of ascending node in one orbit period, radians (DEFL is always negative)
DFELD	DFEL · RTD
SEMP	temporary variable used in computing maximum geocentric angle to spacecraft
TSTLA	temporary variable used in writing station latitude, deg
TSTLO	temporary variable used in writing station longitude, deg
TEL	temporary variable used in writing minimum elevation, deg
TDFE	temporary variable used in writing nodal longitude step size, deg
DIST	maximum slant-range to satellite, n. mi. or km
TSM	temporary variable used in writing maximum geocentric angle to satellite, deg
BFEE	ascending node longitude at start of "orbiting day"
BFEED	BFEE · RTD
FEE	ascending node longitude at nodal crossing for current orbit, radians

FEED	FEE · RTD
TIME	time from start of "orbiting day" to ascending node crossing of current orbit, minutes
TLAG	time from "set" at last station prior to current ascending node to time of current ascending node
SX	x-coordinate of station
SY	y-coordinate of station
SZ	z-coordinate of station
HDTS	$\hat{h} \cdot \hat{s}$ = cosine of geocentric station vector/orbit-normal angle
TX	x-component of projection of station vector on orbit plane at ascending node
TY	y-component of projection of station vector on orbit plane at ascending node
TZ	z-component of projection of station vector on orbit plane at ascending node
TM	magnitude of station vector projection on orbit plane
TX1	TX/TM
THP	in-orbit angle from ascending node to projection of station vector on orbit plane
FEEC	orbit ascending node, corrected for earth/orbit plane rotation during time from ascending node to station passage.
SA	minimum geocentric angle to satellite for current nodal longitude case, radians
TEM	in-orbit incremental angle within station visibility, radians
SSF	variable used as standard for comparison in sorting station passes
STD	variable used as standard for comparison in sorting station passes
TIMP	station acquisition time from beginning of day, minutes
TDL	time since last contact, minutes

Arrays. --

TTL (20)	alphanumeric title information for output header
STA1 (30)	first four alphanumeric characters of station name
STA2 (30)	second four alphanumeric characters of station name
STA3 (30)	third four alphanumeric characters of station name
STLA (30)	station latitude
STLO (30)	station longitude
EL (30)	minimum elevation angle at station <u>or</u> minimum elevation angle supplied by orbit data card, whichever is greater
C (30)	cosine of station latitude
S (30)	sine of station latitude
CE (30)	CE (I) = cosine of EL (I)
SM (30)	maximum geocentric angle to satellite, radians
T (30)	visibility time at station for current nodal longitude case
TAU (30)	in-orbit time from ascending node to closest approach to station
EL2 (30)	minimum elevation angle for particular station, currently not used
JVS (30)	JVS (I) = station number of Ith station contacted on an orbit
K3 (30)	index array used in sorting station passes
UN (2)	alphanumeric constants, n. mi. and km
RET (2)	earth radius values, 3443.9 and 6378.2

Program Listing

See Table A6

TABLE A6. - AUTOMATH 1800 SOURCE PROGRAM LISTING - SICO -

```
                                    AUTOMATH  1800  SOURCE  PROGRAM  LISTING

IFN          EFN              PROGRAM:  SICO                    JOB:    BALTES

0001              DIMENSION TTL(20),STA1(30),STA2(30),STA3(30),STLA(30),STLO(30),
                 1 EL(30),C(30),S(30),CE(30),SM(30),T(30),TAU(30),EL2(30),
                 2 JVS(30),K3(30),UN(2),RET(2)
0002           30 FORMAT(A4)
0003           31 FORMAT(1H1,37H ILLEGAL OR MISSING DATA HEADER CARD  )
0004           32 FORMAT (20A4)
0005           33 FORMAT (I2)
0006           35 FORMAT (3A4,4X,3E8.1)
0007           37 FORMAT (1H1,33H NO NAME CARD PRIOR TO ORBT CARD )
0010           38 FORMAT(4E8.1,A5,3X,2E8.1)
0011           42 FORMAT(1H1,40X,23H* * *   S I C O   * * * // 1X,20A4///34X,
                 1  37HNORTH LAT,   EAST LONG,   MIN ELEV,   /37X,3HDEG,10X,
                 2  3HDEG,9X,3HDEG//)
0012           44 FORMAT (8H STATION ,I3,2X,3A4,9X,F7.2,6X,F7.2,5X,F7.2)
0013           45 FORMAT (// 11H ORBIT ALT= , F8.1,1X,A5   /12H ORBIT INCL= ,F7.2,
                 1  5H DEG./ 27H NODAL LONGITUDE STEP SIZE= ,F6.2, 5H DEG./14H ORBIT
                 2 PERIOD=  ,F8.2,8H MINUTES/14H EARTH RADIUS= ,2PF5.1,44H PERCENT O
                 3VER ACTUAL (REFRACTION CORRECTION) / 14H MINIMUM TIME= ,0PF5.2,
                 4  4H MIN/ 29H WESTWARD SHIFT OF ASC. NODE= ,F7.2,11H DEG./ORBIT//)
0014           46 FORMAT( 52H STATION   MAX. ARC RANGE VISIBLE(DEG)    MAX. DIST, ,
                 1  A5 / )
0015           48 FORMAT(3X,I2,14X,F7.2,19X,F8.1)
0016          105 FORMAT(1H1,36H EAST LONGITUDE,ASC. NODE (TIME=0) =,F7.2,4H DEG//
                 1 19H  TIME,      STATION,4X,38HMINUTES   MINUTES SINCE  LAST ASC.NO
                 2DE/7H   MIN. ,16X,37HIN SIGHT   LAST CONTACT  E.LONG.,DEG. //)
0017          106 FORMAT(F8.2,2X, 3A4, F8.2,6X,F7.2,7X,F8.2)
0020          170 FORMAT(F8.2,2X,3A4, F8.2,20X,F8.2)
0021              ENM = 4HNAME
0022              EBT = 4HORBT
0023              ESP = 4HSTOP
0024              EBTE = 4HORBT
0025              ESPE = 4HSTOP
0026              HMX = 6H MAX
0027              HSM = 6H TOTAL
0030              UN(1) = 5HN.MI.
0031              UN(2) = 5HKM.
0032              RET(1) = 3443.9
0033              RET(2) = 6378.2
0034              BLANK = 5H
0035              NM = 0
0036              DTR = 0.0174532925
0037              RTD = 57.2957795
0040              PI2 =1.570796326
0041              PI = 3.141592652
0042              CRT = 4.3752639E-3
0043           15 READ(5,30) ALAB
0044              IF(ALAB .EQ. ENM) GO TO 10
0045              IF(ALAB .EQ. EBT .OR. ALAB .EQ. EBTE) GO TO 11
0046              IF(ALAB .EQ. ESP .OR. ALAB .EQ. ESPE) GO TO 1
0047              WRITE(9,31)
0050           13 STOP 13
```

TABLE A6. - AUTOMATH 1800 SOURCE PROGRAM LISTING - SICO - Continued

```
                                    AUTOMATH  1800  SOURCE  PROGRAM  LISTING

IFN          EFN            PROGRAM:  SICO                    JOB:    BALTES

0051           1 STOP 1
0052          10 NM = 99
0053             READ (5,32)(TTL(I),I = 1,20)
0054             READ (5,33) NST
0055             DO 34 I = 1,NST
0056             READ (5,35)  STA1(I),STA2(I),STA3(I),STLA(I),STLO(I),EL(I)
0057             STLA(I) = STLA(I) * DTR
0060             STLO(I) = STLO(I) * DTR
0061             EL(I) = EL(I) * DTR
0062             C(I) = COS(STLA(I))
0063             EL2(I) = EL(I)
0064             S(I) = SIN(STLA(I))
0065             CE(I) = COS(EL(I))
0066          34 CONTINUE
0067             GO TO 15
0070          11 IF (NM .GT. 2) GO TO 36
0071             WRITE (9,37)
0072             GO TO 13
0073          36 READ(5,38) H,AI,DFEE,ELEV,UNIT,CORR,TMIN
0074             IUNIT = 2
0075             IF (UNIT .EQ. BLANK) IUNIT = 1
0076             RE = RET(IUNIT)
0077             REC = RE * (1.0 + CORR)
0100             AI = AI * DTR
0101             DFEE = DFEE * DTR
0102             ELEV = ELEV * DTR
0103             HY = -SIN(AI)
0104             HZ = COS(AI)
0105             DO 40 I=1,NST
0106             EL(I) = EL2(I)
0107             IF (ELEV .LE. EL(I)) GO TO 40
0110             EL(I) = ELEV
0111             CE(I) = COS(ELEV)
0112          40 CONTINUE
0113          39 P =84.49*(((H+RE)/RE) ** 1.5)
0114             ODOT =-1.211525E-4 * COS(AI)/(1.0 + H/RE)**3.5
0115             DFEL = P * (ODOT - CRT)
0116             DFELD = -DFEL *RTD
0117             DO 41 I = 1,NST
0120             SEMP = REC * CE(I)/ (REC + H)
0121             SEMP = SEMP / SQRT(1. - SEMP * SEMP)
0122             SEMP = ATAN (SEMP)
0123             SM(I) = PI2 - EL(I) - SEMP
0124             SM(I) = SM(I) * (1.0 + CORR)
0125          41 CONTINUE
0126             WRITE (9,42)(TTL(I), I =1,20)
0127             DO 43 I = 1,NST
0130             TSTLA = RTD * STLA(I)
0131             TSTLO = RTD * STLO(I)
0132             TEL = RTD * EL(I)
0133             WRITE (9,44) I,STA1(I),STA2(I),STA3(I),TSTLA,TSTLO,TEL
```

TABLE A6. - AUTOMATH 1800 SOURCE PROGRAM LISTING - SICO - Continued

```
                                AUTOMATH  1800  SOURCE  PROGRAM  LISTING

IFN        EFN          PROGRAM:  SICO                    JOB:    BALTES

0134          43 CONTINUE
0135             TAI = AI * RTD
0136             TDFE = DFEE * RTD
0137             WRITE(9,45) H,UN(IUNIT),TAI,TDFE,P,CORR,TMIN,DFELD
0140             WRITE (9,46) UN(IUNIT)
0141             DO 47 I = 1,NST
0142             DIST = SIN(SM(I)) * (RE+H) / SIN(PI2+EL(I))
0143             TSM = SM(I) * RTD
0144             WRITE (9,48) I,TSM,DIST
0145          47 CONTINUE
0146             BFEE = 0.0
0147         108 BFEED= BFEE * RTD
0150             WRITE (9,105) BFEED
0151             FEE = BFEE
0152             FEED = BFEED
0153             INIT = 100
0154             TIME = 0.0
0155             TLAG = 0.0
0156           4 DO 50 I = 1,NST
0157             SX = C(I) * COS(STLO(I) -FEE)
0160             SY = C(I) * SIN(STLO(I) -FEE)
0161             SZ = S(I)
0162             HDTS = SY*HY + SZ*HZ
0163             TX = SX
0164             TY = SY - HY*HDTS
0165             TZ = SZ - HZ*HDTS
0166             TM = SQRT(TX*TX + TY*TY + TZ*TZ)
0167             TX1 = TX/TM
0170             THP =0.0
0171             IF (ABS(TX1) .GT. 0.000001) THP = ATAN(SQRT(1.-TX1*TX1)/TX1)
0172             IF (THP .GE. 0.0) GO TO 51
0173             IF (TZ .GE. 0.0) GO TO 52
0174             THP = PI - THP
0175             GO TO 53
0176          52 THP = PI + THP
0177             GO TO 53
0200          51 IF (TZ .LT. 0.0) THP = 2.0 * PI - THP
0201          53 TAU(I) = P * THP /(2.0 * PI)
0202             FEEC = FEE + (ODOT - CRT) * TAU(I)
0203             SX = C(I) * COS(STLO(I) - FEEC)
0204             SY = C(I) * SIN(STLO(I) - FEEC)
0205             HDTS= SY*HY + SZ*HZ
0206             SA = PI2
0207             IF (ABS(HDTS) .LT. 0.999999) SA=ATAN(ABS(HDTS)/SQRT(1.-HDTS*HDTS))
0210             T(I) = 0.0
0211             IF (SA .GE. SM(I)) GO TO 50
0212             TEM = COS(SM(I)) / COS(SA)
0213             TEM = ATAN(SQRT(1.0 - TEM*TEM)/TEM)
0214             T(I) = P * TEM / PI
0215          50 CONTINUE
0216             NVS = 0
```

TABLE A6. - AUTOMATH 1800 SOURCE PROGRAM LISTING - SICO - Concluded

```
                                    AUTOMATH  1800  SOURCE  PROGRAM  LISTING

IFN          EFN            PROGRAM:  SICO                    JOB:    BALTES

0217              DC 100 I = 1,NST
0220              IF (T(I) .LT. (TMIN + 0.00001)) GO TO 100
0221              NVS = NVS + 1
0222              JVS(NVS) = I
0223          100 CONTINUE
0224              IF (NVS .GT. 0) GO TO 101
0225              TLAG = TLAG + P
0226              GC TC 161
0227          101 SSF = -1000.0
0230              DC 120 I1 = 1,NVS
0231              STD = 1000.0
0232              DC 140 K1 = 1,NVS
0233              K2 = JVS(K1)
0234              IF (TAU(K2) .GE. STD) GO TO 140
0235              IF (TAU(K2) .LE. SSF) GO TO 140
0236              STD = TAU(K2)
0237              K3(I1) = K2
0240          140 CONTINUE
0241              SSF = STD + 0.00001
0242          120 CONTINUE
0243              K4 = K3(1)
0244              TIMP = TAU(K4) + TIME - 0.5 * T(K4)
0245              TDL = TAU(K4) + TLAG - 0.5 * T(K4)
0246              IF(TDL .LT. 0.0) TDL = 0.0
0247              IF (INIT .LE. 0) GO TO 180
0250              WRITE (9,170)TIMP,STA1(K4),STA2(K4),STA3(K4),T(K4),FEED
0251              INIT = -100
0252              GC TC 175
0253          180 WRITE(9,106)TIMP,STA1(K4),STA2(K4),STA3(K4),T(K4),TDL,FEED
0254          175 IF (NVS .LE. 1) GO TO 162
0255              DC 160 K1 = 2,NVS
0256              I1 = K3(K1)
0257              I2 = K3(K1-1)
0260              TIMP = TAU(I1) + TIME - 0.5 * T(I1)
0261              TDL = TAU(I1) - TAU(I2) - 0.5 * (T(I1) + T(I2))
0262              IF(TDL .LT. 0.0) TDL = 0.0
0263              WRITE(9,106) TIMP,STA1(I1),STA2(I1),STA3(I1),T(I1),TDL
0264          160 CONTINUE
0265          162 K5 = K3(NVS)
0266              TLAG = P - TAU(K5) - 0.5 * T(K5)
0267          161 FEE = FEE + DFEL
0270              FEED = FEE * RTD
0271              TIME = TIME + P
0272              IF (TIME .LE. (1440.0 + P)) GO TO 4
0273              BFEE = BFEE + DFEE
0274              IF (BFEE .GT. (-DFEL)) GO TO 15
0275              GC TC 108
0276              END
```

PROGRAM PICO

Purpose

PICO generates the time sequence of ground station passes, including time of acquisition, visibility time, time since last contact of a station, and last ascending node longitudes, from orbit injection to a specified cutoff time for a satellite in a circular orbit.

Method

The PICO (Post-Injection Coverage) program is a modification of the SICO program. The major change is in the output and computing sequences. Whereas SICO generates the array of "typical coverage days", PICO generates the continuous sequence which occurs for a reasonably short time just after injection. Because of the nature of orbit nodel drift, very small injection dispersions would tend to invalidate PICO-type data after the first few days of flight. Thus, preflight PICO data is useful for prediction of the first few days of flight, after which the statistical type of data given by SICO must be used to predict coverage.

Input

The sequence of input cards for PICO is the same as for TECO. However, because of the difference in type of data computed, the orbit data card is somewhat different. The format of that card for PICO is as follows:

Columns	1-8	Altitude, n. mi. or km
	9-16	Inclination, deg
	17-24	Launch-to-injection geocentric angle, deg
	25-32	Minimum elevation angle at stations, deg
	33-38	Letters METRIC if altitude is in km, otherwise blank (any characters other than blanks are equivalent to METRIC)
	39-40	+1 if launch is northerly, -1 is southerly
	41-44	Fractional increase in earth radius for refraction correction
	45-48	Minimum acceptable visibility time, minutes
	49-56	East longitude of launch site, deg
	57-64	North latitude of launch site, deg
	65-72	Launch-to-injection time, minutes
	73-80	Launch-to-end time, minutes

(use decimals in all fields except columns 33-38 and 39-40).

PICO will accept up to 30 stations, as does SICO.

Output

Table A7 shows the first two pages of a typical PICO output. The first page essentially lists the input data plus some auxiliary parameters. The second and following pages list the sequence of station passes from injection to the launch-to-end time specified on input. The first column gives the time past launch to station acquisition in minutes, the second column gives the station name, the third column gives the time from "rise" to "set" (at minimum elevation) in minutes, the fourth column gives the elapsed time since "set" at the previous station to "rise" at the current station in minutes, and the fifth column gives the east longitude of the last ascending node (negative values correspond to west longitude). Only passes which exceed the minimum time specified are considered.

Computer Requirements

1. Compiler language: Fortran IV
2. Memory requirement: 2786 words
3. Tape units: common input 5
   common output 9
4. Subroutines: none
5. Library:

ALOG	logarithm to base e
EXP	exponential
COS	cosine
SIN	sine
ABS	absolute value
ASIN	arcsine
SQRT	square root
ATAN	arctangent

Definition of Variables

Fixed-Point Single Variables. --

NM	indicator which specifies that NAME card has been read (if NM > 2)
I	loop counter
NST	number of stations in current cast (maximum 30)

TABLE A7. - PICO TEST CASE

PICO TEST CASE

		NORTH LAT. DEG	EAST LONG. DEG	MIN ELEV. DEG
STATION 1	ALASKA	65.00	212.50	5.00
STATION 2	CARNARVON	-24.50	113.40	5.00
STATION 3	ROSMAN	35.20	277.10	5.00
STATION 4	SANTIAGO	-33.10	289.30	5.00
STATION 5	TANANARIVE	-18.50	47.30	5.00

ORBIT ALT= 500.0 KM.
ORBIT INCL= 97.38 DEG.
LAUNCH-TO-INJECTION ANGLE= 20.00 DEG.
ORBIT PERIOD= 94.62 MINUTES
EARTH RADIUS= 33.0 PERCENT OVER ACTUAL (REFRACTION CORRECTION)
MINIMUM TIME= .00 MIN
WESTWARD SHIFT OF ASC. NODE= 23.65 DEG./ORBIT
LAUNCH LONGITUDE= -120.63 DEG. EAST
LAUNCH LATITUDE= 34.76 DEG. NORTH
LAUNCH VELOCITY HAS SOUTHERLY COMPONENT
LAUNCH TO INJECTION TIME= 10.00 MIN.
TOTAL TIME= 10000.00 MIN.

STATION	MAX. ARC RANGE VISIBLE(DEG)	MAX. DIST.KM.
1	19.71	2329.1
2	19.71	2329.1
3	19.71	2329.1
4	19.71	2329.1
5	19.71	2329.1

TABLE A7. - PICO TEST CASE - Concluded

INJECTION COVERAGE SEQUENCE (INJECTION TIME= 10.00 MIN. AFTER LAUNCH

TIME, MIN.	STATION	MILES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG., DEG.
46.92	TANANARIVE	10.21		63.73
81.91	ALASKA	9.77	24.78	40.08
175.97	ALASKA	10.25	84.29	16.42
270.13	ALASKA	8.68	83.90	-7.23
363.98	ALASKA	6.05	85.18	-30.88
393.41	CARNARVON	5.91	23.37	-30.88
424.75	SANTIAGO	1.41	25.44	-30.88
442.70	ROSMAN	6.07	16.53	-54.54
456.62	ALASKA	4.77	7.85	-54.54
484.11	CARNARVON	10.11	22.73	-54.54
515.91	SANTIAGO	10.36	21.69	-54.54
533.79	ROSMAN	10.29	7.52	-78.19
547.55	ALASKA	6.75	3.46	-78.19
614.37	SANTIAGO	1.97	60.07	-78.19
638.67	ALASKA	9.24	22.34	-101.85
674.37	TANANARIVE	7.42	26.46	-101.85
731.26	ALASKA	10.36	49.47	-125.50
766.48	TANANARIVE	9.53	24.86	-125.50
825.89	ALASKA	9.21	49.89	-149.16
924.05	ALASKA	3.00	88.94	-172.81
1150.44	SANTIAGO	9.19	223.40	130.88
1180.83	CARNARVON	9.71	21.20	139.88
1225.96	ROSMAN	8.26	35.43	116.23
1243.61	SANTIAGO	8.99	9.39	116.23
1276.59	CARNARVON	7.30	23.99	116.23
1319.69	ROSMAN	9.71	35.81	92.57
1408.77	ALASKA	3.37	79.37	68.92
1466.15	TANANARIVE	10.34	54.01	68.92
1501.35	ALASKA	9.29	24.87	45.26
1595.33	ALASKA	10.35	84.70	21.61
1689.50	ALASKA	9.16	83.81	-2.04
1783.46	ALASKA	6.64	84.81	-25.70
1876.49	ALASKA	4.74	86.39	-49.35
1903.53	CARNARVON	10.36	22.29	-49.35
1935.18	SANTIAGO	10.17	21.29	-49.35
1953.24	ROSMAN	10.32	7.89	-73.01
1967.67	ALASKA	6.17	4.11	-73.01
2031.50	SANTIAGO	6.58	57.67	-73.01
2050.07	ROSMAN	5.02	11.99	-96.66
2058.60	ALASKA	8.77	3.52	-96.66
2096.06	TANANARIVE	3.54	28.69	-96.66
2150.81	ALASKA	10.28	51.20	-120.32
2185.61	TANANARIVE	10.24	24.53	-120.32
2244.94	ALASKA	9.71	49.09	-143.97
2341.89	ALASKA	5.46	87.24	-167.62
2570.98	SANTIAGO	7.71	223.63	145.07
2600.62	CARNARVON	8.37	21.93	145.07
2646.27	ROSMAN	5.98	37.28	121.41

IND	indicator specifying northerly (IND > 0) or southerly (IND ≤ 0) launch
IUNIT	indicator which specifies units for distance (IUNIT = 1 implies n. mi., IUNIT = 2 implies km)
NLN	line counter for page output
INIT	flag which indicates whether first station pass of current day has been printed (if INIT < 0) (used to suppress "MINUTES SINCE LAST CONTACT" on first pass)
NVS	number of stations visible for more than minimum visibility time on current nodal longitude case
I1	loop counter
K1	loop counter
K2	index variable
K4	index variable
I2	index variable
K5	index variable

Floating-Point Single Variables. --

ENM	alphanumeric characters NAME
EBT	alphanumeric characters ORBT
ESP	alphanumeric characters STOP
EBTE	alphanumeric characters ORBT (zero in place of letter O; used in case of erroneous punch)
ESPE	alphanumeric characters STOP (zero in place of letter O; used in case of erroneous punch)
HMX	alphanumeric characters MAX
HSM	alphanumeric characters TOTAL
BLANK	five blank alphanumeric characters
ASR	alphanumeric constant SOUTH
ANR	alphanumeric constant NORTH

DTR	degrees-to-radian conversion
RTD	radian-to-degrees conversion
PI2	0.5 times PI
PI	3.141592652
CRT	earth rotation rate, radians/minute
ALAB	alphanumeric indicator variable read from card (should be equal to ENM, EBT, or ESP)
H	orbit altitude, n. mi. or km
AI	orbit inclination
THLBD	launch-to-injection geocentric angle, deg
ELEV	minimum elevation angle applicable to all stations
UNIT	indicator which specifies units of distance (n. mi. if blank, km otherwise)
CORR	fractional increase in earth radius for refraction correction
TMIN	minimum allowable visibility time, minutes
ALOND	east longitude of launch site, deg
ALATD	north latitude of launch site, deg
TLB	launch-to-injection time, minutes
TF	final time, minutes
DIRE	alphanumeric variable used in writing out direction of launch
THLB	launch-to-injection geocentric angle, radians
ALON	east longitude of launch site, radians
ALAT	north latitude of launch site, radians
AEQ	geocentric angle from launch backward to hypothetical previous ascending node, radians
P	orbit period, minutes

ARC	longtiude increment from launch site to hypothetical previous ascending node, radians
FEEL	longitude of ascending node at time of launch
RE	actual earth radius, n. mi. or km
REC	RE · (1.0 + CORR)
HY	y-component of orbit normal
HZ	z-component of orbit normal
ODOT	eastward nodal orbit precession, radians/minute
DFEL	eastward shift of ascending node in one orbit period, radians (DEFL is always negative)
DFELD	DFEL · RTD
SEMP	temporary variable used in computing maximum geocentric angle to spacecraft
TSTLA	temporary variable used in writing station latitude, deg
TSTLO	temporary variable used in writing station longitude, deg
TEL	temporary variable used in writing station minimum elevation, deg
TAI	temporary variable used in writing orbit inclination, deg
DIST	maximum slant-range to satellite, n. mi. or km
TSM	temporary variable used in writing maximum geocentric angle to satellite, deg
BFEE	ascending node longitude at start of "orbiting day"
FEE	ascending node longitude at nodal crossing for current orbit, radians
FEED	FEE · RTD
TIME	time from start of "orbiting day" to ascending node crossing or current orbit, minutes
TLAG	time from "set" at last station prior to current ascending node to time of current ascending node

SX	x-coordinate of station
SY	y-coordinate of station
SZ	z-coordinate of station
HDTS	$\hat{h} \cdot \hat{s}$ = cosine of geocentric station vector/orbit-normal angle
TX	x-component of projection of station vector on orbit plane at ascending node
TY	y-component of projection of station vector on orbit plane at ascending node
TZ	z-component of projection of station vector on orbit plane at ascending node
TM	magnitude of station vector projection on orbit plane
TX1	TX/TM
THP	in-orbit angle from ascending node to projection of station vector on orbit plane
FEEC	orbit ascending node, corrected for earth/orbit plane rotation during time from ascending node to station passage
SA	minimum geocentric angle to satellite for current nodal longitude case, radians
TEM	in-orbit incremental angle within station visibility, radians
SSF	variable used as standard for comparison in sorting station passes
STD	variable used as standard for comparison in sorting station passes
TIMP	station acquisition time from beginning of day, minutes
TDL	time since last contact, minutes

Arrays. --

TTL (20)	alphanumeric title information for output header
STA1 (30)	first four alphanumeric characters of station name
STA2 (30)	second four alphanumeric characters of station name
STA3 (30)	third four alphanumeric characters of station name
STLA (30)	station latitude
STLO (30	station longitude
EL (30)	minimum elevation angle at station or minimum elevation angle supplied by orbit data card, whichever is greater
C (30)	cosine of station latitude
S (30)	sine of station latitude
CE (30)	CE(I) = cosine of EL(I)
SM (30)	maximum geocentric angle to satellite, radians
T (30)	visibility time at station for current nodal longitude case
TAU (30)	in-orbit time from ascending node to closest approach to station
EL2 (30)	minimum elevation angle for particular station, currently not used
JVS (30)	JVS(I) - station number of Ith station contacted on an orbit
K3 (30)	index array used in sorting station passes
UN (2)	alphanumeric constants, n. mi., and km
RET(2)	earth radius values, 3443.9 and 6378.2

Program Listing

See Table A8

TABLE A8. - AUTOMATH 1800 SOURCE PROGRAM LISTING - PICO

```
                                    AUTOMATH  1800  SOURCE  PROGRAM  LISTING

IFN          EFN              PROGRAM:  PICO                    JOB:    BALTES

0001              DIMENSION TTL(20),STA1(30),STA2(30),STA3(30),STLA(30),STLO(30),
                 1 EL(30),C(30),S(30),CE(30),SM(30),T(30),TAU(30),EL2(30),
                 2 JVS(30),K3(30),UN(2),RET(2)
0002           30 FORMAT(A4)
0003           31 FORMAT(1H1,37H ILLEGAL OR MISSING DATA HEADER CARD  )
0004           32 FORMAT (20A4)
0005           33 FORMAT (I2)
0006           35 FORMAT (3A4,4X,3E8.1)
0007           37 FORMAT (1H1,33H NO NAME CARD PRIOR TO ORBT CARD )
0010           38 FORMAT(4E8.1,A5,1X,I2,2F4.1,4E8.1)
0011           42 FORMAT(1H1,40X,23H* * *   P I C O   * * * // 1X,20A4///34X,
                 1  37HNORTH LAT.   EAST LONG,   MIN ELEV,   /37X,3HDEG,10X,
                 2  3HDEG,9X,3HDEG//)
0012           44 FORMAT (8H STATION ,I3,2X,3A4,9X,F7.2,6X,F7.2,5X,F7.2)
0013           45 FORMAT (// 11H ORBIT ALT= , F8.1,1X,A5   /12H ORBIT INCL= ,F7.2,
                 1  5H DEG./ 27H LAUNCH-TO-INJECTION ANGLE= ,F6.2, 5H DEG./14H ORBIT
                 2 PERIOD=  ,F8.2,8H MINUTES/14H EARTH RADIUS= ,2PF5.1,44H PERCENT O
                 3VER ACTUAL (REFRACTION CORRECTION) / 14H MINIMUM TIME= ,0PF5.2,
                 4  4H MIN/ 29H WESTWARD SHIFT OF ASC. NODE= ,F7.2,11H DEG./ORBIT )
0014           46 FORMAT( 52H STATION   MAX. ARC RANGE VISIBLE(DEG)    MAX. DIST, ,
                 1  A5 / )
0015           48 FORMAT(3X,I2,14X,F7.2,19X,F8.1)
0016          105 FORMAT (1H1, 50H POST INJECTION COVERAGE SEQUENCE (INJECTION TIME=
                 1  , F7.2,19H MIN. AFTER LAUNCH)   ///
                 2 19H  TIME,      STATION,4X,38HMINUTES   MINUTES SINCE  LAST ASC.NO
                 3DE/7H   MIN. ,16X,37HIN SIGHT   LAST CONTACT  E.LONG.,DEG. //)
0017          106 FORMAT(F8.2,2X, 3A4, F8.2,6X,F7.2,7X,F8.2)
0020          170 FORMAT(F8.2,2X,3A4,F8.2,20X,F8.2)
0021          182 FORMAT(19H LAUNCH LONGITUDE= ,F7.2,10H DEG. EAST/ 18H LAUNCH LATIT
                 1UDE= ,F7.2,11H DEG. NORTH / 21H LAUNCH VELOCITY HAS , A5, 14HERLY
                 2COMPONENT/ 26H LAUNCH TO INJECTION TIME= , F6.2, 5H MIN./
                 3  12H TOTAL TIME= , F10.2,5H MIN. //)
0022              FNM = 4HNAME
0023              FBT = 4HORBT
0024              FSP = 4HSTOP
0025              FBTF = 4HORBT
0026              FSPF = 4HSTOP
0027              HMX = 6H MAX
0030              HSM = 6H TOTAL
0031              UN(1) = 5HN.MI.
0032              UN(2) = 5HKM.
0033              RET(1) = 3443.9
0034              RET(2) = 6378.2
0035              PLANK = 5H
0036              ASR = 5HSOUTH
0037              ANP = 5HNORTH
0040              NM = 0
0041              DIR = 0.0174532925
0042              RTD = 57.2957795
0043              PI2 =1.570796326
0044              PI = 3.141592652
```

TABLE A8. - AUTOMATH 1800 SOURCE PROGRAM LISTING - PICO - Continued

```
                                    AUTOMATH  1800  SOURCE  PROGRAM  LISTING

IFN          EFN              PROGRAM:  PICO                    JOB:    BALTES

0045              CRT = 4.3752639E-3
0046           15 READ(5,30) ALAB
0047              IF(ALAB .EQ. ENM) GO TO 10
0050              IF(ALAB .EQ. EBT .OR. ALAB .EQ. EBTE) GO TO 11
0051              IF(ALAB .EQ. ESP .OR. ALAB .EQ. ESPE) GO TO 1
0052              WRITE(9,31)
0053           13 STOP 13
0054            1 STOP 1
0055           10 NM = 99
0056              READ (5,32)(TTL(I),I = 1,20)
0057              READ (5,33) NST
0060              DO 34 I = 1,NST
0061              READ (5,35)  STA1(I),STA2(I),STA3(I),STLA(I),STLO(I),EL(I)
0062              STLA(I) = STLA(I) * DTR
0063              STLO(I) = STLO(I) * DTR
0064              EL(I) = EL(I) * DTR
0065              C(I) = COS(STLA(I))
0066              EL2(I) = EL(I)
0067              S(I) = SIN(STLA(I))
0070              CE(I) = COS(EL(I))
0071           34 CONTINUE
0072              GO TO 15
0073           11 IF (NM .GT. 2) GO TO 36
0074              WRITE (9,37)
0075              GO TO 13
0076           36 READ(5,38) H,AI,THLBD,ELEV,UNIT,IND,CORR,TMIN,ALOND,ALATD,TLB,TF
0077              DIRE = ASR
0100              IF (IND.GT. 0) DIRE = ANR
0101              AI = AI * DTR
0102              ELEV = ELEV * DTR
0103              THLB = THLBD * DTR
0104              ALON = ALOND * DTR
0105              ALAT = ALATD * DTR
0106              AEQ = ABS(ASIN(SIN(ALAT)/SIN(AI)))
0107              IF(IND.LT.0) AEQ = PI - AEQ
0110              IF (ALAT.LT. 0.0) AEQ = 2.0 * PI - AEQ
0111              AEQ = AEQ - TLB * 2.0 * PI / P
0112              ARC = ASIN((SIN(ALAT)*COS(AI))/(SIN(AI)*COS(ALAT)))
0113              EEEL = ALON - ARC
0114              IF (IND .LT. 0) EEEL = ALON + ARC - PI
0115              IUNIT = 2
0116              IF (UNIT .EQ. BLANK) IUNIT = 1
0117              RE = RET(IUNIT)
0120              REC = RE * (1.0 + CORR)
0121              HY = -SIN(AI)
0122              HZ = COS(AI)
0123              DO 40 I=1,NST
0124              EL(I) = EL2(I)
0125              IF (ELEV .LE. EL(I)) GO TO 40
0126              EL(I) = ELEV
0127              CE(I) = COS(ELEV)
```

TABLE A8. - AUTOMATH 1800 SOURCE PROGRAM LISTING - PICO - Continued

```
                                    AUTOMATH  1800  SOURCE  PROGRAM  LISTING

IFN          EFN              PROGRAM:  PICO                    JOB:    BALTES

0130          40 CONTINUE
0131          39 P =84.49*(((H+RE)/RE) ** 1.5)
0132             ODOT =-1.211525E-4 * COS(AI)/(1.0 + H/RE)**3.5
0133             DFEL = P * (ODOT - CRT)
0134             DFELD = -DFEL *RTD
0135             DO 41 I = 1,NST
0136             SEMP = REC * CE(I)/ (REC + H)
0137             SEMP = SEMP / SQRT(1. - SEMP * SEMP)
0140             SEMP = ATAN (SEMP)
0141             SM(I) = PI2 - EL(I) - SEMP
0142             SM(I) = SM(I) * (1.0 + CORR)
0143          41 CONTINUE
0144             WRITE (9,42)(TTL(I), I =1,20)
0145             DO 43 I = 1,NST
0146             TSTLA = RTD * STLA(I)
0147             TSTLO = RTD * STLO(I)
0150             TEL = RTD * EL(I)
0151             WRITE (9,44) I,STA1(I),STA2(I),STA3(I),TSTLA,TSTLO,TEL
0152          43 CONTINUE
0153             TAI = AI * RTD
0154             WRITE(9,45) H,UN(IUNIT),TAI,THLBD,P,CORR,TMIN,DFELD
0155             WRITE (9,182) ALOND,ALATD,DIRE,TLB,TF
0156             WRITE (9,46) UN(IUNIT)
0157             DO 47 I = 1,NST
0160             DIST = SIN(SM(I)) * (RE+H) / SIN(PI2+EL(I))
0161             TSM = SM(I) * RTD
0162             WRITE (9,48) I,TSM,DIST
0163          47 CONTINUE
0164             BFEE = FEEL - DFEL * AEQ / (2.0 * PI)
0165         108 BFEED= BFEE * RTD
0166             WRITE (9,105) TLB
0167             NLN = 7
0170             FEE = BFEE
0171         191 IF (FEE .GT. (-PI )) GO TO 190
0172             FEE = FEE + 2.0 * PI
0173             GO TO 191
0174         190 FEED = FEE * RTD
0175             INIT = 100
0176             TIME = -P * AEQ / (2.0 * PI)
0177             TLAG = 0.0
0200           4 DO 50 I = 1,NST
0201             SX = C(I) * COS(STLO(I) -FEE)
0202             SY = C(I) * SIN(STLO(I) -FEE)
0203             SZ = S(I)
0204             HDTS = SY*HY + SZ*HZ
0205             TX = SX
0206             TY = SY - HY*HDTS
0207             TZ = SZ - HZ*HDTS
0210             TM = SQRT(TX*TX + TY*TY + TZ*TZ)
0211             TX1 = TX/TM
0212             THP =0.0
```

TABLE A8. - AUTOMATH 1800 SOURCE PROGRAM LISTING - PICO - Continued

```
                                    AUTOMATH  1800  SOURCE  PROGRAM  LISTING
IFN        EFN              PROGRAM:  PICO                    JOB:    BALTES

C213            IF (ABS(TX1) .GT. 0.000001) THP = ATAN(SQRT(1.-TX1*TX1)/TX1)
C214            IF (THP .GE. 0.0) GO TO 51
C215            IF (TZ .GE. 0.0) GO TO 52
C216            THP = PI - THP
C217            GO TO 53
C220         52 THP = PI + THP
C221            GO TO 53
C222         51 IF (TZ .LT. 0.0) THP = 2.0 * PI - THP
C223         53 TAU(I) = P * THP /(2.0 * PI)
C224            FEFC = FEE + (ODOT - CRT) * TAU(I)
C225            SX = C(I) * COS(STLC(I) - FEFC)
C226            SY = C(I) * SIN(STLC(I) - FEFC)
C227            HDTS= SY*HY + SZ*HZ
C230            SA = PI2
C231            IF (ABS(HDTS) .LT. 0.999999) SA=ATAN(ABS(HDTS)/SQRT(1.-HDTS*HDTS))
C232            T(I) = 0.0
C233            IF (SA .GE. SM(I)) GO TO 50
C234            TEM = COS(SM(I)) / COS(SA)
C235            TEM = ATAN(SQRT(1.0 - TEM*TEM)/TEM)
C236            T(I) = P * TEM / PI
C237         50 CONTINUE
C240            NVS = 0
C241            DO 100 I = 1,NST
C242            IF (T(I) .LT. (TMIN + 0.00001)) GO TO 100
C243            NVS = NVS + 1
C244            JVS(NVS) = I
C245        100 CONTINUE
C246            IF (NVS .GT. 0) GO TO 101
C247            TLAG = TLAG + P
C250            GO TO 161
C251        101 SSF = -1000.0
C252            DO 120 I1 = 1,NVS
C253            STD = 1000.0
C254            DO 140 K1 = 1,NVS
C255            K2 = JVS(K1)
C256            IF (TAU(K2) .GE. STD) GO TO 140
C257            IF (TAU(K2) .LE. SSF) GO TO 140
C260            STD = TAU(K2)
C261            K3(I1) = K2
C262        140 CONTINUE
C263            SSF = STD + 0.00001
C264        120 CONTINUE
C265            K4 = K3(1)
C266            TIMP = TAU(K4) + TIME - 0.5 * T(K4)
C267            IF(TIMP .GT. TF) GO TO 15
C270            IF((TIMP + T(K4)).LT. TLB) GO TO 175
C271            TDL = TAU(K4) + TLAG - 0.5 * T(K4)
C272            IF(TDL .LT. 0.0) TDL = 0.0
C273            IF (INIT .LE. 0) GO TO 205
C274            IF (NLN .LT. 55) GO TO 200
C275            WRITE (9,105) TLB
```

TABLE A8. - AUTOMATH 1800 SOURCE PROGRAM LISTING - PICO - Concluded


```
C276          NLN = 7
C277      200 WRITE (9,170)TIMP,STA1(K4),STA2(K4),STA3(K4),T(K4),FEED
C300          NLN = NLN + 1
C301          INIT = -100
C302          GO TO 175
C303      205 IF (NLN .LT. 55) GO TO 180
C304          WRITE (9,105) TLB
C305          NLN = 7
C306      180 WRITE(9,106)TIMP,STA1(K4),STA2(K4),STA3(K4),T(K4),TDL,FEED
C307          NLN = NLN + 1
C310      175 IF (NVS .LE. 1) GO TO 162
C311          DO 160 K1 = 2,NVS
C312          I1 = K3(K1)
C313          I2 = K3(K1-1)
C314          TIMP = TAU(I1) + TIME - 0.5 * T(I1)
C315          IF (TIMP .GT. TF) GO TO 15
C316          IF (TIMP + T(I1) .LT. TLB) GO TO 160
C317          TDL = TAU(I1) - TAU(I2) - 0.5 * (T(I1) + T(I2))
C320          IF(TDL .LT. 0.0) TDL = 0.0
C321          IF(INIT .LE. 0) GO TO 206
C322          IF (NLN .LT. 55) GO TO 201
C323          WRITE (9,105) TLB
C324          NLN = 7
C325      201 WRITE (9,170)TIMP,STA1(I1),STA2(I1),STA3(I1),T(I1),FEED
C326          NLN = NLN + 1
C327          INIT = -100
C330          GO TO 160
C331      206 IF (NLN .LT. 55) GO TO 198
C332          WRITE (9,105) TLB
C333          NLN = 7
C334      198 WRITE(9,106) TIMP,STA1(I1),STA2(I1),STA3(I1),T(I1),TDL,FEED
C335          NLN = NLN + 1
C336      160 CONTINUE
C337      162 K5 = K3(NVS)
C340          TLAG = P - TAU(K5) - 0.5 * T(K5)
C341      161 FEE = FEE + DFEI
C342      194 IF (FEE .GT. (-PI )) GO TO 195
C343          FEE = FEE + 2.0 * PI
C344          GO TO 194
C345      195 FEED = FEE * RTD
C346          TIME = TIME + P
C347          IF (TIME .LE. TF) GO TO 4
C350          GO TO 15
C351          END
```

APPENDIX B

STADAN TRACKING CAPABILITIES AND SYSTEM DESCRIPTION

APPENDIX B

STADAN TRACKING CAPABILITIES AND SYSTEM DESCRIPTION

This appendix contains general data on the tracking systems at STADAN stations.

There are two satellite tracking schemes available in STADAN. These are the Minitrack and the Range and Range-Rate system. The general characteristics are as follows:

- Minitrack:

Receiving frequency	136-137MHz ±750 Hz 1 KHz steps
Receiver noise figure	3 dB
Minitrack antenna gain	16.3 dB above isotropic
Ambiquity antenna	6.4 dB above isotropic
Tracking accuracy	0.3 milliradian (topocentric)
In-Track error	300 m

- Range and Range-Rate system

vhf Transmitter frequency	148 MHz
vhf Receiver frequency	137 MHz
S-band transmitter frequency	1801 MHz
S-band receiver frequency	2253 MHz
vhf or S-band transmitter power	1 kW or 10 kW
vhf receiving antenna gain	33 dB
Tracking accuracy (each station)	
Range	±15m
Range-rate	0.1 m/sec
In-track error	100 m

The stations associated with the Minitrack and the Range and Range-Rate system are identified below.

Stations	Minitrack	R&RR
Alaska		X
Orroral	X	
Carnarvon		X
College	X	
Fort Myers	X	
Gilmore		
Johannesburg	X	
Lima	X	
Quito	X	
Rosman		X
St. Johns	X	
Santiago	X	X
Tananarive		X
Winkfield	X	

The geodetic locations of these stations are presented in Table G1 of Appendix G.

APPENDIX C

POST INJECTION S-BAND RANGE/RANGE-RATE TRACKING COVERAGE SEQUENCE

APPENDIX C

POST INJECTION S-BAND RANGE/RANGE-RATE TRACKING COVERAGE SEQUENCE

This appendix contains the sequence of tracking station contacts (tracking coverage) for the S-band Range/Range-Rate system during the first 10 000 minutes of the orbit. The first page of Table C1 provides the listing of input parameters and the following pages of the table provide output data on minutes in sight, minutes since last contact, last ascending mode east longitude (degrees), and revolution number.

TABLE C1. - POST-INJECTION S-BAND RANGE/RANGE RATE TRACKING COVERAGE SEQUENCE

POST-INJECTION S-BAND RANGE/RANGE-RATE TRACKING COVERAGE SEQUENCE

			NORTH LAT, DEG	EAST LONG, DEG	MIN ELEV, DEG
STATION	1	ALASKA	65.00	212.50	10.00
STATION	2	CARNARVON	-24.50	113.40	10.00
STATION	3	ROSMAN	35.20	277.10	10.00
STATION	4	SANTIAGO	-33.10	289.30	10.00
STATION	5	TANANARIVE	-18.50	47.30	10.00

ORBIT ALT= 500.0 KM.
ORBIT INCL= 97.38 DEG.
LAUNCH-TO-INJECTION ANGLE= 20.00 DEG.
ORBIT PERIOD= 94.62 MINUTES
EARTH RADIUS= 33.0 PERCENT OVER ACTUAL (REFRACTION CORRECTION)
MINIMUM TIME= .00 MIN
WESTWARD SHIFT OF ASC. NODE= 23.65 DEG./ORBIT
LAUNCH LONGITUDE= -120.63 DEG. EAST
LAUNCH LATITUDE= 34.76 DEG. NORTH
LAUNCH VELOCITY HAS SOUTHERLY COMPONENT
LAUNCH TO INJECTION TIME= 10.00 MIN.
TOTAL TIME= 10000.00 MIN.

STATION	MAX. ARC RANGE VISIBLE(DEG)	MAX. DIST,KM.
1	15.38	1852.8
2	15.38	1852.8
3	15.38	1852.8
4	15.38	1852.8
5	15.38	1852.8

TABLE C1. - POST-INJECTION S-BAND RANGE/RANGE RATE TRACKING COVERAGE SEQUENCE - Continued

POST INJECTION COVERAGE SEQUENCE (INJECTION TIME= 10.00 MIN. AFTER LAUNCH)

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.	REV. NO.
58.25	TANANARIVE	7.52		61.23	1
93.04	ALASKA	7.54	27.28	37.58	1
187.09	ALASKA	7.83	86.51	13.92	2
281.62	ALASKA	5.33	86.69	-9.73	3
404.51	CARNARVON	3.18	117.56	-33.38	5
453.96	ROSMAN	3.12	46.27	-57.04	5
495.39	CARNARVON	7.31	38.31	-57.04	6
527.12	SANTIAGO	7.98	24.41	-57.04	6
544.98	ROSMAN	7.77	9.88	-80.69	6
559.37	ALASKA	2.58	6.62	-80.69	6
649.68	ALASKA	6.84	87.73	-104.35	7
685.20	TANANARIVE	5.32	28.69	-104.35	8
742.29	ALASKA	8.08	51.76	-128.00	8
778.11	TANANARIVE	6.07	27.73	-128.00	9
837.46	ALASKA	6.07	53.28	-151.66	9
1161.23	SANTIAGO	7.14	317.70	137.38	13
1191.88	CARNARVON	7.70	23.50	137.38	13
1237.05	ROSMAN	6.17	37.47	113.73	14
1255.48	SANTIAGO	5.07	12.26	113.73	14
1331.16	ROSMAN	6.59	70.61	90.07	15
1477.27	TANANARIVE	8.07	139.52	66.42	16
1512.54	ALASKA	6.98	27.20	42.76	16
1606.43	ALASKA	8.03	86.91	19.11	17
1700.85	ALASKA	6.11	86.40	-4.54	18
1914.55	CARNARVON	8.02	207.59	-51.85	21
1946.30	SANTIAGO	8.03	23.72	-51.85	21
1964.25	ROSMAN	8.09	9.92	-75.51	21
2069.66	ALASKA	6.22	97.33	-99.16	22
2161.80	ALASKA	8.04	85.92	-122.82	23
2196.82	TANANARIVE	7.58	26.98	-122.82	24
2256.31	ALASKA	6.91	51.91	-146.47	24
2581.82	SANTIAGO	5.48	318.59	142.57	28
2611.68	CARNARVON	6.40	24.38	142.57	28
2657.77	ROSMAN	3.04	39.69	118.91	29
2673.97	SANTIAGO	7.01	13.16	118.91	29
2706.93	CARNARVON	5.24	25.96	118.91	29
2750.05	ROSMAN	7.67	37.88	95.26	30
2896.67	TANANARIVE	7.81	138.95	71.61	31
2932.12	ALASKA	6.16	27.64	47.95	31
3025.79	ALASKA	8.09	87.50	24.30	32
3120.12	ALASKA	6.76	86.25	.64	33
3215.14	ALASKA	2.30	88.27	-23.01	34
3334.15	CARNARVON	7.97	116.70	-46.67	36
3365.74	SANTIAGO	7.43	23.62	-46.67	36
3383.87	ROSMAN	7.82	10.71	-70.32	36
3462.04	SANTIAGO	4.15	70.35	-70.32	37
3481.09	ROSMAN	1.46	14.90	-93.97	37
3489.75	ALASKA	5.46	7.20	-93.97	37

TABLE C1. - POST-INJECTION S-BAND RANGE/RANGE RATE TRACKING COVERAGE SEQUENCE - Continued

POST INJECTION COVERAGE SEQUENCE (INJECTION TIME= 10.00 MIN. AFTER LAUNCH)

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.	REV. NO.
3581.42	ALASKA	7.86	86.20	-117.63	38
3616.08	TANANARIVE	8.08	26.80	-117.63	39
3675.35	ALASKA	7.49	51.19	-141.28	39
4004.33	SANTIAGO	.15	321.49	147.75	43
4032.42	CARNARVON	3.10	27.93	147.75	43
4093.05	SANTIAGO	7.88	57.53	124.10	44
4125.30	CARNARVON	7.17	24.37	124.10	44
4169.21	ROSMAN	8.08	36.75	100.45	45
4316.49	TANANARIVE	6.62	139.20	76.79	46
4351.85	ALASKA	4.95	28.74	53.14	46
4412.17	TANANARIVE	4.17	55.37	53.14	47
4445.17	ALASKA	8.00	28.83	29.48	47
4539.41	ALASKA	7.27	86.24	5.83	48
4634.14	ALASKA	3.75	87.46	-17.83	49
4754.18	CARNARVON	7.18	116.28	-41.48	51
4785.55	SANTIAGO	5.93	24.20	-41.48	51
4803.87	ROSMAN	6.92	12.39	-65.13	51
4849.39	CARNARVON	3.48	38.60	-65.13	52
4880.20	SANTIAGO	6.55	27.32	-65.13	52
4898.24	ROSMAN	5.74	11.49	-88.79	52
4909.96	ALASKA	4.54	5.98	-88.79	52
5001.14	ALASKA	7.56	86.64	-112.44	53
5035.79	TANANARIVE	7.78	27.09	-112.44	54
5094.54	ALASKA	7.85	50.96	-136.10	54
5191.06	ALASKA	3.78	88.67	-159.75	55
5512.53	SANTIAGO	8.08	317.68	129.29	59
5544.19	CARNARVON	7.98	23.58	129.29	59
5588.62	ROSMAN	7.89	36.46	105.63	60
5685.83	ROSMAN	1.29	89.32	81.98	61
5737.19	TANANARIVE	3.57	50.07	81.98	61
5771.95	ALASKA	2.89	31.19	58.32	62
5830.22	TANANARIVE	6.79	55.38	58.32	62
5864.59	ALASKA	7.75	27.58	34.67	62
5958.71	ALASKA	7.67	86.37	11.02	63
6053.30	ALASKA	4.82	86.92	-12.64	64
6174.81	CARNARVON	5.31	116.69	-36.29	66
6206.52	SANTIAGO	1.97	26.40	-36.29	66
6224.40	ROSMAN	5.09	15.91	-59.95	66
6267.33	CARNARVON	6.49	37.84	-59.95	67
6298.93	SANTIAGO	7.68	25.10	-59.95	67
6316.80	ROSMAN	7.30	10.19	-83.60	67
6330.31	ALASKA	3.40	6.21	-83.60	67
6420.97	ALASKA	7.13	87.26	-107.26	68
6456.00	TANANARIVE	6.59	27.90	-107.26	69
6513.86	ALASKA	8.04	51.27	-130.91	69
6550.50	TANANARIVE	4.39	28.60	-130.91	70
6609.44	ALASKA	5.43	54.56	-154.56	70
6932.38	SANTIAGO	7.66	317.50	134.47	74

TABLE C1. - POST-INJECTION S-BAND RANGE/RANGE RATE TRACKING COVERAGE SEQUENCE - Concluded

POST INJECTION COVERAGE SEQUENCE (INJECTION TIME= 10.00 MIN. AFTER LAUNCH)

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.	REV. NO.
6963.41	CARNARVON	8.01	23.37	134.47	74
7008.30	ROSMAN	7.04	36.88	110.82	75
7028.18	SANTIAGO	2.79	12.85	110.82	75
7103.21	ROSMAN	5.56	72.24	87.16	76
7249.01	TANANARIVE	7.87	140.23	63.51	77
7284.05	ALASKA	7.32	27.18	39.86	77
7378.04	ALASKA	7.93	86.66	16.20	78
7472.51	ALASKA	5.69	86.54	-7.45	79
7686.20	CARNARVON	7.73	208.00	-54.76	82
7717.96	SANTIAGO	8.08	24.03	-54.76	82
7735.85	ROSMAN	7.98	9.81	-78.41	82
7750.95	ALASKA	1.72	7.11	-78.41	82
7840.90	ALASKA	6.58	88.22	-102.07	83
7877.11	TANANARIVE	3.71	29.64	-102.07	84
7933.30	ALASKA	8.08	52.48	-125.72	84
7968.69	TANANARIVE	6.90	27.31	-125.72	85
8028.17	ALASKA	6.48	52.58	-149.38	85
8352.65	SANTIAGO	6.55	318.00	139.66	89
8382.97	CARNARVON	7.26	23.77	139.66	89
8428.42	ROSMAN	5.17	38.19	116.01	90
8445.95	SANTIAGO	6.11	12.36	116.01	90
8479.65	CARNARVON	2.98	27.59	116.01	90
8521.87	ROSMAN	7.17	39.24	92.35	91
8668.20	TANANARIVE	8.06	139.17	68.70	92
8703.58	ALASKA	6.66	27.32	45.04	92
8797.38	ALASKA	8.07	87.14	21.39	93
8891.77	ALASKA	6.41	86.31	-2.27	94
8987.26	ALASKA	.82	89.09	-25.92	95
9105.56	CARNARVON	8.09	117.48	-49.57	97
9137.25	SANTIAGO	7.85	23.60	-49.57	97
9155.28	ROSMAN	8.04	10.17	-73.23	97
9260.93	ALASKA	5.90	97.61	-96.88	98
9352.85	ALASKA	7.98	86.03	-120.54	99
9387.68	TANANARIVE	7.91	26.84	-120.54	100
9447.11	ALASKA	7.19	51.53	-144.19	100
9773.60	SANTIAGO	4.24	319.30	144.85	104
9803.04	CARNARVON	5.37	25.20	144.85	104
9864.74	SANTIAGO	7.49	56.33	121.19	105
9897.36	CARNARVON	6.28	25.13	121.19	105
9940.89	ROSMAN	7.92	37.25	97.54	106

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APPENDIX D
S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES

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APPENDIX D

S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES

This appendix contains the tracking station contacts for the S-band tracking system during a typical day of the operational lifetime. The first page of Table D1 provides the listing of input parameters while the following pages of the table provides output data on minutes in sight, minutes since last contact, and last ascending node east longitude (degrees).

TABLE D1. - S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES

S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES

		NORTH LAT. DEG	EAST LONG. DEG	MIN ELEV. DEG
STATION 1	ALASKA	65.00	212.50	10.00
STATION 2	CARNARVON	-24.50	113.40	10.00
STATION 3	ROSMAN	35.20	277.10	10.00
STATION 4	SANTIAGO	-33.10	289.30	10.00
STATION 5	TANANARIVE	-18.50	47.30	10.00

ORBIT ALT= 500.0 KM.
ORBIT INCL= 97.38 DEG.
NODAL LONGITUDE STEP SIZE= 1.00 DEG.
ORBIT PERIOD= 94.62 MINUTES
EARTH RADIUS= 33.3 PERCENT OVER ACTUAL (REFRACTION CORRECTION)
MINIMUM TIME= 1.00 MIN
WESTWARD SHIFT OF ASC. NODE= 23.65 DEG./ORBIT

STATION	MAX. ARC RANGE VISIBLE(DEG)	MAX. DIST.KM.
1	15.39	1854.0
2	15.39	1854.0
3	15.39	1854.0
4	15.39	1854.0
5	15.39	1854.0

EAST LONGITUDE.ASC. NODE (TIME=0) = .00 DEG

TIME. MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.83	ALASKA	6.69		.00
120.91	ALASKA	2.08	88.39	-23.65
239.80	CARNARVON	8.02	116.81	-47.31
271.41	SANTIAGO	7.55	23.59	
289.52	ROSMAN	7.89	10.56	-70.96
367.98	SANTIAGO	3.67	70.57	
395.36	ALASKA	5.57	23.70	-94.62
487.08	ALASKA	7.90	86.15	-118.27
521.77	TANANARIVE	8.07	26.79	
581.08	ALASKA	7.43	51.24	-141.93
909.01	SANTIAGO	2.08	320.49	-212.89
937.82	CARNARVON	3.78	26.73	
998.76	SANTIAGO	7.82	57.16	-236.54
1031.09	CARNARVON	7.01	24.51	
1074.93	ROSMAN	8.06	36.83	-260.20
1222.10	TANANARIVE	6.84	139.11	-283.85
1257.49	ALASKA	5.14	28.55	-307.50
1318.15	TANANARIVE	3.61	55.52	
1350.87	ALASKA	8.02	29.11	-331.16
1445.12	ALASKA	7.22	86.22	-354.81
1539.87	ALASKA	3.61	87.54	-378.47

TABLE D1. - S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 1.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.83	ALASKA	6.80		1.00
120.82	ALASKA	2.44	88.19	-22.65
239.90	CARNARVON	7.95	116.63	-46.31
271.47	SANTIAGO	7.36	23.63	
289.62	ROSMAN	7.79	10.79	-69.96
367.64	SANTIAGO	4.40	70.23	
386.46	ROSMAN	2.17	14.41	-93.62
395.53	ALASKA	5.41	6.90	
487.16	ALASKA	7.85	86.22	-117.27
521.81	TANANARIVE	8.09	26.80	
581.05	ALASKA	7.52	51.15	-140.93
938.34	CARNARVON	2.65	349.77	-211.89
998.76	SANTIAGO	7.92	57.77	-235.54
1030.98	CARNARVON	7.26	24.29	
1074.93	ROSMAN	8.09	36.70	-259.20
1222.26	TANANARIVE	6.50	139.25	-282.85
1257.60	ALASKA	4.85	28.84	-306.50
1317.75	TANANARIVE	4.46	55.29	
1350.90	ALASKA	7.99	28.68	-330.16
1445.12	ALASKA	7.31	86.23	-353.81
1539.84	ALASKA	3.85	87.41	-377.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 2.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.84	ALASKA	6.91		2.00
120.76	ALASKA	2.76	88.01	-21.65
240.02	CARNARVON	7.85	116.50	-45.31
271.55	SANTIAGO	7.14	23.69	
289.74	ROSMAN	7.66	11.04	-68.96
367.37	SANTIAGO	4.99	69.97	
385.86	ROSMAN	3.37	13.49	-92.62
395.70	ALASKA	5.24	6.48	
487.24	ALASKA	7.80	86.29	-116.27
521.87	TANANARIVE	8.08	26.83	
581.03	ALASKA	7.61	51.08	-139.93
678.86	ALASKA	1.26	90.22	-163.58
998.78	SANTIAGO	8.00	318.66	-234.54
1030.88	CARNARVON	7.47	24.10	
1074.94	ROSMAN	8.09	36.59	-258.20
1222.45	TANANARIVE	6.10	139.42	-281.85
1257.73	ALASKA	4.54	29.18	-305.50
1317.44	TANANARIVE	5.13	55.17	
1350.92	ALASKA	7.96	28.36	-329.16
1445.13	ALASKA	7.39	86.25	-352.81
1539.82	ALASKA	4.07	87.29	-376.47

TABLE D1. - S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 3.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.84	ALASKA	7.01		3.00
120.70	ALASKA	3.05	87.84	-20.65
240.15	CARNARVON	7.72	116.40	-44.31
271.64	SANTIAGO	6.89	23.77	
289.87	ROSMAN	7.51	11.33	-67.96
367.14	SANTIAGO	5.49	69.76	
385.45	ROSMAN	4.19	12.82	-91.62
395.88	ALASKA	5.07	6.24	
487.33	ALASKA	7.75	86.37	-115.27
521.95	TANANARIVE	8.05	26.87	
581.01	ALASKA	7.68	51.02	-138.93
678.34	ALASKA	2.25	89.65	-162.58
998.82	SANTIAGO	8.05	318.22	-233.54
1030.80	CARNARVON	7.65	23.93	
1074.97	ROSMAN	8.07	36.52	-257.20
1222.68	TANANARIVE	5.62	139.64	-280.85
1257.87	ALASKA	4.19	29.57	-304.50
1317.19	TANANARIVE	5.67	55.13	
1350.95	ALASKA	7.91	28.09	-328.16
1445.14	ALASKA	7.47	86.27	-351.81
1539.80	ALASKA	4.28	87.18	-375.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 4.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.85	ALASKA	7.11		4.00
120.66	ALASKA	3.32	87.70	-19.65
240.31	CARNARVON	7.56	116.33	-43.31
271.75	SANTIAGO	6.60	23.89	
290.01	ROSMAN	7.33	11.66	-66.96
366.94	SANTIAGO	5.92	69.60	
385.13	ROSMAN	4.84	12.27	-90.62
396.06	ALASKA	4.90	6.10	
487.42	ALASKA	7.69	86.46	-114.27
522.04	TANANARIVE	7.98	26.93	
581.00	ALASKA	7.75	50.98	-137.93
677.99	ALASKA	2.91	89.24	-161.58
998.86	SANTIAGO	8.08	317.96	-232.54
1030.73	CARNARVON	7.79	23.79	
1075.00	ROSMAN	8.03	36.47	-256.20
1222.95	TANANARIVE	5.05	139.92	-279.85
1258.03	ALASKA	3.80	30.03	-303.50
1316.98	TANANARIVE	6.13	55.15	
1350.98	ALASKA	7.87	27.88	-327.16
1445.15	ALASKA	7.55	86.30	-350.81
1539.78	ALASKA	4.48	87.08	-374.47

TABLE D1. - S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 5.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.86	ALASKA	7.21		5.00
120.62	ALASKA	3.57	87.56	-18.65
240.48	CARNARVON	7.37	116.29	-42.31
271.88	SANTIAGO	6.26	24.04	
290.18	ROSMAN	7.12	12.04	-65.96
336.32	CARNARVON	2.49	39.03	
366.77	SANTIAGO	6.29	27.96	
384.87	ROSMAN	5.37	11.81	-89.62
396.25	ALASKA	4.71	6.01	
487.51	ALASKA	7.62	86.55	-113.27
522.14	TANANARIVE	7.89	27.01	
580.99	ALASKA	7.81	50.96	-136.93
677.72	ALASKA	3.43	88.91	-160.58
998.92	SANTIAGO	8.09	317.78	-231.54
1030.68	CARNARVON	7.91	23.66	
1075.04	ROSMAN	7.97	36.45	-255.20
1223.28	TANANARIVE	4.34	140.28	-278.85
1258.21	ALASKA	3.34	30.60	-302.50
1316.80	TANANARIVE	6.52	55.24	
1351.02	ALASKA	7.81	27.70	-326.16
1445.16	ALASKA	7.62	86.33	-349.81
1539.76	ALASKA	4.68	86.99	-373.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 6.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.86	ALASKA	7.29		6.00
120.59	ALASKA	3.81	87.43	-17.65
240.67	CARNARVON	7.14	116.27	-41.31
272.03	SANTIAGO	5.86	24.23	
290.35	ROSMAN	6.89	12.46	-64.96
335.77	CARNARVON	3.66	38.53	
366.63	SANTIAGO	6.61	27.19	
384.66	ROSMAN	5.82	11.42	-88.62
396.44	ALASKA	4.52	5.97	
487.61	ALASKA	7.55	86.65	-112.27
522.27	TANANARIVE	7.76	27.10	
580.99	ALASKA	7.87	50.96	-135.93
677.48	ALASKA	3.87	88.62	-159.58
999.00	SANTIAGO	8.08	317.65	-230.54
1030.63	CARNARVON	7.99	23.56	
1075.08	ROSMAN	7.88	36.45	-254.20
1172.10	ROSMAN	1.69	89.14	-277.85
1223.73	TANANARIVE	3.41	49.94	
1258.45	ALASKA	2.80	31.31	-301.50
1316.65	TANANARIVE	6.85	55.40	
1351.05	ALASKA	7.75	27.55	-325.16
1445.17	ALASKA	7.68	86.37	-348.81
1539.75	ALASKA	4.86	86.90	-372.47

TABLE D1. - S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 7.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.87	ALASKA	7.38		7.00
120.56	ALASKA	4.03	87.31	-16.65
240.88	CARNARVON	6.88	116.29	-40.31
272.22	SANTIAGO	5.40	24.46	
290.55	ROSMAN	6.62	12.93	-63.96
335.39	CARNARVON	4.49	38.22	
366.50	SANTIAGO	6.89	26.62	
384.47	ROSMAN	6.21	11.09	-87.62
396.64	ALASKA	4.32	5.96	
487.71	ALASKA	7.48	86.75	-111.27
522.41	TANANARIVE	7.61	27.22	
580.99	ALASKA	7.92	50.98	-134.93
677.27	ALASKA	4.25	88.36	-158.58
999.08	SANTIAGO	8.04	317.56	-229.54
1030.61	CARNARVON	8.05	23.48	
1075.14	ROSMAN	7.77	36.48	-253.20
1171.49	ROSMAN	3.02	88.58	-276.85
1224.43	TANANARIVE	1.96	49.92	
1258.75	ALASKA	2.10	32.36	-300.50
1316.52	TANANARIVE	7.13	55.67	
1351.09	ALASKA	7.68	27.43	-324.16
1445.18	ALASKA	7.74	86.42	-347.81
1539.74	ALASKA	5.04	86.81	-371.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 8.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.88	ALASKA	7.46		8.00
120.54	ALASKA	4.24	87.20	-15.65
241.11	CARNARVON	6.57	116.33	-39.31
272.44	SANTIAGO	4.86	24.76	
290.77	ROSMAN	6.31	13.47	-62.96
335.10	CARNARVON	5.14	38.01	
366.38	SANTIAGO	7.13	26.15	
384.32	ROSMAN	6.54	10.81	-86.62
396.85	ALASKA	4.11	5.98	
487.82	ALASKA	7.40	86.86	-110.27
522.57	TANANARIVE	7.41	27.35	
581.00	ALASKA	7.96	51.01	-133.93
677.09	ALASKA	4.59	88.13	-157.58
999.18	SANTIAGO	7.98	317.50	-228.54
1030.59	CARNARVON	8.09	23.42	
1075.21	ROSMAN	7.63	36.54	-252.20
1171.11	ROSMAN	3.88	88.27	-275.85
1316.42	TANANARIVE	7.37	141.43	-299.50
1351.12	ALASKA	7.60	27.33	-323.16
1445.19	ALASKA	7.80	86.47	-346.81
1539.73	ALASKA	5.22	86.74	-370.47

TABLE D1. - S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 9.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.89	ALASKA	7.53		9.00
120.52	ALASKA	4.45	87.10	-14.65
241.38	CARNARVON	6.22	116.41	-38.31
272.72	SANTIAGO	4.19	25.13	
291.01	ROSMAN	5.97	14.10	-61.96
334.87	CARNARVON	5.67	37.89	
366.28	SANTIAGO	7.34	25.75	
384.19	ROSMAN	6.83	10.56	-85.62
397.05	ALASKA	3.89	6.03	
487.93	ALASKA	7.32	86.98	-109.27
522.76	TANANARIVE	7.19	27.51	
581.01	ALASKA	7.99	51.07	-132.93
618.76	TANANARIVE	2.14	29.75	
676.93	ALASKA	4.90	56.03	-156.58
999.30	SANTIAGO	7.90	317.48	-227.54
1030.58	CARNARVON	8.09	23.38	
1075.29	ROSMAN	7.47	36.62	-251.20
1170.83	ROSMAN	4.55	88.07	-274.85
1316.33	TANANARIVE	7.57	140.96	-298.50
1351.16	ALASKA	7.52	27.26	-322.16
1445.21	ALASKA	7.85	86.52	-345.81
1539.72	ALASKA	5.38	86.66	-369.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 10.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.90	ALASKA	7.61		10.00
120.51	ALASKA	4.64	87.00	-13.65
241.67	CARNARVON	5.81	116.52	-37.31
273.10	SANTIAGO	3.32	25.62	
291.28	ROSMAN	5.57	14.86	-60.96
334.68	CARNARVON	6.11	37.83	
366.20	SANTIAGO	7.53	25.40	
384.08	ROSMAN	7.08	10.36	-84.62
397.27	ALASKA	3.66	6.10	
488.04	ALASKA	7.23	87.11	-108.27
522.96	TANANARIVE	6.92	27.69	
581.03	ALASKA	8.03	51.15	-131.93
618.12	TANANARIVE	3.49	29.06	
676.78	ALASKA	5.18	55.17	-155.58
999.43	SANTIAGO	7.80	317.47	-226.54
1030.59	CARNARVON	8.07	23.36	
1075.38	ROSMAN	7.27	36.73	-250.20
1170.60	ROSMAN	5.09	87.94	-273.85
1316.26	TANANARIVE	7.74	140.57	-297.50
1351.20	ALASKA	7.43	27.21	-321.16
1445.22	ALASKA	7.90	86.59	-344.81
1539.71	ALASKA	5.54	86.60	-368.47

TABLE D1. - S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 11.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.91	ALASKA	7.67		11.00
120.49	ALASKA	4.83	86.91	-12.65
242.00	CARNARVON	5.32	116.68	-36.31
273.69	SANTIAGO	2.02	26.36	
291.59	ROSMAN	5.11	15.88	-59.96
334.53	CARNARVON	6.49	37.84	
366.12	SANTIAGO	7.68	25.10	
383.99	ROSMAN	7.30	10.19	-83.62
397.49	ALASKA	3.42	6.20	
488.16	ALASKA	7.14	87.25	-107.27
523.19	TANANARIVE	6.60	27.89	
581.05	ALASKA	8.05	51.26	-130.93
617.70	TANANARIVE	4.39	28.60	
676.64	ALASKA	5.43	54.55	-154.58
999.57	SANTIAGO	7.67	317.50	-225.54
1030.60	CARNARVON	8.02	23.36	
1075.49	ROSMAN	7.05	36.87	-249.20
1095.38	SANTIAGO	2.79	12.84	
1170.41	ROSMAN	5.56	72.24	-272.85
1316.20	TANANARIVE	7.87	140.23	-296.50
1351.25	ALASKA	7.33	27.17	-320.16
1445.23	ALASKA	7.94	86.66	-343.81
1539.71	ALASKA	5.70	86.54	-367.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 12.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.92	ALASKA	7.73		12.00
120.48	ALASKA	5.01	86.83	-11.65
242.38	CARNARVON	4.75	116.89	-35.31
291.93	ROSMAN	4.56	44.80	-58.96
334.41	CARNARVON	6.82	37.91	
366.06	SANTIAGO	7.81	24.83	
383.92	ROSMAN	7.49	10.05	-82.62
397.73	ALASKA	3.16	6.32	
488.28	ALASKA	7.04	87.40	-106.27
523.45	TANANARIVE	6.23	28.12	
581.08	ALASKA	8.07	51.40	-129.93
617.39	TANANARIVE	5.08	28.24	
676.52	ALASKA	5.67	54.05	-153.58
999.73	SANTIAGO	7.52	317.54	-224.54
1030.63	CARNARVON	7.94	23.39	
1075.61	ROSMAN	6.79	37.04	-248.20
1094.91	SANTIAGO	3.79	12.51	
1170.25	ROSMAN	5.96	71.55	-271.85
1316.16	TANANARIVE	7.97	139.95	-295.50
1351.29	ALASKA	7.22	27.16	-319.16
1445.25	ALASKA	7.98	86.73	-342.81
1539.71	ALASKA	5.85	86.48	-366.47

TABLE D1. - S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 13.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.93	ALASKA	7.79		13.00
120.47	ALASKA	5.18	86.75	-10.65
242.83	CARNARVON	4.04	117.18	-34.31
292.34	ROSMAN	3.91	45.47	-57.96
334.31	CARNARVON	7.10	38.06	
366.01	SANTIAGO	7.91	24.60	
383.87	ROSMAN	7.65	9.95	-81.62
397.97	ALASKA	2.88	6.45	
488.41	ALASKA	6.94	87.56	-105.27
523.74	TANANARIVE	5.80	28.39	
581.11	ALASKA	8.08	51.56	-128.93
617.14	TANANARIVE	5.64	27.95	
676.40	ALASKA	5.89	53.62	-152.58
999.90	SANTIAGO	7.34	317.61	-223.54
1030.68	CARNARVON	7.83	23.43	
1075.75	ROSMAN	6.49	37.24	-247.20
1094.57	SANTIAGO	4.53	12.33	
1170.12	ROSMAN	6.31	71.02	-270.85
1316.13	TANANARIVE	8.04	139.70	-294.50
1351.34	ALASKA	7.10	27.17	-318.16
1445.26	ALASKA	8.01	86.82	-341.81
1539.70	ALASKA	5.99	86.43	-365.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 14.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.94	ALASKA	7.84		14.00
120.46	ALASKA	5.35	86.68	-9.65
243.40	CARNARVON	3.11	117.58	-33.31
292.84	ROSMAN	3.06	46.33	-56.96
334.23	CARNARVON	7.34	38.33	
365.96	SANTIAGO	7.99	24.39	
383.83	ROSMAN	7.78	9.87	-80.62
398.23	ALASKA	2.57	6.62	
488.54	ALASKA	6.84	87.73	-104.27
524.08	TANANARIVE	5.29	28.71	
581.14	ALASKA	8.09	51.78	-127.93
616.94	TANANARIVE	6.11	27.71	
676.30	ALASKA	6.09	53.25	-151.58
1000.09	SANTIAGO	7.13	317.70	-222.54
1030.73	CARNARVON	7.69	23.51	
1075.91	ROSMAN	6.15	37.49	-246.20
1094.31	SANTIAGO	5.12	12.25	
1170.00	ROSMAN	6.62	70.58	-269.85
1316.12	TANANARIVE	8.08	139.50	-293.50
1351.39	ALASKA	6.98	27.19	-317.16
1445.28	ALASKA	8.03	86.91	-340.81
1539.70	ALASKA	6.13	86.39	-364.47

TABLE D1. - S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 15.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE F.LONG.,DEG.
25.96	ALASKA	7.89		15.00
120.46	ALASKA	5.51	86.61	-8.65
244.25	CARNARVON	1.62	118.28	-32.31
293.57	ROSMAN	1.79	47.70	-55.96
334.18	CARNARVON	7.54	38.83	
365.93	SANTIAGO	8.05	24.21	
383.80	ROSMAN	7.89	9.83	-79.62
398.51	ALASKA	2.23	6.81	
488.67	ALASKA	6.73	87.93	-103.27
524.47	TANANARIVE	4.67	29.07	
581.18	ALASKA	8.09	52.04	-126.93
616.78	TANANARIVE	6.50	27.51	
676.21	ALASKA	6.28	52.92	-150.58
1000.31	SANTIAGO	6.89	317.82	-221.54
1030.80	CARNARVON	7.52	23.60	
1076.09	ROSMAN	5.75	37.77	-245.20
1094.09	SANTIAGO	5.62	12.25	
1169.91	ROSMAN	6.89	70.19	-268.85
1316.12	TANANARIVE	8.09	139.32	-292.50
1351.45	ALASKA	6.84	27.24	-316.16
1445.30	ALASKA	8.06	87.01	-339.81
1539.70	ALASKA	6.26	86.35	-363.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 16.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE F.LONG.,DEG.
25.97	ALASKA	7.93		16.00
120.45	ALASKA	5.67	86.55	-7.65
334.14	CARNARVON	7.70	208.02	-54.96
365.90	SANTIAGO	8.08	24.06	
383.79	ROSMAN	7.97	9.81	-78.62
398.81	ALASKA	1.84	7.05	
488.81	ALASKA	6.61	88.16	-102.27
524.94	TANANARIVE	3.90	29.52	
581.23	ALASKA	8.09	52.38	-125.93
616.65	TANANARIVE	6.84	27.34	
676.12	ALASKA	6.45	52.63	-149.58
1000.54	SANTIAGO	6.62	317.96	-220.54
1030.89	CARNARVON	7.32	23.73	
1076.31	ROSMAN	5.28	38.11	-244.20
1093.92	SANTIAGO	6.04	12.33	
1127.71	CARNARVON	2.74	27.75	
1169.82	ROSMAN	7.13	39.37	-267.85
1316.13	TANANARIVE	8.07	139.18	-291.50
1351.51	ALASKA	6.70	27.30	-315.16
1445.32	ALASKA	8.07	87.11	-338.81
1539.70	ALASKA	6.39	86.31	-362.47

TABLE D1. - S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES -Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 17.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
25.99	ALASKA	7.97		17.00
120.45	ALASKA	5.82	86.49	-6.65
334.13	CARNARVON	7.84	207.86	-53.96
365.89	SANTIAGO	8.09	23.92	
383.79	ROSMAN	8.03	9.81	-77.62
399.16	ALASKA	1.34	7.34	
488.95	ALASKA	6.49	88.44	-101.27
525.55	TANANARIVE	2.85	30.12	
581.27	ALASKA	8.08	52.87	-124.93
616.55	TANANARIVE	7.13	27.20	
676.04	ALASKA	6.61	52.37	-148.58
1000.79	SANTIAGO	6.31	318.13	-219.54
1030.99	CARNARVON	7.07	23.89	
1076.57	ROSMAN	4.73	38.51	-243.20
1093.78	SANTIAGO	6.40	12.48	
1127.20	CARNARVON	3.80	27.02	
1169.75	ROSMAN	7.33	38.75	-266.85
1316.16	TANANARIVE	8.02	139.07	-290.50
1351.57	ALASKA	6.54	27.39	-314.16
1445.33	ALASKA	8.08	87.23	-337.81
1539.70	ALASKA	6.52	86.29	-361.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 18.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
26.00	ALASKA	8.00		18.00
120.45	ALASKA	5.97	86.44	-5.65
334.13	CARNARVON	7.94	207.72	-52.96
365.88	SANTIAGO	8.08	23.81	
383.81	ROSMAN	8.07	9.85	-76.62
489.09	ALASKA	6.37	97.21	-100.27
581.33	ALASKA	8.07	85.87	-123.93
616.47	TANANARIVE	7.37	27.08	
675.97	ALASKA	6.76	52.13	-147.58
1001.07	SANTIAGO	5.95	318.33	-218.54
1031.11	CARNARVON	6.78	24.09	
1076.88	ROSMAN	4.05	38.99	-242.20
1093.66	SANTIAGO	6.72	12.72	
1126.84	CARNARVON	4.57	26.46	
1169.69	ROSMAN	7.51	38.28	-265.85
1316.20	TANANARIVE	7.94	139.00	-289.50
1351.63	ALASKA	6.37	27.49	-313.16
1445.35	ALASKA	8.09	87.35	-336.81
1539.71	ALASKA	6.64	86.26	-360.47

TABLE D1. - S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES -Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 19.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
26.02	ALASKA	8.03		19.00
120.44	ALASKA	6.11	86.40	-4.65
334.14	CARNARVON	8.02	207.59	-51.96
365.88	SANTIAGO	8.04	23.72	
383.84	ROSMAN	8.09	9.91	-75.62
489.24	ALASKA	6.24	97.31	-99.27
581.38	ALASKA	8.05	85.91	-122.93
616.42	TANANARIVE	7.57	26.98	
675.91	ALASKA	6.90	51.92	-146.58
1001.37	SANTIAGO	5.54	318.56	-217.54
1031.25	CARNARVON	6.44	24.34	
1077.30	ROSMAN	3.18	39.60	-241.20
1093.57	SANTIAGO	6.99	13.10	
1126.55	CARNARVON	5.19	26.00	
1169.64	ROSMAN	7.66	37.91	-264.85
1316.25	TANANARIVE	7.83	138.95	-288.50
1351.70	ALASKA	6.19	27.62	-312.16
1445.38	ALASKA	8.09	87.48	-335.81
1539.71	ALASKA	6.75	86.24	-359.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 20.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
26.04	ALASKA	8.05		20.00
120.44	ALASKA	6.24	86.36	-3.65
334.17	CARNARVON	8.07	207.49	-50.96
365.90	SANTIAGO	7.98	23.66	
383.88	ROSMAN	8.09	10.00	-74.62
489.39	ALASKA	6.10	97.42	-98.27
581.44	ALASKA	8.03	85.95	-121.93
616.38	TANANARIVE	7.74	26.91	
675.85	ALASKA	7.03	51.74	-145.58
1001.72	SANTIAGO	5.06	318.83	-216.54
1031.43	CARNARVON	6.05	24.64	
1077.94	ROSMAN	1.82	40.47	-240.20
1093.49	SANTIAGO	7.22	13.73	
1126.31	CARNARVON	5.70	25.60	
1169.60	ROSMAN	7.79	37.60	-263.85
1316.32	TANANARIVE	7.69	138.92	-287.50
1351.78	ALASKA	6.00	27.77	-311.16
1445.40	ALASKA	8.09	87.62	-334.81
1539.71	ALASKA	6.86	86.23	-358.47

TABLE D1. - S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 21.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
26.05	ALASKA	8.07		21.00
120.44	ALASKA	6.37	86.32	-2.65
334.22	CARNARVON	8.09	207.41	-49.96
365.92	SANTIAGO	7.90	23.61	
383.93	ROSMAN	8.06	10.12	-73.62
489.54	ALASKA	5.96	97.55	-97.27
581.51	ALASKA	8.00	86.00	-120.93
616.36	TANANARIVE	7.87	26.85	
675.80	ALASKA	7.16	51.58	-144.58
1002.11	SANTIAGO	4.50	319.15	-215.54
1031.63	CARNARVON	5.58	25.02	
1093.44	SANTIAGO	7.43	56.23	-239.20
1126.11	CARNARVON	6.13	25.25	
1169.58	ROSMAN	7.90	37.33	-262.85
1316.41	TANANARIVE	7.51	138.93	-286.50
1351.86	ALASKA	5.78	27.94	-310.16
1445.42	ALASKA	8.08	87.78	-333.81
1539.72	ALASKA	6.97	86.22	-357.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 22.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
26.07	ALASKA	8.08		22.00
120.44	ALASKA	6.49	86.29	-1.65
215.76	ALASKA	1.31	88.82	-25.31
334.28	CARNARVON	8.09	117.22	-48.96
365.95	SANTIAGO	7.79	23.58	
384.00	ROSMAN	8.02	10.26	-72.62
463.54	SANTIAGO	1.71	71.52	
489.70	ALASKA	5.82	24.45	-96.27
581.57	ALASKA	7.96	86.05	-119.93
616.36	TANANARIVE	7.97	26.82	
675.76	ALASKA	7.27	51.43	-143.58
1002.57	SANTIAGO	3.81	319.54	-214.54
1031.88	CARNARVON	5.02	25.50	
1093.40	SANTIAGO	7.60	56.50	-238.20
1125.94	CARNARVON	6.50	24.94	
1169.56	ROSMAN	7.98	37.11	-261.85
1316.51	TANANARIVE	7.29	138.97	-285.50
1351.95	ALASKA	5.56	28.14	-309.16
1445.44	ALASKA	8.06	87.94	-332.81
1539.72	ALASKA	7.07	86.22	-356.47

TABLE D1. - S-BAND RANGE/RANGE-RATE TRACKING COVERAGE PROFILES - Concluded

EAST LONGITUDE,ASC. NODE (TIME=0) = 23.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
26.09	ALASKA	8.09		23.00
120.45	ALASKA	6.61	86.27	-.65
215.60	ALASKA	1.81	88.54	-24.31
334.36	CARNARVON	8.06	116.94	-47.96
365.99	SANTIAGO	7.65	23.58	
384.08	ROSMAN	7.95	10.43	-71.62
462.89	SANTIAGO	3.07	70.86	
489.87	ALASKA	5.67	23.91	-95.27
581.65	ALASKA	7.93	86.11	-118.93
616.37	TANANARIVE	8.04	26.80	
675.72	ALASKA	7.37	51.31	-142.58
1003.13	SANTIAGO	2.91	320.04	-213.54
1032.18	CARNARVON	4.34	26.14	
1093.38	SANTIAGO	7.74	56.86	-237.20
1125.79	CARNARVON	6.82	24.67	
1169.55	ROSMAN	8.04	36.93	-260.85
1316.63	TANANARIVE	7.03	139.05	-284.50
1352.04	ALASKA	5.31	28.38	-308.16
1413.12	TANANARIVE	2.88	55.77	
1445.47	ALASKA	8.04	29.47	-331.81
1539.73	ALASKA	7.16	86.22	-355.47

APPENDIX E
PULSE CODE MODULATION TELEMETRY STANDARD

APPENDIX E

PULSE CODE MODULATION TELEMETRY STANDARD

The material in this appendix was obtained from the Aerospace Data Systems Standards (ref. 5) and is included here as a reference for assuring compatability with STADAN PCM systems.

PULSE CODE MODULATION TELEMETRY STANDARD

January 27, 1966

1.0 PURPOSE

The primary purpose of these standards is to require the use of techniques that will enable reliable acquisition and reduction of data from spacecraft employing PCM telemeters. The standards are intended to reflect current state of the art and will be revised as new developments dictate.

2.0 SCOPE

This document applies to all spacecraft using PCM telemetry systems that are under the management of the Goddard Space Flight Center and/or using the GSFC Space Tracking and Data Acquisition Network and/or the GSFC Data Processing System. If an exception to this Standard is desired, it must be approved by the GSFC Data Systems Requirements Committee.[a]

3.0 STANDARDS

Since practical considerations often dictate a departure from optimum techniques, some categories will have two approaches; a "PREFERRED" classification which will yield near optimum results and an "ALTERNATE" classification which can be used to provide acceptable results when other considerations influence the design.

3.1 Code Format

A serial binary code shall be used. The following types of coding are acceptable.

NRZ Type C
NRZ Type M
Split Phase

Waveform symmetry shall be maintained within 2 percent of the nominal bit period as measured at the telemetry receiver output.

3.2 Bit Rate

3.2.1 Range--The permissible range of data rates is from 1 bit/sec to 200 000 bits/sec.

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[a]Address: The Director, Goddard Space Flight Center, Greenbelt, Maryland
Attention: Chairman, GSFC Data Systems Requirements Committee, Code 520

3.2.2 Stability

Long Term (one year)--less than ±5% of bit rate.
Short Term (5 minutes)--less than ±1/2% of bit rate.
Instantaneous (e.g., flutter of spacecraft tape recorder)--less than 3% of bit rate (peak-to-peak) measured in a bandwidth wide enough to include all significant components, (nominally 600 Hz).

NOTE: Compatibility must exist between these requirements and those listed in section 3.4.1

3.2.3 Changes in bit rates during real time transmission are permissible only by command from a ground station. Identification of the bit rate in use must be included as part of the telemetered data.

3.3 Format

3.3.1 Minor Frame Length--The minor frame length shall not exceed 8192 bits and shall be of constant length for any one mission.

3.3.2 Major Frame Length--The major frame shall not consist of more than 256 minor frames.

3.3.3 Word Structure

3.3.3.1 Word synchronization may consist of 0, 1, 2, or 3 bits per word and shall be the first bit or bits within the word when used.

3.3.3.2 Data words may be composed of any number of syllables; however, the structure of any particular word shall remain constant. In those cases where the syllable represents a single measurand, the most significant bit shall occur first.

3.3.3.3 Parity shall be optional. If used, it shall be the last bit in a syllable or a word. Error correction and other redundant coding techniques may be used to enhance detection efficiency.

3.3.3.4 Reversal in the sequence of transmission is permissible if a spacecraft tape recorder is readout during rewind.

3.3.4 Word Length--The word length shall not exceed 32 bits and all words shall be of constant length for any particular mission. This does not preclude different word structures as defined in section 3.3.3.

3.3.5 Supermultiplexing and Submultiplexing--Data multiplexing at sampling rates which are multiples or submultiples of the minor frame rate is permissible. Where two or more submultiplexers are used, they must be synchronized together and have either an equal number of channels or binary multiples in order to use a common synchronization word. The submultiplexer cycle shall be complete within 256 minor frames as specified in section 3.3.2.

3.3.6 Variable Formats--Variations in data channel assignments are permissible, however, when variable formats are used each frame must contain positive identification of the format. The frame and word length must remain constant as well as the synchronization pattern except as allowed by section 3.4.3.2.

3.4 Synchronization

3.4.1 Bit Synchronization--Bit synchronization is the first step in acquiring system synchronization and sufficient changes of state must be provided for rapid, reliable synchronization. All operating conditions shall be considered, such as primary power being turned off to many of the experiments which could result in data without transitions. Where similar conditions could exist, techniques such as restricting the dynamic range of the data, odd parity or word synchronization should be used to ensure bit transition. The maximum number of data bits between transitions must not exceed 64.

NOTE: Compatibility must exist between these requirements and those in section 3.2.2. Each spacecraft/ground system must take into account worst case combinations of bit rate stability and bit transition density.

3.4.2 Frame Synchronization

3.4.2.1 The "PREFERRED" method of frame synchronization is to use a pseudo-random code pattern of appropriate length that is repeated every frame. With this technique, it is not necessary to devote one or more bits in each word to synchronization purposes. A comprehensive study of code patterns has been completed and Table E1-1 in Appendix E1 contains codes which are recommended for use. In selecting the pattern length, the telemetry design engineer should carefully consider the probability of the pattern being generated in the data.

3.4.2.2 An "ALTERNATE" method of synchronization is to use one or more bits at the start of each word to establish bit phasing and one word per frame with a unique code that cannot occur in the data.

3.4.3 Submultiplexer Synchronization

3.4.3.1 A syllable in each minor frame shall be used to identify the subchannel number for that frame (e.g., 7 bits for 128 channel submultiplexer). This syllable must occur prior to the first submultiplexed channel.

3.4.3.2 As an "ALTERNATE," the main frame sync pattern may be complemented once per longest submultiplexer frame. The two methods may be used together if desired and the complement of the frame pattern may be used to prevent the ground station from remaining locked to a false frame sync pattern.

3.5 System Design--Shall be governed by this Standard, the RF and Modulation Standards, current ground station equipment capability and spacecraft requirements.

APPENDIX E1

PCM FRAME SYNCHRONIZATION CODES

The codes listed in Table E1-1 have been determined as optimum frame synchronization codes for general use in PCM telemetry.

The technique used in the determination of these codes was essentially that of examining all 2^n binary patterns of a given length, n, for that pattern with the smallest total probability of false sync recognition over the entire overlap portion of the ground station frame synchronization process.

A more detailed account of this investigation will be found in the Proceedings of the National Telemetering Conference, June 1964: "Development of Optimum Frame Synchronization Codes for Goddard Space Flight Center PCM Telemetry Standards," by Jesse L. Maury, Jr. and Frederick J. Styles.

TABLE E1-1. - PCM FRAME SYNCHRONIZATION CODES

CODE LENGTH										
7	101	100	0							
8	101	110	00							
9	101	110	000							
10	110	111	000	0						
11	101	101	110	00						
12	110	101	100	000						
13	111	010	110	000	0					
14	111	001	101	000	00					
15	111	011	001	010	000					
16	111	010	111	001	000	0				
17	111	100	110	101	000	00				
18	111	100	110	101	000	000				
19	111	110	011	001	010	000	0			
20	111	011	011	110	001	000	00			
21	111	011	101	001	011	000	000			
22	111	100	110	110	101	000	000	0		
23	111	101	011	100	110	100	000	00		
24	111	110	101	111	011	100	100	000		
25	111	100	010	110	111	000	100	000	0	
26	111	110	100	110	101	100	010	000	00	
27	111	110	101	101	001	100	110	000	000	
28	111	101	011	110	010	110	011	000	000	0
29	111	101	011	110	011	001	101	000	000	00
30	111	110	101	111	001	100	110	100	000	000

APPENDIX F
POST INJECTION TELEMETRY COVERAGE SEQUENCE

APPENDIX F

POST INJECTION TELEMETRY COVERAGE SEQUENCE

This appendix contains vhf telemetry coverage for the first 10 000 minutes of orbital lifetime. The S-band telemetry coverage for this same period of time can be found in Appendix C where the S-band tracking coverage is presented. The telemetry coverage is identical to the tracking coverage in this case. Table F1 presents the VHF telemetry coverage for 10 stations while Table F2 presents the same for only the College and Rosman stations. The College and Rosman contacts were tabulated separately to show more clearly the contact times when the microwave links between these stations and GSFC could possibly be utilized.

TABLE F1. - POST-INJECTION VHF TELEMETRY COVERAGE SEQUENCE

POST-INJECTION VHF TELEMETRY COVERAGE SEQUENCE

		NORTH LAT, DEG	EAST LONG, DEG	MIN ELEV, DEG
STATION 1	COLLEGE	64.90	212.10	5.00
STATION 2	FT. MYERS	26.50	278.10	5.00
STATION 3	JOHANNESBURG	-25.90	27.70	5.00
STATION 4	LIMA	-11.80	282.80	5.00
STATION 5	CORORAL	-35.60	148.90	5.00
STATION 6	QUITO	-.60	281.40	5.00
STATION 7	ROSMAN	35.20	277.10	5.00
STATION 8	ST. JOHN'S	47.70	307.30	5.00
STATION 9	SANTIAGO	-33.20	289.30	5.00
STATION 10	WINKFIELD	51.50	359.30	5.00

ORBIT ALT= 500.0 KM.
ORBIT INCL= 97.38 DEG.
LAUNCH-TO-INJECTION ANGLE= 20.00 DEG.
ORBIT PERIOD= 94.62 MINUTES
EARTH RADIUS= 33.0 PERCENT OVER ACTUAL (REFRACTION CORRECTION)
MINIMUM TIME= .00 MIN
WESTWARD SHIFT OF ASC. NODE= 23.65 DEG./ORBIT
LAUNCH LONGITUDE= -120.63 DEG. EAST
LAUNCH LATITUDE= 34.76 DEG. NORTH
LAUNCH VELOCITY HAS SOUTHERLY COMPONENT
LAUNCH TO INJECTION TIME= 10.00 MIN.
TOTAL TIME= 10000.00 MIN.

STATION	MAX. ARC RANGE VISIBLE(DEG)	MAX. DIST,KM.
1	19.71	2329.1
2	19.71	2329.1
3	19.71	2329.1
4	19.71	2329.1
5	19.71	2329.1
6	19.71	2329.1
7	19.71	2329.1
8	19.71	2329.1
9	19.71	2329.1
10	19.71	2329.1

TABLE F1. - POST-INJECTION VHF TELEMETRY COVERAGE SEQUENCE - Continued

POST INJECTION COVERAGE SEQUENCE (INJECTION TIME= 10.00 MIN. AFTER LAUNCH)

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.	REV. NO.
46.42	JOHANNESBURG	6.21		63.73	1
69.19	WINKFIELD	6.40	16.56	40.08	1
81.95	COLLEGE	9.74	6.36	40.08	1
139.60	JOHANNESBURG	9.99	47.91	40.08	2
160.03	WINKFIELD	10.28	10.44	16.42	2
176.01	COLLEGE	10.26	5.70	16.42	2
255.04	WINKFIELD	8.31	68.78	-7.23	3
270.17	COLLEGE	8.69	6.81	-7.23	3
298.42	ORROAL	10.22	19.56	-7.23	4
348.84	ST. JOHNS	9.77	40.20	-30.88	4
364.05	COLLEGE	6.03	5.43	-30.88	4
393.79	ORROAL	6.41	23.71	-30.88	5
424.72	SANTIAGO	1.41	24.52	-30.88	5
441.76	FT. MYERS	3.26	15.63	-54.54	5
442.70	ROSMAN	6.07	.00	-54.54	5
442.79	ST. JOHNS	9.31	.00	-54.54	5
456.72	COLLEGE	4.65	4.62	-54.54	5
515.88	SANTIAGO	10.36	54.51	-54.54	6
521.90	LIMA	10.35	.00	-54.54	6
531.48	FT. MYERS	10.33	.00	-78.19	6
533.79	ROSMAN	10.29	.00	-78.19	6
547.63	COLLEGE	6.65	3.54	-78.19	6
614.29	SANTIAGO	2.09	60.00	-78.19	7
638.71	COLLEGE	9.18	22.34	-101.85	7
731.25	COLLEGE	10.36	83.35	-125.50	8
769.62	JOHANNESBURG	9.45	28.02	-125.50	9
825.85	COLLEGE	9.25	46.77	-149.16	9
863.60	JOHANNESBURG	8.06	28.50	-149.16	10
923.90	COLLEGE	3.20	52.24	-172.81	10
936.97	WINKFIELD	9.98	9.86	-172.81	10
990.52	ORROAL	4.00	43.57	-172.81	11
1031.39	WINKFIELD	9.33	36.88	163.54	11
1082.95	ORROAL	10.35	42.23	163.54	12
1127.42	ST. JOHNS	9.49	34.13	139.88	12
1150.46	SANTIAGO	9.20	13.55	139.88	13
1181.37	ORROAL	1.96	21.72	139.88	13
1221.66	ST. JOHNS	9.62	38.33	116.23	13
1225.96	ROSMAN	8.26	.00	116.23	13
1228.10	FT. MYERS	8.85	.00	116.23	13
1234.79	QUITO	10.27	.00	116.23	14
1237.67	LIMA	10.35	.00	116.23	14
1243.64	SANTIAGO	9.98	.00	116.23	14
1319.69	ROSMAN	9.71	67.07	92.57	14
1322.35	FT. MYERS	8.84	.00	92.57	14
1408.94	COLLEGE	3.05	77.74	68.92	15
1490.17	WINKFIELD	4.13	78.19	45.26	16
1501.39	COLLEGE	9.24	7.10	45.26	16
1558.68	JOHANNESBURG	10.36	48.05	45.26	17

TABLE F1. - POST-INJECTION VHF TELEMETRY COVERAGE SEQUENCE - Continued

POST INJECTION COVERAGE SEQUENCE

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.	REV. NO.
1579.75	WINKFIELD	9.95	10.71	21.61	17
1595.37	COLLEGE	10.35	5.67	21.61	17
1673.82	WINKFIELD	9.34	68.09	-2.04	18
1689.54	COLLEGE	9.17	6.38	-2.04	18
1718.41	ORROPAL	9.65	19.70	-2.04	19
1768.85	ST. JOHNS	9.01	40.80	-25.70	19
1783.52	COLLEGE	6.62	5.66	-25.70	19
1812.15	ORROPAL	8.50	22.00	-25.70	20
1861.80	ST. JOHNS	9.99	41.15	-49.35	20
1876.59	COLLEGE	4.64	4.79	-49.35	20
1935.15	SANTIAGO	10.16	53.92	-49.35	21
1941.46	LIMA	9.86	.00	-49.35	21
1943.93	QUITO	9.95	.00	-73.01	21
1950.98	FT. MYERS	10.25	.00	-73.01	21
1953.24	ROSMAN	10.32	.00	-73.01	21
1967.76	COLLEGE	6.06	4.20	-73.01	21
2031.46	SANTIAGO	6.60	57.65	-73.01	22
2037.70	LIMA	5.69	.00	-73.01	22
2048.03	FT. MYERS	4.34	4.64	-96.66	22
2050.07	ROSMAN	5.02	.00	-96.66	22
2058.65	COLLEGE	8.71	3.56	-96.66	22
2150.81	COLLEGE	10.26	83.45	-120.32	23
2190.08	JOHANNESBURG	8.00	29.00	-120.32	24
2244.90	COLLEGE	9.75	46.82	-143.97	24
2282.33	JOHANNESBURG	9.52	27.68	-143.97	25
2341.80	COLLEGE	5.57	49.95	-167.62	25
2356.49	WINKFIELD	9.35	9.12	-167.62	25
2450.57	WINKFIELD	9.93	84.73	168.72	26
2502.18	ORROPAL	10.24	41.68	168.72	27
2546.73	WINKFIELD	3.88	34.31	145.07	27
2547.10	ST. JOHNS	8.45	.00	145.07	27
2571.00	SANTIAGO	7.73	15.45	145.07	28
2598.57	ORROPAL	6.47	19.84	145.07	28
2640.83	ST. JOHNS	10.14	35.80	121.41	28
2646.27	ROSMAN	5.88	.00	121.41	28
2648.34	FT. MYERS	6.77	.00	121.41	28
2654.61	QUITO	9.54	.00	121.41	29
2657.29	LIMA	10.14	.00	121.41	29
2662.65	SANTIAGO	9.94	.00	121.41	29
2737.27	ST. JOHNS	3.86	64.69	97.76	29
2738.82	ROSMAN	10.25	.00	97.76	29
2741.25	FT. MYERS	9.90	.00	97.76	29
2749.89	QUITO	6.53	.00	97.76	30
2754.34	LIMA	3.42	.00	97.76	30
2920.88	COLLEGE	8.56	163.12	50.45	31
2977.99	JOHANNESBURG	10.17	48.55	50.45	32
2999.65	WINKFIELD	9.37	11.50	26.80	32
3014.74	COLLEGE	10.34	5.72	26.80	32

TABLE F1. - POST-INJECTION VHF TELEMETRY COVERAGE SEQUENCE - Continued

POST INJECTION COVERAGE SEQUENCE (INJECTION TIME= 10.00 MIN. AFTER LAUNCH)

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.	REV. NO.
3074.79	JOHANNESBURG	5.43	49.71	26.80	33
3092.84	WINKFIELD	9.97	12.63	3.14	33
3108.89	COLLEGE	9.58	6.09	3.14	33
3138.72	ORROAL	8.56	20.24	3.14	34
3189.12	ST. JOHNS	7.86	41.84	-20.51	34
3202.96	COLLEGE	7.24	5.98	-20.51	34
3231.03	ORROAL	9.66	20.84	-20.51	35
3281.05	ST. JOHNS	10.32	40.35	-44.17	35
3296.34	COLLEGE	4.84	4.97	-44.17	35
3354.62	SANTIAGO	9.44	53.43	-44.17	36
3361.41	LIMA	8.57	.00	-44.17	36
3363.97	QUITO	8.75	.00	-67.82	36
3370.81	FT. MYERS	9.61	.00	-67.82	36
3372.96	ROSMAN	9.90	.00	-67.82	36
3378.32	ST. JOHNS	4.64	.00	-67.82	36
3387.88	COLLEGE	5.51	4.92	-67.82	36
3449.86	SANTIAGO	8.58	56.47	-67.82	37
3455.73	LIMA	8.43	.00	-67.82	37
3465.64	FT. MYERS	7.70	1.48	-91.47	37
3467.92	ROSMAN	7.82	.00	-91.47	37
3478.65	COLLEGE	8.17	2.91	-91.47	37
3570.46	COLLEGE	10.07	83.64	-115.13	38
3611.25	JOHANNESBURG	5.29	30.72	-115.13	39
3664.08	COLLEGE	10.08	47.54	-138.78	39
3701.48	JOHANNESBURG	10.22	27.31	-138.78	40
3760.19	COLLEGE	7.04	48.49	-162.44	40
3776.14	WINKFIELD	8.33	8.90	-162.44	40
3869.82	WINKFIELD	10.27	85.35	173.91	41
3921.58	ORROAL	9.65	41.49	173.91	42
3965.22	WINKFIELD	6.27	33.99	150.25	42
3967.03	ST. JOHNS	6.76	.00	150.25	42
3992.20	SANTIAGO	5.11	18.41	150.25	43
4016.96	ORROAL	8.44	19.66	150.25	43
4060.10	ST. JOHNS	10.35	34.69	126.60	43
4074.90	QUITO	7.90	4.44	126.60	44
4077.30	LIMA	9.24	.00	126.60	44
4081.99	SANTIAGO	10.34	.00	126.60	44
4155.61	ST. JOHNS	6.51	63.28	102.95	44
4158.11	ROSMAN	10.34	.00	102.95	44
4160.41	FT. MYERS	10.34	.00	102.95	44
4168.15	QUITO	8.88	.00	102.95	45
4171.68	LIMA	7.56	.00	102.95	45
4254.49	ROSMAN	5.14	75.25	79.29	45
4340.43	COLLEGE	7.64	80.80	55.64	46
4397.54	JOHANNESBURG	9.37	49.46	55.64	47
4419.76	WINKFIELD	8.51	12.85	31.98	47
4434.12	COLLEGE	10.21	5.85	31.98	47
4492.83	JOHANNESBURG	8.11	48.50	31.98	48

TABLE F1. - POST-INJECTION VHF TELEMETRY COVERAGE SEQUENCE - Continued

POST INJECTION COVERAGE SEQUENCE (INJECTION TIME= 10.00 MIN. AFTER LAUNCH)

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.	REV. NO.
4512.08	WINKFIELD	10.29	11.14	8.33	48
4528.25	COLLEGE	9.92	5.88	8.33	48
4559.50	CORCRAL	6.73	21.33	8.33	49
4608.99	WINKFIELD	5.38	42.77	-15.33	49
4609.74	ST. JOHNS	6.15	.00	-15.33	49
4622.37	COLLEGE	7.83	6.48	-15.33	49
4650.27	CORCRAL	10.24	20.07	-15.33	50
4700.51	ST. JOHNS	10.33	40.00	-38.98	50
4715.99	COLLEGE	5.22	5.15	-38.98	50
4774.36	SANTIAGO	8.01	53.15	-38.98	51
4782.01	LIMA	5.92	.00	-38.98	51
4784.65	QUITO	6.27	.00	-62.63	51
4791.03	FT. MYERS	8.31	.11	-62.63	51
4793.00	ROSMAN	8.99	.00	-62.63	51
4796.20	ST. JOHNS	7.25	.00	-62.63	51
4807.97	COLLEGE	5.05	4.51	-62.63	51
4868.62	SANTIAGO	9.70	55.59	-62.63	52
4874.43	LIMA	9.78	.00	-62.63	52
4884.16	FT. MYERS	9.33	.00	-86.29	52
4886.49	ROSMAN	9.29	.00	-86.29	52
4898.70	COLLEGE	7.60	2.92	-86.29	52
4990.20	COLLEGE	9.79	83.90	-109.94	53
5083.38	COLLEGE	10.28	83.39	-133.60	54
5120.98	JOHANNESBURG	10.34	27.31	-133.60	55
5178.84	COLLEGE	8.11	47.52	-157.25	55
5196.01	WINKFIELD	6.72	9.07	-157.25	55
5289.13	WINKFIELD	10.36	86.40	179.10	56
5341.21	CORCRAL	8.45	41.72	179.10	57
5384.09	WINKFIELD	7.79	34.43	155.44	57
5387.65	ST. JOHNS	3.54	.00	155.44	57
5435.72	CORCRAL	9.60	44.53	155.44	58
5479.46	ST. JOHNS	10.27	34.14	131.79	58
5496.18	QUITO	4.31	6.45	131.79	59
5497.84	LIMA	7.37	.00	131.79	59
5501.63	SANTIAGO	10.26	.00	131.79	59
5574.40	ST. JOHNS	8.11	62.50	108.13	59
5577.58	ROSMAN	9.97	.00	108.13	59
5579.79	FT. MYERS	10.23	.00	108.13	59
5587.02	QUITO	10.01	.00	108.13	60
5590.22	LIMA	9.36	.00	108.13	60
5597.49	SANTIAGO	5.59	.00	108.13	60
5672.75	ROSMAN	7.72	69.67	84.48	60
5676.29	FT. MYERS	5.02	.00	84.48	60
5760.09	COLLEGE	6.41	78.77	60.82	61
5817.44	JOHANNESBURG	7.74	50.94	60.82	62
5840.10	WINKFIELD	7.29	14.92	37.17	62
5853.52	COLLEGE	9.95	6.12	37.17	62
5911.46	JOHANNESBURG	9.52	48.00	37.17	63

TABLE F1. - POST-INJECTION VHF TELEMETRY COVERAGE SEQUENCE -Continued

POST INJECTION COVERAGE SEQUENCE (INJECTION TIME= 10.00 MIN. AFTER LAUNCH)

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE F.LONG.,DEG.	REV. NO.
5931.51	WINKFIELD	10.35	10.52	13.52	63
5947.61	COLLEGE	10.16	5.74	13.52	63
5981.30	ORROPAL	3.03	23.53	13.52	64
6027.11	WINKFIELD	7.51	42.78	-10.14	64
6031.09	ST. JOHNS	3.13	.00	-10.14	64
6041.75	COLLEGE	8.40	7.54	-10.14	64
6069.80	ORROPAL	10.35	19.65	-10.14	65
6120.17	ST. JOHNS	10.06	40.03	-33.79	65
6135.56	COLLEGE	5.71	5.32	-33.79	65
6166.41	ORROPAL	4.35	25.14	-33.79	66
6194.67	SANTIAGO	5.27	23.91	-33.79	66
6211.86	FT. MYERS	5.89	11.92	-57.45	66
6213.43	ROSMAN	7.42	.00	-57.45	66
6214.71	ST. JOHNS	8.74	.00	-57.45	66
6227.99	COLLEGE	4.74	4.54	-57.45	66
6287.60	SANTIAGO	10.26	54.87	-57.45	67
6293.51	LIMA	10.33	.00	-57.45	67
6303.14	FT. MYERS	10.14	.00	-81.10	67
6305.47	ROSMAN	10.08	.00	-81.10	67
6318.80	COLLEGE	6.99	3.25	-81.10	67
6410.02	COLLEGE	9.42	84.22	-104.76	68
6502.78	COLLEGE	10.36	83.34	-128.41	69
6540.80	JOHANNESBURG	9.93	27.66	-128.41	70
6597.67	COLLEGE	8.90	46.94	-152.06	70
6616.45	WINKFIELD	3.84	9.88	-152.06	70
6635.83	JOHANNESBURG	6.72	15.54	-152.06	71
6708.51	WINKFIELD	10.19	65.96	-175.72	71
6761.26	ORROPAL	6.25	42.55	-175.72	72
6803.12	WINKFIELD	8.87	35.61	160.63	72
6854.69	ORROPAL	10.21	42.69	160.63	73
6898.91	ST. JOHNS	9.87	34.02	136.97	73
6919.66	LIMA	3.05	10.87	136.97	74
6921.58	SANTIAGO	9.73	.00	136.97	74
6993.40	ST. JOHNS	9.18	62.09	113.32	74
6997.26	ROSMAN	9.07	.00	113.32	74
6999.42	FT. MYERS	9.55	.00	113.32	74
7006.29	QUITO	10.36	.00	113.32	75
7009.27	LIMA	10.19	.00	113.32	75
7015.62	SANTIAGO	8.13	.00	113.32	75
7091.51	ROSMAN	9.18	67.77	89.66	75
7094.36	FT. MYERS	7.89	.00	89.66	75
7179.98	COLLEGE	4.61	77.72	66.01	76
7238.15	JOHANNESBURG	4.33	53.56	66.01	77
7260.78	WINKFIELD	5.55	18.30	42.36	77
7272.94	COLLEGE	9.54	6.61	42.36	77
7330.41	JOHANNESBURG	10.22	47.92	42.36	78
7351.12	WINKFIELD	10.16	10.50	18.70	78
7366.96	COLLEGE	10.31	5.68	18.70	78

TABLE F1. - POST-INJECTION VHF TELEMETRY COVERAGE SEQUENCE - Continued

POST INJECTION COVERAGE SEQUENCE (INJECTION TIME= 10.00 MIN. AFTER LAUNCH)

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.	REV. NO.
7445.71	WINKFIELD	8.82	68.43	-4.95	79
7461.13	COLLEGE	8.91	6.60	-4.95	79
7489.61	ORROPAL	10.03	19.58	-4.95	80
7540.06	ST. JOHNS	9.48	40.41	-28.61	80
7555.06	COLLEGE	6.29	5.52	-28.61	80
7584.22	ORROPAL	7.49	22.87	-28.61	81
7634.57	ROSMAN	4.56	42.87	-52.26	81
7633.56	ST. JOHNS	9.66	.00	-52.26	81
7647.91	COLLEGE	4.62	4.69	-52.26	81
7706.77	SANTIAGO	10.33	54.24	-52.26	82
7712.90	LIMA	10.22	.00	-52.26	82
7722.46	FT. MYERS	10.36	.00	-75.91	82
7724.75	ROSMAN	10.36	.00	-75.91	82
7738.92	COLLEGE	6.39	3.81	-75.91	82
7803.94	SANTIAGO	4.77	58.63	-75.91	83
7811.09	LIMA	2.04	2.38	-75.91	83
7824.11	ROSMAN	.29	10.98	-99.57	83
7829.91	COLLEGE	8.98	5.51	-99.57	83
7922.28	COLLEGE	10.33	83.39	-123.22	84
7961.00	JOHANNESBURG	8.92	28.39	-123.22	85
8016.65	COLLEGE	9.49	46.74	-146.88	85
8054.21	JOHANNESBURG	8.82	28.07	-146.88	86
8114.11	COLLEGE	4.43	51.08	-170.53	86
8127.98	WINKFIELD	9.74	9.43	-170.53	86
8222.26	WINKFIELD	9.63	84.53	165.81	87
8273.83	ORROPAL	10.36	41.94	165.81	88
8319.71	WINKFIELD	.68	35.52	142.16	88
8318.49	ST. JOHNS	9.10	.00	142.16	88
8341.87	SANTIAGO	8.65	14.29	142.16	89
8371.03	ORROPAL	4.64	20.51	142.16	89
8412.52	ST. JOHNS	9.88	36.85	118.51	89
8417.25	ROSMAN	7.40	.00	118.51	89
8419.37	FT. MYERS	8.10	.00	118.51	89
8425.90	QUITO	10.04	.00	118.51	90
8428.70	LIMA	10.34	.00	118.51	90
8434.39	SANTIAGO	9.48	.00	118.51	90
8510.52	ROSMAN	10.01	66.65	94.85	90
8513.07	FT. MYERS	9.39	.00	94.85	90
8522.74	QUITO	3.95	.28	94.85	91
8682.21	WINKFIELD	2.41	155.53	47.54	92
8692.40	COLLEGE	8.97	7.77	47.54	92
8749.59	JOHANNESBURG	10.34	48.22	47.54	93
8770.92	WINKFIELD	9.73	10.99	23.89	93
8786.33	COLLEGE	10.36	5.68	23.89	93
8848.05	JOHANNESBURG	2.01	51.36	23.89	94
8864.60	WINKFIELD	9.66	14.53	.23	94
8880.49	COLLEGE	9.36	6.24	.23	94
8909.73	ORROPAL	9.25	19.88	.23	95

TABLE F1. - POST-INJECTION VHF TELEMETRY COVERAGE SEQUENCE - Concluded

POST INJECTION COVERAGE SEQUENCE (INJECTION TIME= 10.00 MIN. AFTER LAUNCH)

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.	REV. NO.
8960.17	ST. JOHNS	8.56	41.19	-23.42	95
8974.52	COLLEGE	6.89	5.78	-23.42	95
9002.84	ORROAL	9.10	21.44	-23.42	96
9052.68	ST. JOHNS	10.18	40.74	-47.07	96
9067.73	COLLEGE	4.71	4.87	-47.07	96
9126.13	SANTIAGO	9.92	53.69	-47.07	97
9132.62	LIMA	9.41	.00	-47.07	97
9135.13	QUITO	9.53	.00	-70.73	97
9142.10	FT. MYERS	10.04	.00	-70.73	97
9144.32	ROSMAN	10.19	.00	-70.73	97
9151.90	ST. JOHNS	.92	.00	-70.73	97
9159.05	COLLEGE	5.81	6.23	-70.73	97
9221.93	SANTIAGO	7.61	57.07	-70.73	98
9227.94	LIMA	7.15	.00	-70.73	98
9238.03	FT. MYERS	6.19	2.93	-94.38	98
9240.22	ROSMAN	6.50	.00	-94.38	98
9249.88	COLLEGE	8.48	3.15	-94.38	98
9341.88	COLLEGE	10.19	83.52	-118.04	99
9381.70	JOHANNESBURG	7.04	29.63	-118.04	100
9435.76	COLLEGE	9.91	47.02	-141.69	100
9473.14	JOHANNESBURG	9.90	27.47	-141.69	101
9532.29	COLLEGE	6.28	49.24	-165.35	101
9547.55	WINKFIELD	8.96	8.98	-165.35	101
9641.47	WINKFIELD	10.11	84.96	171.00	102
9693.13	ORROAL	10.05	41.55	171.00	103
9737.22	WINKFIELD	5.10	34.05	147.35	103
9738.26	ST. JOHNS	7.81	.00	147.35	103
9762.64	SANTIAGO	6.78	16.57	147.35	104
9789.04	ORROAL	7.47	19.61	147.35	104
9831.74	ST. JOHNS	10.27	35.23	123.69	104
9838.02	ROSMAN	4.04	.00	123.69	104
9839.98	FT. MYERS	5.23	.00	123.69	104
9845.90	QUITO	8.96	.69	123.69	105
9848.48	LIMA	9.84	.00	123.69	105
9853.56	SANTIAGO	10.17	.00	123.69	105
9927.68	ST. JOHNS	5.24	63.95	100.04	105
9929.72	ROSMAN	10.35	.00	100.04	105
9932.09	FT. MYERS	10.16	.00	100.04	105
9940.26	QUITO	7.77	.00	100.04	106
9944.12	LIMA	5.80	.00	100.04	106

TABLE F2. - POST-INJECTION COLLEGE AND ROSMAN TELEMETRY COVERAGE SEQUENCE

POST-INJECTION COLLEGE AND ROSMAN TELEMETRY COVERAGE SEQUENCE

	NORTH LAT, DEG	EAST LONG, DEG	MIN ELEV, DEG
STATION 1 COLLEGE	64.90	212.10	5.00
STATION 2 ROSMAN	35.20	277.10	5.00

ORBIT ALT= 500.0 KM.
ORBIT INCL= 97.38 DEG.
LAUNCH-TO-INJECTION ANGLE= 20.00 DEG.
ORBIT PERIOD= 94.62 MINUTES
EARTH RADIUS= 33.0 PERCENT OVER ACTUAL (REFRACTION CORRECTION)
MINIMUM TIME= .00 MIN
WESTWARD SHIFT OF ASC. NODE= 23.65 DEG./ORBIT
LAUNCH LONGITUDE= -120.63 DEG. EAST
LAUNCH LATITUDE= 34.76 DEG. NORTH
LAUNCH VELOCITY HAS SOUTHERLY COMPONENT
LAUNCH TO INJECTION TIME= 10.00 MIN.
TOTAL TIME= 10000.00 MIN.

STATION	MAX. ARC RANGE VISIBLE(DEG)	MAX. DIST,KM.
1	19.71	2329.1
2	19.71	2329.1

TABLE F2. - POST-INJECTION COLLEGE AND ROSMAN TELEMETRY COVERAGE SEQUENCE - Continued

POST INJECTION COVERAGE SEQUENCE (INJECTION TIME= 10.00 MIN. AFTER LAUNCH)

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.	REV. NO.
91.88	COLLEGE	9.92		37.58	1
185.96	COLLEGE	10.18	84.16	13.92	2
280.11	COLLEGE	8.44	83.97	-9.73	3
373.92	COLLEGE	5.76	85.37	-33.38	4
451.89	ROSMAN	7.26	72.21	-57.04	5
466.39	COLLEGE	4.73	7.25	-57.04	5
543.81	ROSMAN	10.12	72.69	-80.69	6
557.22	COLLEGE	6.94	3.29	-80.69	6
648.41	COLLEGE	9.39	84.25	-104.35	7
741.14	COLLEGE	10.36	83.34	-128.00	8
835.99	COLLEGE	8.95	84.48	-151.66	9
1235.65	ROSMAN	8.97	390.70	113.73	14
1329.83	ROSMAN	9.26	85.21	90.07	15
1418.39	COLLEGE	4.43	79.30	66.42	15
1511.30	COLLEGE	9.50	88.48	42.76	16
1605.32	COLLEGE	10.32	84.51	19.11	17
1699.48	COLLEGE	8.95	83.84	-4.54	18
1793.42	COLLEGE	6.33	84.99	-28.20	19
1873.13	ROSMAN	4.22	73.38	-51.85	20
1886.31	COLLEGE	4.62	8.96	-51.85	20
1963.11	ROSMAN	10.36	72.18	-75.51	21
1977.34	COLLEGE	6.34	3.86	-75.51	21
2061.62	ROSMAN	1.96	77.94	-99.16	22
2068.31	COLLEGE	8.95	4.73	-99.16	22
2160.65	COLLEGE	10.32	83.39	-122.82	23
2254.98	COLLEGE	9.53	84.01	-146.47	24
2352.36	COLLEGE	4.61	87.84	-170.12	25
2655.68	ROSMAN	7.22	298.71	118.91	29
2748.86	ROSMAN	10.05	85.96	95.26	30
2930.76	COLLEGE	8.91	171.85	47.95	31
3024.68	COLLEGE	10.36	85.01	24.30	32
3118.85	COLLEGE	9.40	83.80	.64	33
3212.88	COLLEGE	6.94	84.64	-23.01	34
3306.11	COLLEGE	4.72	86.30	-46.67	35
3382.70	ROSMAN	10.16	71.86	-70.32	36
3397.47	COLLEGE	5.76	4.61	-70.32	36
3478.46	ROSMAN	6.72	75.23	-93.97	37
3488.28	COLLEGE	8.44	3.10	-93.97	37
3580.26	COLLEGE	10.17	83.54	-117.63	38
3674.11	COLLEGE	9.94	83.67	-141.28	39
3770.57	COLLEGE	6.40	86.53	-164.94	40
4076.58	ROSMAN	3.58	299.61	124.10	44
4168.08	ROSMAN	10.36	87.92	100.45	45
4265.53	ROSMAN	2.73	87.10	76.79	46
4350.28	COLLEGE	8.12	82.02	53.14	46
4444.06	COLLEGE	10.29	85.66	29.48	47
4538.20	COLLEGE	9.77	83.86	5.83	48
4632.30	COLLEGE	7.55	84.33	-17.83	49

TABLE F2. - POST-INJECTION COLLEGE AND ROSMAN TELEMETRY COVERAGE SEQUENCE - Concluded

POST INJECTION COVERAGE SEQUENCE (INJECTION TIME= 10.00 MIN. AFTER LAUNCH)

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.	REV. NO.
4725.81	COLLEGE	5.02	85.97	-41.48	50
4802.58	ROSMAN	9.50	71.75	-65.13	51
4817.57	COLLEGE	5.26	5.50	-65.13	51
4896.76	ROSMAN	8.69	73.93	-88.79	52
4908.31	COLLEGE	7.88	2.86	-88.79	52
4999.96	COLLEGE	9.93	83.76	-112.44	53
5093.35	COLLEGE	10.20	83.46	-136.10	54
5189.11	COLLEGE	7.63	85.56	-159.75	55
5587.46	ROSMAN	10.21	390.72	105.63	60
5683.13	ROSMAN	6.69	85.46	81.98	61
5769.88	COLLEGE	7.05	80.06	58.32	61
5863.45	COLLEGE	10.09	86.52	34.67	62
5957.56	COLLEGE	10.06	84.02	11.02	63
6051.69	COLLEGE	8.13	84.08	-12.64	64
6145.42	COLLEGE	5.46	85.59	-36.29	65
6222.80	ROSMAN	8.28	71.93	-59.95	66
6237.63	COLLEGE	4.87	6.55	-59.95	66
6315.56	ROSMAN	9.77	73.06	-83.60	67
6328.39	COLLEGE	7.29	3.06	-83.60	67
6419.74	COLLEGE	9.61	84.06	-107.26	68
6512.70	COLLEGE	10.34	83.35	-130.91	69
6607.86	COLLEGE	8.55	84.82	-154.56	70
7007.03	ROSMAN	9.58	390.62	110.82	75
7101.71	ROSMAN	8.57	85.10	87.16	76
7189.63	COLLEGE	5.58	79.35	63.51	76
7282.86	COLLEGE	9.76	87.65	39.86	77
7376.91	COLLEGE	10.25	84.30	16.20	78
7471.07	COLLEGE	8.67	83.91	-7.45	79
7564.95	COLLEGE	6.00	85.20	-31.11	80
7643.53	ROSMAN	6.19	72.58	-54.76	81
7657.60	COLLEGE	4.66	7.88	-54.76	81
7734.70	ROSMAN	10.28	72.44	-78.41	82
7748.50	COLLEGE	6.68	3.52	-78.41	82
7839.60	COLLEGE	9.20	84.42	-102.07	83
7932.15	COLLEGE	10.36	83.35	-125.72	84
8026.77	COLLEGE	9.23	84.26	-149.38	85
8124.90	COLLEGE	3.05	88.90	-173.03	86
8426.84	ROSMAN	8.33	298.89	116.01	90
8520.61	ROSMAN	9.67	85.44	92.35	91
8609.78	COLLEGE	3.20	79.50	68.70	91
8702.30	COLLEGE	9.27	89.32	45.04	92
8796.28	COLLEGE	10.35	84.71	21.39	93
8890.44	COLLEGE	9.15	83.81	-2.27	94
8984.42	COLLEGE	6.60	84.83	-25.92	95
9077.47	COLLEGE	4.64	86.45	-49.57	96
9154.13	ROSMAN	10.33	72.02	-73.23	97
9168.63	COLLEGE	6.08	4.17	-73.23	97
9251.07	ROSMAN	4.84	76.36	-96.88	98
9259.53	COLLEGE	8.73	3.62	-96.88	98
9351.71	COLLEGE	10.27	83.45	-120.54	99
9445.82	COLLEGE	9.73	83.84	-144.19	100
9542.75	COLLEGE	5.49	87.21	-167.85	101
9847.12	ROSMAN	6.02	298.87	121.19	105
9939.73	ROSMAN	10.24	86.59	97.54	106

APPENDIX G

STADAN DATA ACQUISITION CAPABILITIES AND SYSTEM DESCRIPTIONS

APPENDIX G

STADAN DATA ACQUISITION CAPABILITIES AND SYSTEM DESCRIPTIONS

This appendix contains tabular data on the capabilities of the STADAN stations in the areas of telemetry and command systems. This information was obtained from reference 4 where further details can be found.

TABLE G1. - GEODETIC LOCATION OF STADAN STATIONS

Station	East longitude	Latitude
College, Alaska	212-09-47.383	N-64-52-18.582
Ft. Myers, Fla.	278-08-03.887	N-26-32-53.516
Alaska	212-29-05.794	N-64-58-36.572
Gilmore Creek, Alaska	212-30-18.045	N-64-58-42.667
Carnarvon	289-18	S-24-30
Johannesburg, South Africa	027-42-27.931	S-25-52-58.862
(40-foot dish)	027.42-27.931	S-25-53-08.025
Lima, Peru	282-50-58.184	S-11-46-36.492
Quito, Ecuador	281-25-14.770	S-00-37-21.751
(40-foot dish)	281-25-08.109	S-00-37-23.241
Rosman, N. C.	277-07-40.532	N-35-12-00.499
St. Johns, Newfoundland	307-16-43.240	N-47-44-29.049
Tananarive	47-30	S-18-30
Santiago, Chile	289-19-51.283	S-33-08-58.106
(40-foot dish)	289-19-51.283	S-33-09-04.934
Winkfield, England	359-18-14.615	N-51-26-44.122
Orroral, Australia	148-57-0	S-35-38-0

TABLE G2. - GSFC SPACE-TO-GROUND TELEMETRY FREQUENCY AND CHANNEL ALLOCATIONS

Frequency bands, MHz	GSFC application	Center freq, MHz	Bandwidth	
			Nominal	Maximum
136 - 137	Space research telemetering and tracking (Minitrack)	136.020 to 136.980	30 kHz	90 kHz (max.)
137 - 138	Space research telemetering	137.020 to 137.980	30 kHz	90 kHz (max.)
400.05 - 401	Space research telemetering	400.100 to 400.950	50 kHz	300 kHz (max.)
401 - 402	Space research telemetering	401.000 to 401.950	50 kHz	300 kHz (max.)
1700 -1710	Space research telemetering	1705	1.5 kHz	-

TABLE G3. - MINITRACK TELEMETRY ANTENNAS

Nine yagi antenna characteristics

Center frequency	136.5 MHz
Frequency range	135-138 MHz
Gain	19.2 dB above isotropic
Polarization	Horizontal, vertical, right and left circular
"E" -- and "H" -- plane pattern	19.5 deg at the half-power points
Sidelobes	Down 12 dB or better
VSWR	Under 1.1 at 136.5 MHz Under 2.0 from 135-135 MHz
Nominal impedance	50 ohms

Sixteen yagi antenna characteristics

Center frequency	136.5 MHz
Frequency range	135-138 MHz
Gain	22.4 dB above isotropic
Polarization	Horizontal, vertical, right and left circular
"E" and "H" plane pattern	13 deg
VSWR	Under 1.1 at 136.5 MHz Under 1.5 from 135-138 MHz

TABLE G4. - MINITRACK TELEMETRY CHARACTERISTICS

Preamplifier characteristics

Noise figure	3.5 dB nominal
Gain	35 dB
Center frequency	136.5 MHz
Bandwidth	4.3 MHz
Output impedance	50 ohms

Receiver characteristics

Receiver	Triple conversion superheterodyne
Local oscillators	Crystal controlled
Tuning range	136-137 MHz
Noise figure	Less than 3 dB
Image frequency	At least 60 dB
I. F. frequencies	Predetection bandwidths
1st 20.75 MHz	1 MHz
2nd 3.25 MHz	300 kHz or 100 kHz
3rd 455 kHz	30 kHz or 10 kHz
Converted signal	Bandwidth in use
555 kHz	1 MHz
162 kHz	300 kHz
62 kHz	100 kHz
22 kHz	30 kHz
12 kHz	10 kHz
FM detection	Limiter and Foster-Seeley discriminator (all bandwidths)
AM detection	Unbalanced diode with post-detection filtering (all bandwidths)
AGC response	3 Hz, 10 Hz, 30 Hz, "A" pulse (slow response): "B" pulse (fast response): manual gain control
BFO	±30 kHz
Calibration oscillator	455 Hz ±10 Hz
Calibrator attenuator	-60 dBm to -150 dBm in 5-dB steps

TABLE G5. - PCM DATA HANDLING EQUIPMENT CHARACTERISTICS

Signal conditioner	
PCM inputs	RZ, NRZ-(C), NRZ-(M), split phase
Bit rate range	1-200 000 bits/sec
Code type output	NRZ-(C)
Synchronization	To -6 dB (peak signal/rms noise)
Bit rate tracking range	±10 percent bit-rate frequency, minimum
Bit jitter capability	±25 percent bit period
Synchronizer	
Number of formats	10
Word length	32 bits, max.
Frame length	512 words, max.
Subframe length	512 frames, max.
Parallel computer word output	37 lines
Serial output	Two lines (one for remote)
Data word selector	
DWS outputs	Nine-bit parallel digital readout Timing clock
Display units	
Outputs	Chart recorder Bar graph Decimal
PCM simulator	
Type data	Serial
Code type	RZ, NRZ-(C), NRZ-(M), split phase
Bit frequency	Variable 1-200 000 bits/sec
Word length	4-32 bits
Frame length	512 words max.
Subframe length	512 frames max.

TABLE G6. - R & RR SYSTEM PERFORMANCE CHARACTERISTICS

Range resolution, S band/vhf	±15 m
Range-rate resolution, S band	±0.1 m/sec
Range-rate resolution, vhf	±1.0 m/sec
S-band up-link frequency	1801 MHz nominal
S-band down-link frequency	2253 MHz nominal
VHF up-link frequency	147 to 151 MHz
VHF down-link frequency	136 to 137 MHz
Data rates	8, 4, 2, or 1 measurements per second
Data format	5-level Baudot code
S-band transmitter power output	1 to 10 kW
VHF transmitter power output	1 to 10 kW
Modulation system	PM/PM
S-band receiving antenna	14-ft parabola with Cassegrain feed (X-Y mounted)
Frequency	2253 MHz (nominal)
Gain	37 dB
Tracking method	Amplitude monopulse
Polarization	Vertical linear Horizontal linear Right-hand circular Left-hand circular
S-band transmitting antenna	14-ft parabola with Cassegrain feed (X-Y mounted)
Gain	35 dB

TABLE G6. - R & RR SYSTEM PERFORMANCE CHARACTERISTICS
(Continued)

Polarization	Right-hand circular Left-hand circular
Frequency	1801 MHz (nominal)
Carrier and subcarrier loop tracking bandwidth	400 and 20 Hz
Carrier and subcarrier loop acquisition bandwidth	1600, 800, 300, 20 Hz
Range tone tracking	For 500 kHz, 100 kHz, and 20 kHz tones: 1.0 or 0.1 Hz. For remaining tones: 0.25 or 0.1 Hz
VHF receiving system	
Frequency	136 to 137 MHz
I.F. frequencies	60 MHz and 10 MHz (dual conversion)
Noise figure	3 dB, max.
Dynamic signal range	-66 to -144 dBm
L.O. frequency	196 to 197 MHz (voltage controlled)
VHF antenna (receive and transmit)	Slotted array (X-Y mounted
Frequency range	136 to 150 MHz
Gain	21.25 dB (transmitting) 20.5 dB (receiving)
Polarization	Vertical linear Horizontal linear Right-hand circular Left-hand circular

TABLE G6. - R & RR SYSTEM PERFORMANCE CHARACTERISTICS
(Concluded)

S-band receiving system

Frequency	2253 MHz, nominal
I..F. frequencies	60 MHz and 10 MHz (dual conversion)
Noise figure	3 dB, max.
Dynamic signal range	-78 to -148 dBm
Second i.f. bandwidth	10 kHz
Loop tracking bandwidth	160 and 10 Hz
Loop acquisition bandwidth	400, 140, 10 Hz
Range-tone tracking bandwidth	For 100 kc tone: 2.0 Hz or 0.1 Hz. For remaining tones: 1.0 Hz or 0.1 Hz

TABLE G7. - COMMAND TRANSMITTERS

There are four types of command am. transmitters that will normally be used with the station command consoles. They are listed below with some pertinent characteristics.

The transmitter is energized 0.5 sec prior to the command message.

	GE-4BT91A1	ITA 2500H	Collins 242G	Hughes
Frequency	147-157 MHz	120-155 MHz	108-152 MHz	120-122 MHz 147-157 MHz
Maximum rf power output	5000 W cw	2500 W cw	200 W cw	2500 W cw
Output attenuation	6 or 10 dB	5 dB or variable by detuning	detuning	0-10 dB in 2 dB steps
Audio distortion	5% max. at 95% modulation 100 to 12 000 Hz	5% max. at 95% modulation 100 to 12 000 Hz	10% max. at 90% modulation 300 to 10 000 Hz	5% max. at 95% modulation 100 to 12 000 Hz
Stability	±0.001% per day 0 to +50°C	±200 Hz of nominal frequency +30°F to 120°F	±0.002%	±0.001%
Location	Quito, Ecuador Santiago, Chile Johannesburg, S. Africa Rosman, N. Carolina Fairbanks, Alaska	Fairbanks, Alaska Rosman, N. Carolina	Fairbanks, Alaska Orroral, Australia Barstow, Calif. Ft. Myers, Fla. Quito, Ecuador Lima, Peru Santiago, Chile Saint Johns, Newfoundland Winkfield, England Johannesburg, S. Africa Tananarive, Malagasy	Rosman, N. C. Barstow, Calif. Ft. Myers, Fla. Fairbanks, Alaska Tananarive, Malagasy Winkfield, Eng.

TABLE G8. - COMMAND ANTENNAS

There are three types of command antennas that are used at the various STADAN stations. They are listed below with pertinent characteristics.

	RSI-054	RSI-071-024	TACO D-1444
Type	Disc-on-rod, crossed dipoles, cavity, 10 discs (mod. 0-3) or 5 discs (mod. 4)	9 disc-on-rod array, crossed dipoles, cavity	Dual 7 element Yagi/crossed folded dipoles
Frequency	123 and 148-150 MHz	123 and 148-150 MHz	123 and 148 MHz
Gain	13 dB nominal (mods 0-3) or 9.5 dB nom (mod 4)	22 dB nominal	13 dB nominal
Power	3 kW av	5 kW av	2 kW nominal
Polarization	Right, Left, and 2 linears	Right, Left, and 2 linears	Right, Left, and 2 linears
Beamwidth	36° nom (mods 0-3) or 54° nom (mod 4) at 1/2 power pts	15° nom at 1/2 power pts	36° nominal at 1/2 power pts
Control and Speed	On 85' tracking antenna, 3°/sec	Slaved or manual, X-Y Dalmo-Victor (SATAN pedestal). 5°/sec	Manual, CDR HAM-M rotator. 6°/sec
VSWR, max.	1.3 to 1	1.25 to 1	1.4 to 1
Locations	Rosman, N. Carolina (2) and Orroral, Australia, mods 0-3; Fairbanks, Alaska mod 4	Quito, Ecuador Santiago, Chile Johannesburg, S. Africa Fairbanks, Alaska (2) Rosman, N. Carolina (2) Orroral, Australia (2) Tananarive, Malagasy (2) Winkfield, England Barstow, California Ft. Myers, Florida Lima, Peru	Fairbanks, Alaska Orroral, Australia Barstow, California Ft. Myers, Florida Quito, Ecuador Lima, Peru Santiago, Chile St. Johns, Newfoundland Winkfield, England Johannesburg, S. Africa Tananarive, Malagasy

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APPENDIX H
TELEMETRY COVERAGE PROFILES

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APPENDIX H
TELEMETRY COVERAGE PROFILES

This appendix contains examples of telemetry coverage for typical days of operation that are expected to be encountered during the lifetime of the satellite. Table H1 and H2 contain vhf and S-band telemetry coverage information, respectively. There are 24 typical days represented corresponding to 24 different east longitude ascending nodes (degrees). This covers all of the possible "coverage days" to a resolution of 1° in nodal longitude.

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES

VHF TELEMETRY COVERAGE PROFILES

			NORTH LAT. DEG	EAST LONG. DEG	MIN ELEV. DEG
STATION	1	COLLEGE	64.90	212.10	5.00
STATION	2	FT. MYERS	26.50	278.10	5.00
STATION	3	JOHANNESBURG	-25.90	27.70	5.00
STATION	4	LIMA	-11.80	282.80	5.00
STATION	5	CORCORAL	-35.60	148.90	5.00
STATION	6	QUITO	-.60	281.40	5.00
STATION	7	ROSMAN	35.20	277.10	5.00
STATION	8	ST. JOHNS	47.70	307.30	5.00
STATION	9	SANTIAGO	-33.20	289.30	5.00
STATION	10	WINKFIELD	51.50	359.30	5.00

ORBIT ALT= 500.0 KM.
ORBIT INCL= 97.38 DEG.
NODAL LONGITUDE STEP SIZE= 1.00 DEG.
ORBIT PERIOD= 94.62 MINUTES
EARTH RADIUS= 33.3 PERCENT OVER ACTUAL (REFRACTION CORRECTION)
MINIMUM TIME= 3.00 MIN
WESTWARD SHIFT OF ASC. NODE= 23.65 DEG./ORBIT

STATION	MAX. ARC RANGE VISIBLE(DEG)	MAX. DIST.KM.
1	19.73	2331.1
2	19.73	2331.1
3	19.73	2331.1
4	19.73	2331.1
5	19.73	2331.1
6	19.73	2331.1
7	19.73	2331.1
8	19.73	2331.1
9	19.73	2331.1
10	19.73	2331.1

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = .00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.67	WINKFIELD	9.64		.00
24.55	COLLEGE	9.35	6.24	
53.75	ORROPAL	9.30	19.85	
104.19	ST. JOHNS	8.62	41.14	-23.65
118.56	COLLEGE	6.88	5.76	
146.92	ORROPAL	9.05	21.48	
196.74	ST. JOHNS	10.17	40.76	-47.31
211.76	COLLEGE	4.72	4.85	
270.18	SANTIAGO	9.96	53.70	
276.65	LIMA	9.47	.00	
279.16	QUITO	9.60	.00	-70.96
286.13	FT. MYERS	10.08	.00	
288.36	ROSMAN	10.22	.00	
303.07	COLLEGE	5.85	4.49	
366.03	SANTIAGO	7.53	57.11	
372.06	LIMA	7.04	.00	
382.16	FT. MYERS	6.05	3.06	-94.62
384.35	ROSMAN	6.39	.00	
393.90	COLLEGE	8.52	3.17	
485.92	COLLEGE	10.21	83.51	-118.27
525.68	JOHANNESBURG	7.17	29.55	
579.83	COLLEGE	9.91	46.98	-141.93
617.21	JOHANNESBURG	9.88	27.48	
676.39	COLLEGE	6.23	49.30	-165.58
691.59	WINKFIELD	9.01	8.97	
785.53	WINKFIELD	10.10	84.93	-189.23
837.18	ORROPAL	10.08	41.55	
881.31	WINKFIELD	5.01	34.05	-212.89
882.29	ST. JOHNS	7.90	.00	
906.62	SANTIAGO	6.91	16.43	
933.14	ORROPAL	7.39	19.61	
975.80	ST. JOHNS	10.27	35.27	-236.54
981.96	ROSMAN	4.30	.00	
983.94	FT. MYERS	5.44	.00	
989.91	QUITO	9.04	.53	
992.51	LIMA	9.88	.00	
997.61	SANTIAGO	10.16	.00	
1071.77	ST. JOHNS	5.14	64.00	-260.20
1073.78	ROSMAN	10.35	.00	
1076.15	FT. MYERS	10.15	.00	
1084.36	QUITO	7.68	.00	
1088.27	LIMA	5.63	.00	
1255.95	COLLEGE	8.24	162.06	-307.50
1313.04	JOHANNESBURG	9.94	48.84	
1334.93	WINKFIELD	9.08	11.95	-331.16
1349.75	COLLEGE	10.31	5.75	
1409.16	JOHANNESBURG	6.73	49.10	
1427.78	WINKFIELD	10.14	11.88	-354.81
1443.90	COLLEGE	9.74	5.98	
1474.22	ORROPAL	7.97	20.58	
1525.93	WINKFIELD	3.08	43.75	-378.47
1524.58	ST. JOHNS	7.28	.00	
1537.99	COLLEGE	7.49	6.13	
1565.96	ORROPAL	9.96	20.48	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 1.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.62	WINKFIELD	9.76		1.00
24.57	COLLEGE	9.43	6.19	
53.95	CORCORAL	9.10	19.95	
104.38	ST. JOHNS	8.40	41.34	-22.65
118.60	COLLEGE	7.00	5.82	
146.85	CORCORAL	9.28	21.25	
196.74	ST. JOHNS	10.23	40.61	-46.31
211.85	COLLEGE	4.76	4.88	
270.22	SANTIAGO	9.82	53.60	
276.78	LIMA	9.23	.00	
279.30	QUITO	9.37	.00	-69.96
286.24	FT. MYERS	9.96	.00	
288.45	ROSMAN	10.14	.00	
303.24	COLLEGE	5.74	4.65	
365.86	SANTIAGO	7.91	56.89	
371.83	LIMA	7.55	.00	
381.86	FT. MYERS	6.66	2.48	-93.62
384.08	ROSMAN	6.91	.00	
394.05	COLLEGE	8.41	3.05	
486.00	COLLEGE	10.17	83.54	-117.27
526.04	JOHANNESBURG	6.66	29.87	
579.81	COLLEGE	9.97	47.11	-140.93
617.19	JOHANNESBURG	10.02	27.41	
676.22	COLLEGE	6.51	49.01	-164.58
691.67	WINKFIELD	8.82	8.93	
785.53	WINKFIELD	10.17	85.04	-188.23
837.21	CORCORAL	9.97	41.51	
881.17	WINKFIELD	5.46	34.00	-211.89
882.42	ST. JOHNS	7.58	.00	
906.98	SANTIAGO	6.42	16.99	
932.97	CORCORAL	7.77	19.57	
975.80	ST. JOHNS	10.31	35.06	-235.54
982.50	ROSMAN	3.14	.00	
984.36	FT. MYERS	4.56	.00	
990.11	QUITO	8.73	1.19	
992.65	LIMA	9.71	.00	
997.63	SANTIAGO	10.24	.00	
1071.61	ST. JOHNS	5.63	63.73	-259.20
1073.79	ROSMAN	10.37	.00	
1076.13	FT. MYERS	10.23	.00	
1084.17	QUITO	8.12	.00	
1087.93	LIMA	6.36	.00	
1171.02	ROSMAN	3.24	76.73	-282.85
1256.01	COLLEGE	8.07	81.75	-306.50
1313.10	JOHANNESBURG	9.79	49.02	
1335.09	WINKFIELD	8.91	12.20	-330.16
1349.78	COLLEGE	10.29	5.77	
1408.94	JOHANNESBURG	7.24	48.87	
1427.77	WINKFIELD	10.20	11.60	-353.81
1443.92	COLLEGE	9.80	5.94	
1474.51	CORCORAL	7.62	20.79	
1525.45	WINKFIELD	4.00	43.32	-377.47
1524.84	ST. JOHNS	6.96	.00	
1538.02	COLLEGE	7.60	6.22	
1565.95	CORCORAL	10.07	20.33	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 2.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.58	WINKFIELD	9.87		2.00
24.58	COLLEGE	9.51	6.13	
54.17	CORDRAL	8.87	20.07	
104.59	ST. JOHNS	8.16	41.55	-21.65
118.63	COLLEGE	7.11	5.88	
146.79	ORROPAL	9.47	21.05	
196.74	ST. JOHNS	10.28	40.47	-45.31
211.95	COLLEGE	4.80	4.92	
270.26	SANTIAGO	9.66	53.51	
276.93	LIMA	8.95	.00	
279.47	QUITO	9.11	.00	-68.96
286.36	FT. MYERS	9.81	.00	
288.55	ROSMAN	10.04	.00	
294.52	ST. JOHNS	3.73	.00	
303.40	COLLEGE	5.64	5.16	
365.72	SANTIAGO	8.24	56.68	
371.63	LIMA	8.00	.00	
381.60	FT. MYERS	7.19	1.97	-92.62
383.86	ROSMAN	7.37	.00	
394.19	COLLEGE	8.31	2.97	
486.08	COLLEGE	10.13	83.58	-116.27
526.43	JOHANNESBURG	6.09	30.23	
579.80	COLLEGE	10.03	47.28	-139.93
617.18	JOHANNESBURG	10.13	27.35	
676.07	COLLEGE	6.77	48.75	-163.58
691.75	WINKFIELD	8.60	8.91	
785.53	WINKFIELD	10.23	85.18	-187.23
837.24	ORROPAL	9.84	41.49	
881.05	WINKFIELD	5.86	33.97	-210.89
882.56	ST. JOHNS	7.22	.00	
907.39	SANTIAGO	5.87	17.61	
932.83	ORROPAL	8.11	19.57	
975.80	ST. JOHNS	10.34	34.87	-234.54
984.93	FT. MYERS	3.38	.00	
990.33	QUITO	8.38	2.02	
992.81	LIMA	9.51	.00	
997.66	SANTIAGO	10.30	.00	
1071.46	ST. JOHNS	6.07	63.50	-258.20
1073.80	ROSMAN	10.37	.00	
1076.12	FT. MYERS	10.30	.00	
1084.02	QUITO	8.51	.00	
1087.65	LIMA	6.98	.00	
1170.57	ROSMAN	4.27	75.94	-281.85
1256.07	COLLEGE	7.88	81.23	-305.50
1313.16	JOHANNESBURG	9.62	49.21	
1335.26	WINKFIELD	8.73	12.49	-329.16
1349.80	COLLEGE	10.26	5.80	
1408.74	JOHANNESBURG	7.68	48.68	
1427.78	WINKFIELD	10.76	11.36	-352.81
1443.94	COLLEGE	9.86	5.91	
1474.82	ORROPAL	7.24	21.02	
1525.06	WINKFIELD	4.72	43.01	-376.47
1525.11	ST. JOHNS	6.61	.00	
1538.05	COLLEGE	7.72	6.33	
1565.96	ORROPAL	10.16	20.20	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 3.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.56	WINKFIELD	9.97		3.00
24.60	COLLEGE	9.58	6.08	
54.40	ORROPAL	9.61	20.21	
104.80	ST. JOHNS	7.91	41.79	-20.65
118.66	COLLEGE	7.23	5.95	
146.75	ORROPAL	9.65	20.85	
196.76	ST. JOHNS	10.32	40.36	-44.31
212.03	COLLEGE	4.86	4.95	
270.32	SANTIAGO	9.48	53.43	
277.09	LIMA	8.63	.00	
279.65	QUITO	8.81	.00	-67.96
286.50	FT. MYERS	9.65	.00	
288.66	ROSMAN	9.93	.00	
294.08	ST. JOHNS	4.56	.00	
303.57	COLLEGE	5.54	4.93	
365.58	SANTIAGO	8.55	56.48	
371.46	LIMA	8.39	.00	
381.38	FT. MYERS	7.66	1.53	-91.62
383.66	ROSMAN	7.78	.00	
394.34	COLLEGE	8.20	2.91	
486.16	COLLEGE	10.09	83.62	-115.27
526.88	JOHANNESBURG	5.42	30.64	
579.80	COLLEGE	10.08	47.49	-138.93
617.19	JOHANNESBURG	10.22	27.31	
675.92	COLLEGE	7.02	48.51	-162.58
691.83	WINKFIELD	8.37	8.89	
785.53	WINKFIELD	10.27	85.32	-186.23
837.29	ORROPAL	9.69	41.48	
880.95	WINKFIELD	6.24	33.97	-209.89
882.71	ST. JOHNS	6.83	.00	
907.84	SANTIAGO	5.23	18.29	
932.69	ORROPAL	8.42	19.63	
975.81	ST. JOHNS	10.36	34.70	-233.54
990.57	QUITO	7.97	4.40	
992.99	LIMA	9.28	.00	
997.70	SANTIAGO	10.34	.00	
1071.33	ST. JOHNS	6.47	63.29	-257.20
1073.82	ROSMAN	10.36	.00	
1076.12	FT. MYERS	10.34	.00	
1083.88	QUITO	8.84	.00	
1087.42	LIMA	7.51	.00	
1170.24	ROSMAN	5.06	75.31	-280.85
1256.13	COLLEGE	7.69	80.83	-304.50
1313.24	JOHANNESBURG	9.41	49.42	
1335.44	WINKFIELD	8.55	12.79	-328.16
1349.83	COLLEGE	10.22	5.84	
1408.56	JOHANNESBURG	8.07	48.51	
1427.79	WINKFIELD	10.30	11.15	-351.81
1443.96	COLLEGE	9.92	5.87	
1475.16	ORROPAL	6.81	21.28	
1524.74	WINKFIELD	5.32	42.78	-375.47
1525.41	ST. JOHNS	6.22	.00	
1538.07	COLLEGE	7.83	6.45	
1565.98	ORROPAL	10.24	20.07	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 4.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.53	WINKFIELD	10.05		4.00
24.62	COLLEGE	9.66	6.04	
54.65	ORROPAL	8.33	20.37	
105.03	ST. JOHNS	7.64	42.05	-19.65
118.70	COLLEGE	7.35	6.03	
146.72	ORROPAL	9.80	20.67	
196.78	ST. JOHNS	10.35	40.26	-43.31
212.12	COLLEGE	4.92	4.99	
270.39	SANTIAGO	9.27	53.35	
277.28	LIMA	8.27	.00	
279.86	QUITO	8.46	.00	-66.96
286.65	FT. MYERS	9.46	.00	
288.78	ROSMAN	9.80	.00	
293.72	ST. JOHNS	5.23	.00	
303.73	COLLEGE	5.44	4.77	
365.47	SANTIAGO	8.82	56.29	
371.31	LIMA	8.73	.00	
381.18	FT. MYERS	8.06	1.14	-90.62
383.48	ROSMAN	8.14	.00	
394.49	COLLEGE	8.09	2.87	
486.25	COLLEGE	10.04	83.66	-114.27
527.41	JOHANNESBURG	4.60	31.12	
579.79	COLLEGE	10.13	47.78	-137.93
617.21	JOHANNESBURG	10.29	27.28	
675.79	COLLEGE	7.25	48.29	-161.58
691.93	WINKFIELD	8.12	8.89	
785.53	WINKFIELD	10.31	85.48	-185.23
837.34	ORROPAL	9.51	41.49	
880.85	WINKFIELD	6.58	34.00	-208.89
882.89	ST. JOHNS	6.40	.00	
908.35	SANTIAGO	4.46	19.07	
932.57	ORROPAL	8.69	19.76	
975.82	ST. JOHNS	10.37	34.56	-232.54
990.84	QUITO	7.51	4.65	
993.18	LIMA	9.02	.00	
997.75	SANTIAGO	10.37	.00	
1071.22	ST. JOHNS	6.84	63.11	-256.20
1073.85	ROSMAN	10.32	.00	
1076.13	FT. MYERS	10.37	.00	
1083.77	QUITO	9.14	.00	
1087.23	LIMA	7.96	.00	
1169.97	ROSMAN	5.72	74.78	-279.85
1256.20	COLLEGE	7.48	80.51	-303.50
1313.33	JOHANNESBURG	9.18	49.65	
1335.63	WINKFIELD	8.34	13.12	-327.16
1349.85	COLLEGE	10.19	5.88	
1408.41	JOHANNESBURG	8.42	48.37	
1427.81	WINKFIELD	10.33	10.98	-350.81
1443.98	COLLEGE	9.97	5.84	
1475.52	ORROPAL	6.33	21.57	
1524.46	WINKFIELD	5.84	42.61	-374.47
1525.72	ST. JOHNS	5.80	.00	
1538.10	COLLEGE	7.94	6.58	
1566.01	ORROPAL	10.30	19.96	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 5.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.52	WINKFIELD	10.13		5.00
24.64	COLLEGE	9.72	5.99	
54.91	ORROPAL	8.03	20.55	
105.27	ST. JOHNS	7.34	42.33	-18.65
118.73	COLLEGE	7.47	6.11	
146.70	ORROPAL	9.94	20.51	
196.81	ST. JOHNS	10.37	40.17	-42.31
212.20	COLLEGE	4.98	5.02	
270.46	SANTIAGO	9.04	53.29	
277.49	LIMA	7.86	.00	
280.09	QUITO	8.07	.00	-65.96
286.81	FT. MYERS	9.25	.00	
288.91	ROSMAN	9.65	.00	
293.42	ST. JOHNS	5.80	.00	
303.89	COLLEGE	5.35	4.66	
365.36	SANTIAGO	9.07	56.11	
371.19	LIMA	9.03	.00	
381.02	FT. MYERS	8.42	.80	-89.62
383.33	ROSMAN	8.46	.00	
394.64	COLLEGE	7.98	2.85	
486.33	COLLEGE	9.99	83.71	-113.27
528.06	JOHANNESBURG	3.55	31.73	
579.80	COLLEGE	10.18	48.19	-136.93
617.24	JOHANNESBURG	10.34	27.26	
675.66	COLLEGE	7.47	48.08	-160.58
692.03	WINKFIELD	7.85	8.90	
785.54	WINKFIELD	10.34	85.66	-184.23
837.39	ORROPAL	9.32	41.51	
880.77	WINKFIELD	6.90	34.06	-207.89
883.09	ST. JOHNS	5.90	.00	
908.98	SANTIAGO	3.48	19.98	
932.46	ORROPAL	8.94	20.01	
975.84	ST. JOHNS	10.37	34.43	-231.54
991.15	QUITO	6.98	4.95	
993.39	LIMA	8.72	.00	
997.81	SANTIAGO	10.37	.00	
1071.12	ST. JOHNS	7.18	62.94	-255.20
1073.88	ROSMAN	10.28	.00	
1076.14	FT. MYERS	10.37	.00	
1083.67	QUITO	9.40	.00	
1087.06	LIMA	8.36	.00	
1169.75	ROSMAN	6.28	74.32	-278.85
1256.27	COLLEGE	7.26	80.24	-302.50
1313.43	JOHANNESBURG	8.92	49.90	
1335.83	WINKFIELD	8.13	13.48	-326.16
1349.88	COLLEGE	10.14	5.92	
1408.27	JOHANNESBURG	8.73	48.25	
1427.83	WINKFIELD	10.35	10.83	-349.81
1444.00	COLLEGE	10.03	5.81	
1475.92	ORROPAL	5.79	21.90	
1524.22	WINKFIELD	6.30	42.51	-373.47
1526.07	ST. JOHNS	5.33	.00	
1538.13	COLLEGE	8.05	6.73	
1566.05	ORROPAL	10.34	19.87	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 6.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.52	WINKFIELD	10.19		6.00
24.66	COLLEGE	9.79	5.95	
55.20	ORROPAL	7.69	20.75	
106.27	WINKFIELD	3.85	43.39	-17.65
105.53	ST. JOHNS	7.02	.00	
118.75	COLLEGE	7.58	6.21	
146.69	ORROPAL	10.05	20.36	
196.84	ST. JOHNS	10.37	40.10	-41.31
212.27	COLLEGE	5.05	5.06	
270.55	SANTIAGO	8.77	53.23	
277.73	LIMA	7.38	.00	
280.35	QUITO	7.62	.00	-64.96
286.99	FT. MYERS	9.00	.00	
289.06	ROSMAN	9.48	.00	
293.16	ST. JOHNS	6.30	.00	
304.05	COLLEGE	5.26	4.59	
365.26	SANTIAGO	9.29	55.95	
371.08	LIMA	9.30	.00	
380.87	FT. MYERS	8.74	.50	-88.62
383.19	ROSMAN	8.75	.00	
394.79	COLLEGE	7.87	2.85	
486.43	COLLEGE	9.94	83.76	-112.27
579.80	COLLEGE	10.22	83.44	-135.93
617.28	JOHANNESBURG	10.36	27.26	
675.54	COLLEGE	7.68	47.89	-159.58
692.15	WINKFIELD	7.55	8.93	
785.55	WINKFIELD	10.36	85.86	-183.23
837.46	ORROPAL	9.09	41.55	
880.69	WINKFIELD	7.19	34.14	-206.89
883.33	ST. JOHNS	5.34	.00	
932.37	ORROPAL	9.17	43.70	
975.86	ST. JOHNS	10.36	34.32	-230.54
991.51	QUITO	6.36	5.30	
993.63	LIMA	8.38	.00	
997.88	SANTIAGO	10.36	.00	
1071.03	ST. JOHNS	7.49	62.79	-254.20
1073.92	ROSMAN	10.21	.00	
1076.16	FT. MYERS	10.36	.00	
1083.59	QUITO	9.62	.00	
1086.92	LIMA	8.71	.00	
1094.96	SANTIAGO	3.47	.00	
1169.55	ROSMAN	6.78	71.12	-277.85
1256.34	COLLEGE	7.03	80.01	-301.50
1313.55	JOHANNESBURG	8.62	50.18	
1336.03	WINKFIELD	7.90	13.87	-325.16
1349.91	COLLEGE	10.09	5.97	
1408.15	JOHANNESBURG	9.00	48.15	
1427.86	WINKFIELD	10.37	10.71	-348.81
1444.02	COLLEGE	10.07	5.79	
1476.37	ORROPAL	5.16	22.28	
1524.00	WINKFIELD	6.71	42.47	-372.47
1526.44	ST. JOHNS	4.80	.00	
1538.15	COLLEGE	8.16	6.91	
1566.10	ORROPAL	10.36	19.78	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 7.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.52	WINKFIELD	10.25		7.00
24.68	COLLEGE	9.85	5.91	
55.50	ORROPAL	7.31	20.97	
105.87	WINKFIELD	4.59	43.06	-16.65
105.80	ST. JOHNS	6.67	.00	
118.78	COLLEGE	7.70	6.31	
146.70	ORROPAL	10.15	20.22	
196.89	ST. JOHNS	10.37	40.04	-40.31
212.35	COLLEGE	5.13	5.09	
270.65	SANTIAGO	9.48	53.18	
278.01	LIMA	6.83	.00	
280.64	QUITO	7.11	.00	-63.96
287.19	FT. MYERS	8.73	.00	
289.22	ROSMAN	9.29	.00	
292.92	ST. JOHNS	6.75	.00	
304.21	COLLEGE	5.18	4.54	
365.17	SANTIAGO	9.48	55.78	
370.98	LIMA	9.53	.00	
380.75	FT. MYERS	9.02	.23	-87.62
383.08	ROSMAN	9.00	.00	
394.95	COLLEGE	7.76	2.87	
486.52	COLLEGE	9.88	83.81	-111.27
579.81	COLLEGE	10.25	83.41	-134.93
617.34	JOHANNESBURG	10.37	27.27	
675.43	COLLEGE	7.87	47.72	-158.58
692.28	WINKFIELD	7.22	8.97	
785.56	WINKFIELD	10.37	86.07	-182.23
837.54	ORROPAL	8.84	41.61	
880.62	WINKFIELD	7.47	34.24	-205.89
883.61	ST. JOHNS	4.68	.00	
932.28	ORROPAL	9.37	43.99	
975.88	ST. JOHNS	10.33	34.23	-229.54
991.93	QUITO	5.61	5.72	
993.89	LIMA	7.99	.00	
997.96	SANTIAGO	10.34	.00	
1070.95	ST. JOHNS	7.77	62.65	-253.20
1073.96	ROSMAN	10.13	.00	
1076.19	FT. MYERS	10.32	.00	
1083.53	QUITO	9.81	.00	
1086.80	LIMA	9.02	.00	
1094.44	SANTIAGO	4.55	.00	
1169.39	ROSMAN	7.22	70.40	-276.85
1173.31	FT. MYERS	3.76	.00	
1256.42	COLLEGE	6.78	79.35	-300.50
1313.68	JOHANNESBURG	8.28	50.48	
1336.25	WINKFIELD	7.66	14.29	-324.16
1349.93	COLLEGE	10.04	6.03	
1408.04	JOHANNESBURG	9.25	48.07	
1427.90	WINKFIELD	10.37	10.61	-347.81
1444.03	COLLEGE	10.12	5.76	
1476.88	ORROPAL	4.40	22.73	
1523.80	WINKFIELD	7.08	42.51	-371.47
1526.86	ST. JOHNS	4.18	.00	
1538.18	COLLEGE	8.27	7.13	
1566.16	ORROPAL	10.37	19.71	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 8.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.53	WINKFIELD	10.29		8.00
24.70	COLLEGE	9.91	5.88	
55.83	ORROPAL	6.89	21.23	
105.54	WINKFIELD	5.21	42.81	-15.65
106.09	ST. JOHNS	6.30	.00	
118.81	COLLEGE	7.81	6.42	
146.71	ORROPAL	10.23	20.10	
196.94	ST. JOHNS	10.35	40.00	-39.31
212.41	COLLEGE	5.21	5.12	
270.77	SANTIAGO	8.14	53.15	
278.34	LIMA	6.18	.00	
280.98	QUITO	6.51	.00	-62.96
287.40	FT. MYERS	8.43	.00	
289.39	ROSMAN	9.08	.00	
292.72	ST. JOHNS	7.14	.00	
304.36	COLLEGE	5.10	4.50	
365.09	SANTIAGO	9.66	55.63	
370.91	LIMA	9.73	.00	
380.64	FT. MYERS	9.27	.01	-86.62
382.98	ROSMAN	9.23	.00	
395.10	COLLEGE	7.65	2.90	
486.62	COLLEGE	9.82	83.87	-110.27
579.83	COLLEGE	10.28	83.39	-133.93
617.40	JOHANNESBURG	10.36	27.29	
675.32	COLLEGE	8.06	47.56	-157.58
692.41	WINKFIELD	6.86	9.03	
785.58	WINKFIELD	10.37	86.30	-181.23
837.63	ORROPAL	8.56	41.68	
880.56	WINKFIELD	7.73	34.37	-204.89
883.96	ST. JOHNS	3.88	.00	
932.20	ORROPAL	9.56	44.36	
975.90	ST. JOHNS	10.30	34.15	-228.54
992.43	QUITO	4.69	6.23	
994.19	LIMA	7.54	.00	
998.05	SANTIAGO	10.29	.00	
1070.88	ST. JOHNS	8.04	62.53	-252.20
1074.02	ROSMAN	10.02	.00	
1076.23	FT. MYERS	10.26	.00	
1083.49	QUITO	9.97	.00	
1086.70	LIMA	9.29	.00	
1094.05	SANTIAGO	5.37	.00	
1169.24	ROSMAN	7.61	69.82	-275.85
1172.86	FT. MYERS	4.77	.00	
1256.51	COLLEGE	6.51	78.88	-299.50
1313.83	JOHANNESBURG	7.89	50.81	
1336.48	WINKFIELD	7.39	14.75	-323.16
1349.96	COLLEGE	9.98	6.09	
1407.94	JOHANNESBURG	9.47	48.00	
1427.94	WINKFIELD	10.37	10.53	-346.81
1444.05	COLLEGE	10.16	5.74	
1477.50	ORROPAL	3.45	23.29	
1523.62	WINKFIELD	7.42	42.66	-370.47
1527.35	ST. JOHNS	3.45	.00	
1538.20	COLLEGE	8.37	7.41	
1566.23	ORROPAL	10.37	19.65	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 9.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.54	WINKFIELD	10.33		9.00
24.72	COLLEGE	9.96	5.85	
56.19	ORROROAL	6.42	21.51	
105.25	WINKFIELD	5.75	42.64	-14.65
106.40	ST. JOHNS	5.88	.00	
118.84	COLLEGE	7.92	6.55	
146.74	ORROROAL	10.29	19.98	
197.00	ST. JOHNS	10.32	39.97	-38.31
212.48	COLLEGE	5.29	5.16	
270.90	SANTIAGO	7.77	53.13	
278.72	LIMA	5.40	.05	
281.37	QUITO	5.79	.00	-61.96
287.64	FT. MYERS	8.09	.48	
289.58	ROSMAN	8.84	.00	
292.53	ST. JOHNS	7.50	.00	
304.52	COLLEGE	5.03	4.49	
365.02	SANTIAGO	9.81	55.48	
370.84	LIMA	9.90	.00	
380.55	FT. MYERS	9.49	.00	-85.62
382.89	ROSMAN	9.44	.00	
395.26	COLLEGE	7.53	2.93	
486.72	COLLEGE	9.76	83.92	-109.27
579.84	COLLEGE	10.31	83.37	-132.93
617.48	JOHANNESBURG	10.33	27.33	
675.23	COLLEGE	8.23	47.41	-156.58
692.57	WINKFIELD	6.46	9.11	
785.60	WINKFIELD	10.36	86.56	-180.23
837.74	ORROROAL	8.25	41.78	
880.51	WINKFIELD	7.97	34.52	-203.89
932.12	ORROROAL	9.72	43.65	
975.93	ST. JOHNS	10.25	34.09	-227.54
993.10	QUITO	3.45	6.92	
994.51	LIMA	7.04	.00	
998.16	SANTIAGO	10.23	.00	
1070.81	ST. JOHNS	8.29	62.42	-251.20
1074.08	ROSMAN	9.90	.00	
1076.28	FT. MYERS	10.19	.00	
1083.46	QUITO	10.10	.00	
1086.63	LIMA	9.52	.00	
1093.73	SANTIAGO	6.05	.00	
1169.12	ROSMAN	7.97	69.34	-274.85
1172.52	FT. MYERS	5.56	.00	
1256.60	COLLEGE	6.23	78.53	-298.50
1314.01	JOHANNESBURG	7.46	51.18	
1336.72	WINKFIELD	7.12	15.25	-322.16
1349.99	COLLEGE	9.91	6.16	
1407.86	JOHANNESBURG	9.66	47.96	
1428.00	WINKFIELD	10.35	10.48	-345.81
1444.07	COLLEGE	10.20	5.72	
1523.46	WINKFIELD	7.73	69.19	-369.47
1538.22	COLLEGE	8.48	7.04	
1566.31	ORROROAL	10.34	19.61	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 10.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.57	WINKFIELD	10.35		10.00
24.73	COLLEGE	10.02	5.82	
56.59	ORROPAL	5.89	21.84	
105.00	WINKFIELD	6.22	42.52	-13.65
106.74	ST. JOHNS	5.42	.00	
118.86	COLLEGE	8.03	6.70	
146.78	ORROPAL	10.33	19.88	
197.07	ST. JOHNS	10.29	39.96	-37.31
212.54	COLLEGE	5.38	5.19	
271.06	SANTIAGO	7.35	53.13	
279.21	LIMA	4.42	.81	
281.85	QUITO	4.92	.00	-60.96
287.90	FT. MYERS	7.70	1.14	
289.78	ROSMAN	8.58	.00	
292.36	ST. JOHNS	7.83	.00	
304.67	COLLEGE	4.96	4.48	
364.96	SANTIAGO	9.95	55.33	
370.79	LIMA	10.04	.00	
380.48	FT. MYERS	9.68	.00	-84.62
382.82	ROSMAN	9.62	.00	
395.42	COLLEGE	7.42	2.99	
486.82	COLLEGE	9.69	83.98	-108.27
579.87	COLLEGE	10.33	83.36	-131.93
617.58	JOHANNESBURG	10.28	27.38	
675.14	COLLEGE	8.40	47.28	-155.58
692.75	WINKFIELD	6.02	9.21	
714.32	JOHANNESBURG	3.98	15.55	
785.62	WINKFIELD	10.35	67.32	-179.23
837.86	ORROPAL	7.90	41.89	
880.46	WINKFIELD	8.19	34.70	-202.89
932.06	ORROPAL	9.86	43.40	
975.96	ST. JOHNS	10.19	34.04	-226.54
994.88	LIMA	6.45	8.72	
998.28	SANTIAGO	10.15	.00	
1070.75	ST. JOHNS	8.51	62.32	-250.20
1074.14	ROSMAN	9.76	.00	
1076.34	FT. MYERS	10.09	.00	
1083.44	QUITO	10.21	.00	
1086.56	LIMA	9.72	.00	
1093.47	SANTIAGO	6.62	.00	
1169.00	ROSMAN	8.29	68.91	-273.85
1172.24	FT. MYERS	6.21	.00	
1256.71	COLLEGE	5.93	78.25	-297.50
1314.22	JOHANNESBURG	6.96	51.58	
1336.97	WINKFIELD	6.82	15.80	-321.16
1350.02	COLLEGE	9.84	6.24	
1407.79	JOHANNESBURG	9.83	47.92	
1428.06	WINKFIELD	10.33	10.44	-344.81
1444.09	COLLEGE	10.23	5.71	
1523.31	WINKFIELD	8.01	68.99	-368.47
1538.25	COLLEGE	8.58	6.93	
1566.40	ORROPAL	10.30	19.57	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 11.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.60	WINKFIELD	10.37		11.00
24.75	COLLEGE	10.07	5.79	
57.03	ORROPAL	5.28	22.21	
104.78	WINKFIELD	6.64	42.47	-12.65
107.11	ST. JOHNS	4.90	.00	
118.89	COLLEGE	8.14	6.88	
146.83	ORROPAL	10.36	19.80	
197.15	ST. JOHNS	10.24	39.96	-36.31
212.60	COLLEGE	5.48	5.22	
271.24	SANTIAGO	6.87	53.15	
279.90	LIMA	3.05	1.79	
282.46	QUITO	3.76	.00	-59.96
288.18	FT. MYERS	7.27	1.96	
289.99	ROSMAN	8.29	.00	
292.21	ST. JOHNS	8.12	.00	
304.82	COLLEGE	4.89	4.48	
364.91	SANTIAGO	10.06	55.19	
370.75	LIMA	10.16	.00	
380.42	FT. MYERS	9.84	.00	-83.62
382.76	ROSMAN	9.78	.00	
395.58	COLLEGE	7.30	3.05	
486.93	COLLEGE	9.62	84.05	-107.27
579.89	COLLEGE	10.35	83.34	-130.93
617.68	JOHANNESBURG	10.21	27.44	
675.05	COLLEGE	8.55	47.16	-154.58
692.95	WINKFIELD	5.52	9.34	
713.84	JOHANNESBURG	4.99	15.37	
785.64	WINKFIELD	10.32	66.82	-178.23
837.99	ORROPAL	7.51	42.04	
880.41	WINKFIELD	8.41	34.91	-201.89
932.00	ORROPAL	9.98	43.18	
976.00	ST. JOHNS	10.12	34.01	-225.54
995.30	LIMA	5.76	9.18	
998.40	SANTIAGO	10.06	.00	
1070.70	ST. JOHNS	8.73	62.24	-249.20
1074.22	ROSMAN	9.60	.00	
1076.40	FT. MYERS	9.97	.00	
1083.43	QUITO	10.29	.00	
1086.52	LIMA	9.89	.00	
1093.24	SANTIAGO	7.13	.00	
1168.90	ROSMAN	8.58	68.54	-272.85
1172.01	FT. MYERS	6.78	.00	
1256.82	COLLEGE	5.60	78.04	-296.50
1314.46	JOHANNESBURG	6.38	52.04	
1337.23	WINKFIELD	6.50	16.40	-320.16
1350.05	COLLEGE	9.77	6.32	
1407.72	JOHANNESBURG	9.97	47.90	
1428.12	WINKFIELD	10.30	10.43	-343.81
1444.11	COLLEGE	10.26	5.69	
1523.18	WINKFIELD	8.27	68.81	-367.47
1538.27	COLLEGE	8.68	6.82	
1566.50	ORROPAL	10.25	19.56	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 12.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.63	WINKFIELD	10.37		12.00
24.77	COLLEGE	10.11	5.77	
57.52	ORRORAL	4.56	22.64	
104.57	WINKFIELD	7.01	42.49	-11.65
107.52	ST. JOHNS	4.31	.00	
118.91	COLLEGE	8.25	7.08	
146.89	ORRORAL	10.37	19.72	
197.23	ST. JOHNS	10.18	39.97	-35.31
212.66	COLLEGE	5.58	5.26	
271.45	SANTIAGO	6.31	53.21	
288.50	FT. MYERS	6.79	10.74	-58.96
290.23	ROSMAN	7.98	.00	
292.08	ST. JOHNS	8.39	.00	
304.96	COLLEGE	4.84	4.49	
364.86	SANTIAGO	10.16	55.06	
370.72	LIMA	10.25	.00	
380.37	FT. MYERS	9.98	.00	-82.62
382.71	ROSMAN	9.92	.00	
395.74	COLLEGE	7.18	3.12	
487.04	COLLEGE	9.55	84.11	-106.27
579.92	COLLEGE	10.36	83.34	-129.93
617.80	JOHANNESBURG	10.12	27.51	
674.97	COLLEGE	8.70	47.06	-153.58
693.18	WINKFIELD	4.95	9.51	
713.46	JOHANNESBURG	5.78	15.33	
785.66	WINKFIELD	10.28	66.42	-177.23
838.15	ORRORAL	7.06	42.21	
880.37	WINKFIELD	8.61	35.16	-200.89
931.95	ORRORAL	10.09	42.97	
976.04	ST. JOHNS	10.04	34.00	-224.54
995.80	LIMA	4.92	9.73	
998.54	SANTIAGO	9.94	.00	
1070.65	ST. JOHNS	8.92	62.17	-248.20
1074.30	ROSMAN	9.41	.00	
1076.48	FT. MYERS	9.82	.00	
1083.44	QUITO	10.34	.00	
1086.49	LIMA	10.04	.00	
1093.05	SANTIAGO	7.56	.00	
1168.82	ROSMAN	8.84	68.20	-271.85
1171.81	FT. MYERS	7.27	.00	
1256.94	COLLEGE	5.24	77.87	-295.50
1314.75	JOHANNESBURG	5.69	52.56	
1337.51	WINKFIELD	6.15	17.07	-319.16
1350.08	COLLEGE	9.69	6.42	
1407.67	JOHANNESBURG	10.09	47.90	
1428.19	WINKFIELD	10.26	10.44	-342.81
1444.13	COLLEGE	10.29	5.68	
1523.06	WINKFIELD	8.50	68.64	-366.47
1538.29	COLLEGE	8.78	6.73	
1566.62	ORRORAL	10.18	19.55	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 13.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.68	WINKFIELD	10.37		13.00
24.79	COLLEGE	10.15	5.74	
58.11	ORROAL	3.65	23.17	
104.39	WINKFIELD	7.36	42.62	-10.65
107.99	ST. JOHNS	3.60	.00	
118.94	COLLEGE	8.35	7.35	
146.95	ORROAL	10.37	19.66	
197.32	ST. JOHNS	10.11	40.00	-34.31
212.72	COLLEGE	5.68	5.29	
243.85	ORROAL	3.85	25.46	
271.70	SANTIAGO	5.67	24.00	
288.85	FT. MYERS	6.23	11.48	-57.96
290.48	ROSMAN	7.63	.00	
291.96	ST. JOHNS	8.64	.00	
305.10	COLLEGE	4.79	4.51	
364.82	SANTIAGO	10.24	54.92	
370.71	LIMA	10.31	.00	
380.34	FT. MYERS	10.10	.00	-81.62
382.67	ROSMAN	10.04	.00	
395.91	COLLEGE	7.07	3.20	
487.15	COLLEGE	9.47	84.18	-105.27
579.96	COLLEGE	10.37	83.33	-128.93
617.92	JOHANNESBURG	10.01	27.60	
674.90	COLLEGE	8.84	46.97	-152.58
693.47	WINKFIELD	4.27	9.72	
713.16	JOHANNESBURG	6.44	15.42	
785.69	WINKFIELD	10.23	66.10	-176.23
838.34	ORROAL	6.56	42.42	
880.34	WINKFIELD	8.79	35.44	-199.89
931.90	ORROAL	10.18	42.77	
976.08	ST. JOHNS	9.94	34.00	-223.54
996.43	LIMA	3.82	10.41	
998.69	SANTIAGO	9.81	.00	
1070.61	ST. JOHNS	9.11	62.11	-247.20
1074.40	ROSMAN	9.20	.00	
1076.56	FT. MYERS	9.65	.00	
1083.46	QUITO	10.37	.00	
1086.47	LIMA	10.15	.00	
1092.89	SANTIAGO	7.95	.00	
1168.74	ROSMAN	9.08	67.90	-270.85
1171.63	FT. MYERS	7.70	.00	
1257.08	COLLEGE	4.85	77.75	-294.50
1315.11	JOHANNESBURG	4.87	53.17	
1337.81	WINKFIELD	5.77	17.83	-318.16
1350.12	COLLEGE	9.60	6.54	
1407.62	JOHANNESBURG	10.19	47.90	
1428.27	WINKFIELD	10.20	10.46	-341.81
1444.15	COLLEGE	10.31	5.67	
1522.95	WINKFIELD	8.72	68.49	-365.47
1538.31	COLLEGE	8.87	6.64	
1566.74	ORROAL	10.09	19.56	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 14.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.73	WINKFIELD	10.36		14.00
24.81	COLLEGE	10.19	5.73	
104.23	WINKFIELD	7.67	69.23	-9.65
118.96	COLLEGE	8.46	7.06	
147.03	ORROPAL	10.35	19.62	
197.42	ST. JOHNS	10.02	40.04	-33.31
212.77	COLLEGE	5.78	5.33	
243.39	ORROPAL	4.80	24.84	
272.02	SANTIAGO	4.90	23.82	
289.26	FT. MYERS	5.58	12.34	-56.96
290.76	ROSMAN	7.24	.00	
291.85	ST. JOHNS	8.86	.00	
305.24	COLLEGE	4.75	4.53	
364.78	SANTIAGO	10.30	54.79	
370.71	LIMA	10.35	.00	
380.32	FT. MYERS	10.20	.00	-80.62
382.65	ROSMAN	10.14	.00	
396.07	COLLEGE	6.95	3.29	
487.27	COLLEGE	9.39	84.25	-104.27
579.99	COLLEGE	10.37	83.33	-127.93
618.07	JOHANNESBURG	9.87	27.70	
674.83	COLLEGE	8.97	46.89	-151.58
693.83	WINKFIELD	3.43	10.02	
712.91	JOHANNESBURG	7.00	15.65	
785.72	WINKFIELD	10.17	65.82	-175.23
838.56	ORROPAL	5.97	42.66	
880.30	WINKFIELD	8.97	35.77	-198.89
931.86	ORROPAL	10.25	42.59	
976.13	ST. JOHNS	9.83	34.02	-222.54
998.86	SANTIAGO	9.66	12.90	
1070.57	ST. JOHNS	9.27	62.06	-246.20
1074.50	ROSMAN	8.96	.00	
1076.66	FT. MYERS	9.46	.00	
1083.50	QUITO	10.37	.00	
1086.47	LIMA	10.24	.00	
1092.74	SANTIAGO	8.30	.00	
1168.67	ROSMAN	9.29	67.62	-269.85
1171.48	FT. MYERS	8.09	.00	
1257.24	COLLEGE	4.42	77.67	-293.50
1315.59	JOHANNESBURG	3.79	53.92	
1338.13	WINKFIELD	5.36	18.75	-317.16
1350.15	COLLEGE	9.51	6.67	
1407.58	JOHANNESBURG	10.26	47.93	
1428.36	WINKFIELD	10.14	10.51	-340.81
1444.17	COLLEGE	10.33	5.66	
1522.85	WINKFIELD	8.92	68.35	-364.47
1538.33	COLLEGE	8.97	6.55	
1566.88	ORROPAL	9.09	19.58	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 15.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.79	WINKFIELD	10.33		15.00
24.83	COLLEGE	10.23	5.71	
104.08	WINKFIELD	7.96	69.02	-8.65
118.98	COLLEGE	8.56	6.95	
147.12	CORDOBAL	10.31	19.58	
197.53	ST. JOHNS	9.93	40.09	-32.31
212.82	COLLEGE	5.89	5.36	
243.04	CORDOBAL	5.56	24.33	
272.44	SANTIAGO	3.92	23.84	
289.72	FT. MYERS	4.80	13.37	-55.96
291.06	ROSMAN	6.80	.00	
291.75	ST. JOHNS	9.07	.00	
305.38	COLLEGE	4.71	4.56	
364.76	SANTIAGO	10.34	54.67	
370.71	LIMA	10.37	.00	
380.32	FT. MYERS	10.27	.00	-79.62
382.64	ROSMAN	10.22	.00	
396.24	COLLEGE	6.83	3.38	
487.39	COLLEGE	9.31	84.32	-103.27
580.04	COLLEGE	10.37	83.33	-126.93
618.22	JOHANNESBURG	9.72	27.82	
674.77	COLLEGE	9.10	46.83	-150.58
712.70	JOHANNESBURG	7.48	28.83	
785.76	WINKFIELD	10.11	65.58	-174.23
838.83	CORDOBAL	5.29	42.97	
880.27	WINKFIELD	9.13	36.15	-197.89
931.83	CORDOBAL	10.31	42.43	
976.18	ST. JOHNS	9.70	34.05	-221.54
999.03	SANTIAGO	9.49	13.14	
1070.54	ST. JOHNS	9.43	62.02	-245.20
1074.62	ROSMAN	8.70	.00	
1076.77	FT. MYERS	9.24	.00	
1083.55	QUITO	10.35	.00	
1086.48	LIMA	10.31	.00	
1092.62	SANTIAGO	8.61	.00	
1168.61	ROSMAN	9.48	67.38	-268.85
1171.35	FT. MYERS	8.43	.00	
1257.43	COLLEGE	3.93	77.65	-292.50
1338.47	WINKFIELD	4.90	77.11	-316.16
1350.19	COLLEGE	9.41	6.82	
1407.56	JOHANNESBURG	10.32	47.96	
1428.45	WINKFIELD	10.08	10.58	-339.81
1444.19	COLLEGE	10.35	5.66	
1522.77	WINKFIELD	9.11	68.23	-363.47
1538.35	COLLEGE	9.06	6.48	
1567.02	CORDOBAL	9.87	19.61	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 16.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
8.85	WINKFIELD	10.30		16.00
24.85	COLLEGE	10.26	5.69	
103.94	WINKFIELD	8.22	68.84	-7.65
119.00	COLLEGE	8.66	6.84	
147.22	CORDRAL	10.26	19.56	
197.64	ST. JOHNS	9.83	40.16	-31.31
212.87	COLLEGE	6.00	5.40	
242.74	CORDRAL	6.19	23.87	
290.30	FT. MYERS	3.82	41.37	-54.96
291.39	ROSMAN	6.32	.00	
291.67	ST. JOHNS	9.25	.00	
305.51	COLLEGE	4.68	4.59	
364.73	SANTIAGO	10.36	54.54	
370.73	LIMA	10.37	.00	
380.32	FT. MYERS	10.32	.00	-78.62
382.64	ROSMAN	10.28	.00	
396.40	COLLEGE	6.72	3.49	
487.51	COLLEGE	9.23	84.39	-102.27
580.08	COLLEGE	10.37	83.34	-125.93
618.39	JOHANNESBURG	9.54	27.95	
674.71	COLLEGE	9.22	46.78	-149.58
712.51	JOHANNESBURG	7.91	28.58	
785.80	WINKFIELD	10.03	65.37	-173.23
839.18	CORDRAL	4.45	43.35	
880.25	WINKFIELD	9.28	36.62	-196.89
931.80	CORDRAL	10.35	42.28	
976.24	ST. JOHNS	9.56	34.09	-220.54
999.22	SANTIAGO	9.30	13.42	
1070.51	ST. JOHNS	9.57	61.99	-244.20
1074.75	ROSMAN	8.40	.00	
1076.89	FT. MYERS	8.98	.00	
1083.60	QUITO	10.30	.00	
1086.50	LIMA	10.35	.00	
1092.52	SANTIAGO	8.89	.00	
1168.56	ROSMAN	9.65	67.15	-267.85
1171.24	FT. MYERS	8.73	.00	
1257.66	COLLEGE	3.36	77.68	-291.50
1338.84	WINKFIELD	4.39	77.83	-315.16
1350.22	COLLEGE	9.30	6.99	
1407.54	JOHANNESBURG	10.36	48.01	
1428.55	WINKFIELD	10.00	10.66	-338.81
1444.21	COLLEGE	10.36	5.66	
1522.69	WINKFIELD	9.28	68.12	-362.47
1538.37	COLLEGE	9.15	6.40	
1567.18	CORDRAL	9.73	19.66	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 17.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
.8.92	WINKFIELD	10.26		17.00
24.87	COLLEGE	10.29	5.68	
103.82	WINKFIELD	8.46	68.67	-6.65
119.03	COLLEGE	8.76	6.74	
147.34	ORROPAL	10.19	19.55	
197.76	ST. JOHNS	9.71	40.24	-30.31
212.92	COLLEGE	6.11	5.44	
242.49	ORROPAL	6.73	23.47	
291.76	ROSMAN	5.76	42.53	-53.96
291.60	ST. JOHNS	9.42	.00	
305.64	COLLEGE	4.66	4.62	
364.72	SANTIAGO	10.37	54.42	
370.76	LIMA	10.33	.00	
380.34	FT. MYERS	10.36	.00	-77.62
382.65	ROSMAN	10.33	.00	
396.57	COLLEGE	6.60	3.60	
462.67	SANTIAGO	3.06	59.50	
487.63	COLLEGE	9.15	21.90	-101.27
580.13	COLLEGE	10.36	83.35	-124.93
618.58	JOHANNESBURG	9.34	28.09	
674.66	COLLEGE	9.33	46.75	-148.58
712.36	JOHANNESBURG	8.28	28.37	
772.54	COLLEGE	3.59	51.90	-172.23
785.84	WINKFIELD	9.94	9.71	
839.65	ORROPAL	3.34	43.88	
880.22	WINKFIELD	9.42	37.24	-195.89
931.78	ORROPAL	10.37	42.14	
976.31	ST. JOHNS	9.41	34.16	-219.54
999.43	SANTIAGO	9.08	13.71	
1070.49	ST. JOHNS	9.70	61.98	-243.20
1074.89	ROSMAN	8.07	.00	
1077.03	FT. MYERS	8.69	.00	
1083.68	QUITO	10.23	.00	
1086.54	LIMA	10.37	.00	
1092.44	SANTIAGO	9.13	.00	
1168.52	ROSMAN	9.80	66.95	-266.85
1171.14	FT. MYERS	9.01	.00	
1339.25	WINKFIELD	3.80	159.11	-314.16
1350.26	COLLEGE	9.19	7.21	
1407.52	JOHANNESBURG	10.37	48.07	
1428.66	WINKFIELD	9.91	10.76	-337.81
1444.23	COLLEGE	10.37	5.66	
1522.62	WINKFIELD	9.43	68.03	-361.47
1538.39	COLLEGE	9.23	6.34	
1567.35	ORROPAL	9.57	19.73	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 18.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
9.00	WINKFIELD	10.21		18.00
24.89	COLLEGE	10.31	5.67	
103.71	WINKFIELD	8.68	68.52	-5.65
119.05	COLLEGE	8.86	6.65	
147.46	CORDRAL	10.11	19.55	
197.89	ST. JOHNS	9.58	40.33	-29.31
212.96	COLLEGE	6.22	5.48	
242.28	CORDRAL	7.20	23.10	
292.17	ROSMAN	5.11	42.69	-52.96
291.54	ST. JOHNS	9.57	.00	
305.76	COLLEGE	4.65	4.65	
364.71	SANTIAGO	10.36	54.31	
370.80	LIMA	10.28	.00	
380.37	FT. MYERS	10.37	.00	-76.62
382.67	ROSMAN	10.36	.00	
396.74	COLLEGE	6.48	3.71	
462.15	SANTIAGO	4.18	58.93	
487.76	COLLEGE	9.06	21.43	-100.27
580.18	COLLEGE	10.35	83.37	-123.93
618.78	JOHANNESBURG	9.11	28.25	
674.62	COLLEGE	9.43	46.73	-147.58
712.23	JOHANNESBURG	8.62	28.18	
772.23	COLLEGE	4.12	51.39	-171.23
785.88	WINKFIELD	9.83	9.53	
880.20	WINKFIELD	9.55	84.49	-194.89
931.77	CORDRAL	10.37	42.01	
976.38	ST. JOHNS	9.24	34.23	-218.54
999.65	SANTIAGO	8.84	14.03	
1029.24	CORDRAL	4.06	20.75	
1070.47	ST. JOHNS	9.82	37.17	-242.20
1075.06	ROSMAN	7.70	.00	
1077.19	FT. MYERS	8.37	.00	
1083.76	QUITO	10.13	.00	
1086.59	LIMA	10.37	.00	
1092.37	SANTIAGO	9.35	.00	
1168.48	ROSMAN	9.93	66.76	-265.85
1171.05	FT. MYERS	9.25	.00	
1339.73	WINKFIELD	3.09	159.43	-313.16
1350.30	COLLEGE	9.07	7.49	
1407.52	JOHANNESBURG	10.37	48.15	
1428.77	WINKFIELD	9.81	10.88	-336.81
1444.25	COLLEGE	10.37	5.67	
1522.57	WINKFIELD	9.57	67.95	-360.47
1538.41	COLLEGE	9.32	6.27	
1567.53	CORDRAL	9.39	19.81	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 19.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
9.08	WINKFIELD	10.16		19.00
24.90	COLLEGE	10.33	5.67	
103.61	WINKFIELD	8.89	68.38	-4.65
119.07	COLLEGE	8.95	6.57	
147.59	ORROAL	10.01	19.57	
198.03	ST. JOHNS	9.44	40.44	-28.31
213.00	COLLEGE	6.34	5.52	
242.10	ORROAL	7.62	22.76	
292.66	ROSMAN	4.34	42.93	-51.96
291.48	ST. JOHNS	9.71	.00	
305.88	COLLEGE	4.64	4.68	
364.71	SANTIAGO	10.33	54.19	
370.86	LIMA	10.20	.00	
380.41	FT. MYERS	10.37	.00	-75.62
382.70	ROSMAN	10.37	.00	
396.91	COLLEGE	6.37	3.84	
461.77	SANTIAGO	5.02	58.49	
487.89	COLLEGE	8.97	21.10	-99.27
580.24	COLLEGE	10.33	83.38	-122.93
619.00	JOHANNESBURG	8.85	28.43	
674.57	COLLEGE	9.53	46.73	-146.58
712.12	JOHANNESBURG	8.91	28.01	
771.97	COLLEGE	4.59	50.94	-170.23
785.93	WINKFIELD	9.72	9.38	
880.19	WINKFIELD	9.67	84.54	-193.89
931.76	ORROAL	10.36	41.90	
976.45	ST. JOHNS	9.05	34.33	-217.54
999.88	SANTIAGO	8.58	14.38	
1028.86	ORROAL	4.89	20.40	
1070.45	ST. JOHNS	9.92	36.70	-241.20
1075.24	ROSMAN	7.29	.00	
1077.36	FT. MYERS	8.00	.00	
1083.86	QUITO	10.01	.00	
1086.65	LIMA	10.34	.00	
1092.31	SANTIAGO	9.55	.00	
1168.45	ROSMAN	10.05	66.59	-264.85
1170.98	FT. MYERS	9.47	.00	
1180.49	QUITO	4.33	.05	
1350.35	COLLEGE	8.94	165.52	-312.16
1407.52	JOHANNESBURG	10.34	48.24	
1428.89	WINKFIELD	9.71	11.02	-335.81
1444.27	COLLEGE	10.37	5.67	
1522.52	WINKFIELD	9.70	67.88	-359.47
1538.43	COLLEGE	9.40	6.21	
1567.73	ORROAL	9.20	19.90	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 20.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
9.17	WINKEFIELD	10.09		20.00
24.92	COLLEGE	10.35	5.66	
103.52	WINKEFIELD	9.08	68.25	-3.65
119.09	COLLEGE	9.04	6.49	
147.74	CORDRAL	9.89	19.60	
198.18	ST. JOHNS	9.29	40.56	-27.31
213.04	COLLEGE	6.45	5.57	
241.94	CORDRAL	8.00	22.45	
293.25	ROSMAN	3.35	43.31	-50.96
291.44	ST. JOHNS	9.83	.00	
305.99	COLLEGE	4.65	4.72	
364.72	SANTIAGO	10.29	54.08	
370.92	LIMA	10.09	.00	
380.46	FT. MYERS	10.34	.00	-74.62
382.74	ROSMAN	10.37	.00	
397.07	COLLEGE	6.25	3.97	
461.45	SANTIAGO	5.71	58.13	
468.00	LIMA	4.19	.83	
480.46	ROSMAN	3.46	8.27	-98.27
488.02	COLLEGE	8.87	4.11	
580.30	COLLEGE	10.31	83.40	-121.93
619.24	JOHANNESBURG	8.56	28.63	
674.54	COLLEGE	9.62	46.74	-145.58
712.02	JOHANNESBURG	9.17	27.87	
771.73	COLLEGE	5.00	50.53	-169.23
785.98	WINKEFIELD	9.59	9.25	
880.17	WINKEFIELD	9.78	84.60	-192.89
931.76	CORDRAL	10.33	41.80	
976.53	ST. JOHNS	8.84	34.44	-216.54
1000.13	SANTIAGO	8.28	14.76	
1028.55	CORDRAL	5.58	20.13	
1070.44	ST. JOHNS	10.02	36.31	-240.20
1075.45	ROSMAN	6.81	.00	
1077.55	FT. MYERS	7.58	.00	
1083.98	QUITO	9.86	.00	
1086.73	LIMA	10.29	.00	
1092.27	SANTIAGO	9.72	.00	
1168.43	ROSMAN	10.14	66.44	-263.85
1170.92	FT. MYERS	9.66	.00	
1180.02	QUITO	5.34	.00	
1350.39	COLLEGE	8.80	165.03	-311.16
1407.54	JOHANNESBURG	10.30	48.34	
1429.02	WINKEFIELD	9.59	11.19	-334.81
1444.29	COLLEGE	10.37	5.68	
1505.04	JOHANNESBURG	4.01	50.38	
1522.48	WINKEFIELD	9.82	13.43	-358.47
1538.45	COLLEGE	9.48	6.16	
1567.94	CORDRAL	8.98	20.01	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 21.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
9.27	WINKFIELD	10.01		21.00
24.94	COLLEGE	10.36	5.66	
103.45	WINKFIELD	9.25	68.14	-2.65
119.11	COLLEGE	9.13	6.42	
147.89	ORROPAL	9.75	19.65	
198.34	ST. JOHNS	9.13	40.70	-26.31
213.08	COLLEGE	6.57	5.62	
241.81	ORROPAL	8.33	22.15	
291.40	ST. JOHNS	9.94	41.27	-49.96
306.10	COLLEGE	4.66	4.75	
364.73	SANTIAGO	10.22	53.97	
371.00	LIMA	9.96	.00	
373.46	QUITO	10.04	.00	-73.62
380.52	FT. MYERS	10.29	.00	
382.79	ROSMAN	10.35	.00	
397.24	COLLEGE	6.14	4.10	
461.19	SANTIAGO	6.30	57.81	
467.52	LIMA	5.20	.03	
477.97	FT. MYERS	3.65	5.25	-97.27
479.91	ROSMAN	4.52	.00	
488.15	COLLEGE	8.78	3.72	
580.36	COLLEGE	10.29	83.43	-120.93
619.49	JOHANNESBURG	8.23	28.85	
674.51	COLLEGE	9.71	46.78	-144.58
711.95	JOHANNESBURG	9.40	27.74	
771.51	COLLEGE	5.37	50.15	-168.23
786.04	WINKFIELD	9.45	9.16	
880.16	WINKFIELD	9.88	84.67	-191.89
931.76	ORROPAL	10.29	41.72	
976.45	WINKFIELD	3.50	34.41	-215.54
976.62	ST. JOHNS	9.61	.00	
1000.41	SANTIAGO	7.96	15.17	
1028.29	ORROPAL	6.16	19.93	
1070.43	ST. JOHNS	10.10	35.97	-239.20
1075.69	ROSMAN	6.27	.00	
1077.78	FT. MYERS	7.11	.00	
1084.11	QUITO	9.68	.00	
1086.82	LIMA	10.21	.00	
1092.24	SANTIAGO	9.87	.00	
1167.04	ST. JOHNS	3.40	64.93	-262.85
1168.41	ROSMAN	10.22	.00	
1170.86	FT. MYERS	9.82	.00	
1179.66	QUITO	6.13	.00	
1350.44	COLLEGE	8.66	164.64	-310.16
1407.56	JOHANNESBURG	10.23	48.46	
1429.15	WINKFIELD	9.46	11.37	-333.81
1444.31	COLLEGE	10.36	5.70	
1504.59	JOHANNESBURG	4.96	49.92	
1522.44	WINKFIELD	9.92	12.89	-357.47
1538.47	COLLEGE	9.55	6.11	
1568.16	ORROPAL	8.73	20.14	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 22.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
9.38	WINKFIELD	9.93		22.00
24.96	COLLEGE	10.37	5.66	
103.38	WINKFIELD	9.41	68.05	-1.65
119.13	COLLEGE	9.22	6.35	
148.06	CORCORAL	9.60	19.71	
198.51	ST. JOHNS	8.95	40.85	-25.31
213.12	COLLEGE	6.69	5.67	
241.69	CORCORAL	8.63	21.88	
291.38	ST. JOHNS	10.04	41.06	-48.96
306.21	COLLEGE	4.67	4.79	
364.75	SANTIAGO	10.14	53.86	
371.09	LIMA	9.80	.00	
373.56	QUITO	9.90	.00	-72.62
380.60	FT. MYERS	10.23	.00	
382.85	ROSMAN	10.31	.00	
397.41	COLLEGE	6.03	4.25	
460.96	SANTIAGO	6.81	57.53	
467.15	LIMA	6.00	.00	
477.42	FT. MYERS	4.75	4.27	-96.27
479.50	ROSMAN	5.34	.00	
488.29	COLLEGE	8.68	3.46	
580.42	COLLEGE	10.26	83.45	-119.93
619.77	JOHANNESBURG	7.87	29.09	
674.48	COLLEGE	9.79	46.84	-143.58
711.89	JOHANNESBURG	9.60	27.63	
771.30	COLLEGE	5.72	49.81	-167.23
786.10	WINKFIELD	9.30	9.07	
880.15	WINKFIELD	9.97	84.76	-190.89
931.77	CORCORAL	10.22	41.64	
976.22	WINKFIELD	4.14	34.23	-214.54
976.72	ST. JOHNS	8.36	.00	
1000.70	SANTIAGO	7.60	15.61	
1028.07	CORCORAL	6.67	19.77	
1070.42	ST. JOHNS	10.17	35.68	-238.20
1075.97	ROSMAN	5.64	.00	
1078.03	FT. MYERS	6.56	.00	
1084.25	QUITO	9.47	.00	
1086.92	LIMA	10.11	.00	
1092.23	SANTIAGO	10.00	.00	
1166.75	ST. JOHNS	4.16	64.52	-261.85
1168.40	ROSMAN	10.28	.00	
1170.82	FT. MYERS	9.96	.00	
1179.37	QUITO	6.79	.00	
1183.66	LIMA	3.98	.00	
1350.49	COLLEGE	8.51	162.84	-309.16
1407.59	JOHANNESBURG	10.14	48.59	
1429.29	WINKFIELD	9.33	11.57	-332.81
1444.33	COLLEGE	10.34	5.71	
1504.24	JOHANNESBURG	5.73	49.56	
1522.42	WINKFIELD	10.01	12.45	-356.47
1538.49	COLLEGE	9.62	6.06	
1568.40	CORCORAL	8.47	20.29	

TABLE H1. - VHF TELEMETRY COVERAGE PROFILES - Concluded

EAST LONGITUDE,ASC. NODE (TIME=0) = 23.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
9.49	WINKFIELD	9.83		23.00
24.99	COLLEGE	10.37	5.66	
103.32	WINKFIELD	9.55	67.96	-.65
119.15	COLLEGE	9.30	6.28	
148.24	CORDRAI	9.43	19.79	
198.68	ST. JOHNS	8.75	41.02	-24.31
213.16	COLLEGE	6.80	5.72	
241.59	CORDRAL	8.90	21.63	
291.36	ST. JOHNS	10.12	40.87	-47.96
306.31	COLLEGE	4.70	4.83	
364.77	SANTIAGO	10.04	53.76	
371.19	LIMA	9.61	.00	
373.69	QUITO	9.73	.00	-71.62
380.69	FT. MYERS	10.14	.00	
382.92	ROSMAN	10.26	.00	
397.58	COLLEGE	5.92	4.39	
460.76	SANTIAGO	7.26	57.27	
466.85	LIMA	6.66	.00	
477.00	FT. MYERS	5.58	3.50	-95.27
479.16	ROSMAN	6.01	.00	
488.43	COLLEGE	8.58	3.26	
580.49	COLLEGE	10.23	83.48	-118.93
620.08	JOHANNESBURG	7.46	29.36	
674.46	COLLEGE	9.86	46.92	-142.58
711.85	JOHANNESBURG	9.78	27.53	
771.12	COLLEGE	6.04	49.49	-166.23
786.16	WINKFIELD	9.13	9.01	
880.15	WINKFIELD	10.06	84.86	-189.89
931.79	CORDRAI	10.14	41.58	
976.04	WINKFIELD	4.69	34.11	-213.54
976.83	ST. JOHNS	8.09	.00	
1001.01	SANTIAGO	7.20	16.09	
1027.87	CORDRAI	7.12	19.66	
1070.41	ST. JOHNS	10.23	35.42	-237.20
1076.31	ROSMAN	4.89	.00	
1078.33	FT. MYERS	5.92	.00	
1084.41	QUITO	9.22	.16	
1087.04	LIMA	9.98	.00	
1092.23	SANTIAGO	10.10	.00	
1166.52	ST. JOHNS	4.78	64.19	-260.85
1168.40	ROSMAN	10.33	.00	
1170.79	FT. MYERS	10.08	.00	
1179.12	QUITO	7.35	.00	
1183.15	LIMA	5.06	.00	
1350.54	COLLEGE	8.35	162.32	-308.16
1407.63	JOHANNESBURG	10.03	48.74	
1429.44	WINKFIELD	9.18	11.79	-331.81
1444.36	COLLEGE	10.33	5.73	
1503.95	JOHANNESBURG	6.37	49.26	
1522.40	WINKFIELD	10.09	12.09	-355.47
1538.51	COLLEGE	9.69	6.01	
1568.66	CORDRAL	8.17	20.46	

TABLE H2. - S-BAND TELEMETRY COVERAGE PROFILES

S-BAND TELEMETRY COVERAGE PROFILES

			NORTH LAT. DEG	EAST LONG. DEG	MIN ELEV. DEG
STATION	1	ALASKA	65.00	212.50	5.00
STATION	2	CARNARVON	-24.50	113.40	5.00
STATION	3	ROSMAN	35.20	277.10	5.00
STATION	4	SANTIAGO	-33.10	289.30	5.00
STATION	5	TANANARIVE	-18.50	47.30	5.00

ORBIT ALT= 500.0 KM.
ORBIT INCL= 97.38 DEG.
NODAL LONGITUDE STEP SIZE= 1.00 DEG.
ORBIT PERIOD= 94.62 MINUTES
EARTH RADIUS= 33.3 PERCENT OVER ACTUAL (REFRACTION CORRECTION)
MINIMUM TIME= 3.00 MIN
WESTWARD SHIFT OF ASC. NODE= 23.65 DEG./ORBIT

STATION	MAX. ARC RANGE VISIBLE(DEG)	MAX. DIST.KM.
1	19.73	2331.1
2	19.73	2331.1
3	19.73	2331.1
4	19.73	2331.1
5	19.73	2331.1

EAST LONGITUDE,ASC. NODE (TIME=0) = .00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.51	ALASKA	9.34		.00
118.51	ALASKA	6.89	84.66	-23.65
211.66	ALASKA	4.81	86.27	-47.31
238.65	CARNARVON	10.32	22.17	
270.21	SANTIAGO	9.96	21.24	
288.36	ROSMAN	10.22	8.19	-70.96
302.97	ALASKA	5.97	4.40	
366.06	SANTIAGO	7.51	57.13	
384.35	ROSMAN	6.39	10.77	-94.62
393.85	ALASKA	8.58	3.11	
485.92	ALASKA	10.23	83.48	-118.27
520.63	TANANARIVE	10.35	24.49	
579.86	ALASKA	9.88	48.88	-141.93
676.47	ALASKA	6.13	86.73	-165.58
906.61	SANTIAGO	6.89	224.00	-212.89
935.93	CARNARVON	7.57	22.44	
981.96	ROSMAN	4.30	38.47	-236.54
997.59	SANTIAGO	10.17	11.32	
1029.81	CARNARVON	9.57	22.06	
1073.78	ROSMAN	10.35	34.41	-260.20
1220.80	TANANARIVE	9.44	136.67	-283.85
1255.90	ALASKA	8.31	25.66	-307.50
1316.22	TANANARIVE	7.48	52.00	
1349.72	ALASKA	10.32	26.02	-331.16
1443.87	ALASKA	9.72	83.83	-354.81
1537.94	ALASKA	7.48	84.35	-378.47

TABLE H2. - S-BAND TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 1.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
				1.00
24.53	ALASKA	9.42		
118.54	ALASKA	7.00	84.60	-22.65
211.76	ALASKA	4.85	86.21	-46.31
238.74	CARNARVON	10.26	22.14	
270.24	SANTIAGO	9.82	21.24	
288.45	ROSMAN	10.14	8.38	-69.96
303.14	ALASKA	5.86	4.55	
335.48	CARNARVON	3.98	26.48	
365.90	SANTIAGO	7.89	26.44	
384.08	ROSMAN	6.91	10.30	-93.62
393.99	ALASKA	8.48	2.99	
485.99	ALASKA	10.19	83.52	-117.27
520.67	TANANARIVE	10.37	24.49	
579.85	ALASKA	9.94	48.80	-140.93
676.30	ALASKA	6.42	86.51	-164.58
906.97	SANTIAGO	6.40	224.25	-211.89
936.13	CARNARVON	7.08	22.76	
982.50	ROSMAN	3.14	39.29	-235.54
997.60	SANTIAGO	10.24	11.96	
1029.73	CARNARVON	9.75	21.89	
1073.79	ROSMAN	10.37	34.31	-259.20
1171.02	ROSMAN	3.24	86.86	-282.85
1220.91	TANANARIVE	9.20	46.65	
1255.96	ALASKA	8.14	25.84	-306.50
1316.02	TANANARIVE	7.92	51.92	
1349.74	ALASKA	10.30	25.80	-330.16
1443.89	ALASKA	9.79	83.85	-353.81
1537.97	ALASKA	7.60	84.30	-377.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 2.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
				2.00
24.55	ALASKA	9.49		
118.58	ALASKA	7.12	84.54	-21.65
211.85	ALASKA	4.89	86.16	-45.31
238.85	CARNARVON	10.19	22.11	
270.29	SANTIAGO	9.66	21.26	
288.55	ROSMAN	10.04	8.59	-68.96
303.30	ALASKA	5.76	4.71	
334.99	CARNARVON	5.00	25.93	
365.75	SANTIAGO	8.23	25.76	
383.86	ROSMAN	7.37	9.88	-92.62
394.13	ALASKA	8.38	2.91	
486.07	ALASKA	10.15	83.55	-116.27
520.73	TANANARIVE	10.37	24.51	
579.83	ALASKA	10.01	48.74	-139.93
676.15	ALASKA	6.69	86.31	-163.58
907.38	SANTIAGO	5.84	224.54	-210.89
936.37	CARNARVON	6.51	23.16	
997.63	SANTIAGO	10.30	54.75	-234.54
1029.66	CARNARVON	9.90	21.73	
1073.80	ROSMAN	10.37	34.24	-258.20
1170.57	ROSMAN	4.27	86.40	-281.85
1221.04	TANANARIVE	8.93	46.20	
1256.02	ALASKA	7.96	26.05	-305.50
1315.85	TANANARIVE	8.31	51.87	
1349.77	ALASKA	10.27	25.61	-329.16
1443.90	ALASKA	9.85	83.87	-352.81
1538.00	ALASKA	7.71	84.25	-376.47

TABLE H2. - S-BAND TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 3.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.57	ALASKA	9.57		3.00
118.61	ALASKA	7.23	84.48	-20.65
211.94	ALASKA	4.94	86.10	-44.31
238.97	CARNARVON	10.09	22.09	
270.35	SANTIAGO	9.48	21.29	
288.66	ROSMAN	9.93	8.83	-67.96
303.46	ALASKA	5.66	4.88	
334.62	CARNARVON	5.79	25.49	
365.62	SANTIAGO	8.53	25.20	
383.66	ROSMAN	7.78	9.51	-91.62
394.28	ALASKA	8.28	2.85	
486.15	ALASKA	10.11	83.59	-115.27
520.80	TANANARIVE	10.34	24.54	
579.82	ALASKA	10.06	48.69	-138.93
676.00	ALASKA	6.94	86.11	-162.58
907.83	SANTIAGO	5.19	224.89	-209.89
936.66	CARNARVON	5.85	23.64	
997.67	SANTIAGO	10.34	55.16	-233.54
1029.60	CARNARVON	10.03	21.59	
1073.82	ROSMAN	10.36	34.18	-257.20
1170.24	ROSMAN	5.06	86.06	-280.85
1221.18	TANANARIVE	8.62	45.88	
1256.08	ALASKA	7.77	26.28	-304.50
1315.70	TANANARIVE	8.65	51.85	
1349.79	ALASKA	10.24	25.44	-328.16
1443.92	ALASKA	9.91	83.90	-351.81
1538.03	ALASKA	7.82	84.20	-375.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 4.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.59	ALASKA	9.64		4.00
118.64	ALASKA	7.35	84.42	-19.65
212.03	ALASKA	4.99	86.04	-43.31
239.10	CARNARVON	9.97	22.08	
270.41	SANTIAGO	9.27	21.35	
288.78	ROSMAN	9.80	9.09	-66.96
303.63	ALASKA	5.57	5.05	
334.31	CARNARVON	6.46	25.12	
365.50	SANTIAGO	8.81	24.73	
383.48	ROSMAN	8.14	9.18	-90.62
394.43	ALASKA	8.17	2.81	
486.23	ALASKA	10.07	83.63	-114.27
520.88	TANANARIVE	10.29	24.59	
579.82	ALASKA	10.11	48.65	-137.93
675.86	ALASKA	7.17	85.93	-161.58
908.35	SANTIAGO	4.41	225.32	-208.89
937.01	CARNARVON	5.04	24.25	
997.72	SANTIAGO	10.37	55.67	-232.54
1029.56	CARNARVON	10.14	21.47	
1073.85	ROSMAN	10.32	34.15	-256.20
1169.97	ROSMAN	5.72	85.80	-279.85
1221.34	TANANARIVE	8.26	45.65	
1256.14	ALASKA	7.57	26.54	-303.50
1315.57	TANANARIVE	8.95	51.85	
1349.82	ALASKA	10.20	25.30	-327.16
1443.94	ALASKA	9.96	83.93	-350.81
1538.05	ALASKA	7.93	84.15	-374.47

TABLE H2. - S-BAND TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 5.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.60	ALASKA	9.71		5.00
118.67	ALASKA	7.46	84.36	-18.65
212.11	ALASKA	5.05	85.97	-42.31
239.25	CARNARVON	9.83	22.09	
270.49	SANTIAGO	9.04	21.42	
288.91	ROSMAN	9.65	9.38	-65.96
303.79	ALASKA	5.47	5.23	
334.06	CARNARVON	7.02	24.80	
365.39	SANTIAGO	9.06	24.31	
383.33	ROSMAN	8.46	8.88	-89.62
394.58	ALASKA	8.06	2.79	
486.32	ALASKA	10.02	83.68	-113.27
520.98	TANANARIVE	10.22	24.65	
579.82	ALASKA	10.16	48.62	-136.93
617.97	TANANARIVE	3.49	27.99	
675.73	ALASKA	7.40	54.26	-160.58
908.99	SANTIAGO	3.41	225.86	-207.89
937.47	CARNARVON	4.02	25.07	
997.78	SANTIAGO	10.37	56.29	-231.54
1029.51	CARNARVON	10.23	21.36	
1073.88	ROSMAN	10.28	34.13	-255.20
1169.75	ROSMAN	6.28	85.59	-278.85
1221.53	TANANARIVE	7.85	45.49	
1256.21	ALASKA	7.36	26.83	-302.50
1315.45	TANANARIVE	9.22	51.88	
1349.84	ALASKA	10.16	25.17	-326.16
1443.96	ALASKA	10.01	83.96	-349.81
1538.08	ALASKA	8.04	84.11	-373.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 6.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.62	ALASKA	9.77		6.00
118.70	ALASKA	7.58	84.31	-17.65
212.19	ALASKA	5.12	85.91	-41.31
239.41	CARNARVON	9.66	22.10	
270.58	SANTIAGO	8.78	21.51	
289.06	ROSMAN	9.48	9.70	-64.96
303.95	ALASKA	5.39	5.41	
333.85	CARNARVON	7.51	24.51	
365.29	SANTIAGO	9.28	23.94	
383.19	ROSMAN	8.75	8.62	-88.62
394.73	ALASKA	7.95	2.79	
486.41	ALASKA	9.97	83.73	-112.27
521.09	TANANARIVE	10.12	24.72	
579.83	ALASKA	10.20	48.61	-135.93
617.41	TANANARIVE	4.68	27.38	
675.61	ALASKA	7.61	53.52	-159.58
997.85	SANTIAGO	10.36	314.64	-230.54
1029.48	CARNARVON	10.30	21.27	
1073.92	ROSMAN	10.21	34.14	-254.20
1094.93	SANTIAGO	3.47	10.81	
1169.55	ROSMAN	6.78	71.15	-277.85
1221.74	TANANARIVE	7.39	45.40	
1256.28	ALASKA	7.13	27.16	-301.50
1315.35	TANANARIVE	9.45	51.94	
1349.87	ALASKA	10.11	25.07	-325.16
1443.98	ALASKA	10.06	84.00	-348.81
1538.11	ALASKA	8.15	84.06	-372.47

TABLE H2. - S-BAND TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 7.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.64	ALASKA	9.84		7.00
118.73	ALASKA	7.69	84.26	-16.65
212.26	ALASKA	5.19	85.84	-40.31
239.58	CARNARVON	9.47	22.13	
270.68	SANTIAGO	8.48	21.63	
289.22	ROSMAN	9.29	10.06	-63.96
304.10	ALASKA	5.30	5.60	
333.66	CARNARVON	7.94	24.26	
365.20	SANTIAGO	9.48	23.60	
383.08	ROSMAN	9.00	8.40	-87.62
394.88	ALASKA	7.84	2.80	
486.50	ALASKA	9.91	83.78	-111.27
521.21	TANANARIVE	10.00	24.80	
579.83	ALASKA	10.24	48.62	-134.93
616.99	TANANARIVE	5.57	26.91	
675.49	ALASKA	7.81	52.94	-158.58
997.94	SANTIAGO	10.33	314.64	-229.54
1029.46	CARNARVON	10.34	21.19	
1073.96	ROSMAN	10.13	34.16	-253.20
1094.41	SANTIAGO	4.55	10.32	
1169.39	ROSMAN	7.22	70.43	-276.85
1221.98	TANANARIVE	6.85	45.37	
1256.36	ALASKA	6.89	27.52	-300.50
1315.26	TANANARIVE	9.65	52.01	
1349.90	ALASKA	10.06	24.98	-324.16
1444.00	ALASKA	10.11	84.04	-347.81
1538.13	ALASKA	8.26	84.02	-371.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 8.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.66	ALASKA	9.89		8.00
118.76	ALASKA	7.80	84.21	-15.65
212.33	ALASKA	5.27	85.77	-39.31
239.77	CARNARVON	9.25	22.17	
270.80	SANTIAGO	8.15	21.77	
289.39	ROSMAN	9.08	10.45	-62.96
304.26	ALASKA	5.22	5.79	
333.51	CARNARVON	8.31	24.03	
365.12	SANTIAGO	9.65	23.30	
382.98	ROSMAN	9.23	8.20	-86.62
395.03	ALASKA	7.73	2.83	
486.59	ALASKA	9.85	83.83	-110.27
521.35	TANANARIVE	9.86	24.90	
579.85	ALASKA	10.27	48.64	-133.93
616.65	TANANARIVE	6.29	26.54	
675.39	ALASKA	7.99	52.44	-157.58
998.03	SANTIAGO	10.29	314.65	-228.54
1029.45	CARNARVON	10.37	21.13	
1074.02	ROSMAN	10.02	34.20	-252.20
1094.02	SANTIAGO	5.37	9.98	
1169.24	ROSMAN	7.61	69.85	-275.85
1222.27	TANANARIVE	6.22	45.41	
1256.44	ALASKA	6.64	27.95	-299.50
1315.19	TANANARIVE	9.83	52.11	
1349.92	ALASKA	10.00	24.90	-323.16
1444.02	ALASKA	10.15	84.09	-346.81
1538.16	ALASKA	8.36	83.99	-370.47

TABLE H2. - S-BAND TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 9.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.68	ALASKA	9.95		9.00
118.79	ALASKA	7.91	84.16	-14.65
212.40	ALASKA	5.35	85.70	-38.31
239.98	CARNARVON	9.01	22.23	
270.93	SANTIAGO	7.77	21.94	
289.58	ROSMAN	8.84	10.87	-61.96
304.41	ALASKA	5.15	6.00	
333.38	CARNARVON	8.65	23.82	
365.05	SANTIAGO	9.81	23.03	
382.89	ROSMAN	9.44	8.03	-85.62
395.19	ALASKA	7.62	2.86	
486.69	ALASKA	9.79	83.88	-109.27
521.50	TANANARIVE	9.69	25.02	
579.86	ALASKA	10.30	48.67	-132.93
616.38	TANANARIVE	6.90	26.22	
675.29	ALASKA	8.17	52.01	-156.58
998.13	SANTIAGO	10.23	314.68	-227.54
1029.44	CARNARVON	10.37	21.08	
1074.08	ROSMAN	9.90	34.26	-251.20
1093.70	SANTIAGO	6.05	9.73	
1169.12	ROSMAN	7.97	69.36	-274.85
1222.62	TANANARIVE	5.47	45.53	
1256.53	ALASKA	6.36	28.44	-298.50
1315.13	TANANARIVE	9.98	52.23	
1349.95	ALASKA	9.94	24.84	-322.16
1444.04	ALASKA	10.19	84.14	-345.81
1538.18	ALASKA	8.47	83.95	-369.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 10.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.70	ALASKA	10.00		10.00
118.82	ALASKA	8.02	84.11	-13.65
212.47	ALASKA	5.43	85.63	-37.31
240.21	CARNARVON	8.74	22.30	
271.09	SANTIAGO	7.35	22.14	
289.78	ROSMAN	8.58	11.34	-60.96
304.56	ALASKA	5.08	6.21	
333.27	CARNARVON	8.94	23.62	
364.99	SANTIAGO	9.94	22.78	
382.82	ROSMAN	9.62	7.88	-84.62
395.35	ALASKA	7.51	2.91	
486.80	ALASKA	9.73	83.94	-108.27
521.67	TANANARIVE	9.50	25.15	
579.88	ALASKA	10.32	48.71	-131.93
616.15	TANANARIVE	7.43	25.94	
675.20	ALASKA	8.34	51.62	-155.58
998.25	SANTIAGO	10.15	314.72	-226.54
1029.44	CARNARVON	10.35	21.04	
1074.14	ROSMAN	9.76	34.34	-250.20
1093.44	SANTIAGO	6.63	9.54	
1169.00	ROSMAN	8.29	68.94	-273.85
1223.05	TANANARIVE	4.54	45.76	
1256.63	ALASKA	6.07	29.03	-297.50
1315.08	TANANARIVE	10.10	52.38	
1349.98	ALASKA	9.87	24.80	-321.16
1444.06	ALASKA	10.22	84.20	-344.81
1538.20	ALASKA	8.57	83.92	-368.47

TABLE H2. - S-BAND TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 11.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.72	ALASKA	10.05		11.00
118.84	ALASKA	8.13	84.07	-12.65
212.53	ALASKA	5.52	85.56	-36.31
240.45	CARNARVON	8.43	22.40	
271.27	SANTIAGO	6.87	22.39	
289.99	ROSMAN	8.29	11.86	-59.96
304.71	ALASKA	5.02	6.42	
333.18	CARNARVON	9.20	23.45	
364.93	SANTIAGO	10.06	22.56	
382.76	ROSMAN	9.78	7.76	-83.62
395.51	ALASKA	7.39	2.97	
486.90	ALASKA	9.66	84.00	-107.27
521.85	TANANARIVE	9.28	25.29	
579.91	ALASKA	10.34	48.78	-130.93
615.95	TANANARIVE	7.88	25.71	
675.11	ALASKA	8.50	51.28	-154.58
998.38	SANTIAGO	10.05	314.77	-225.54
1029.46	CARNARVON	10.32	21.02	
1074.22	ROSMAN	9.60	34.45	-249.20
1093.21	SANTIAGO	7.13	9.40	
1127.36	CARNARVON	3.15	27.02	
1168.90	ROSMAN	8.58	38.39	-272.85
1223.66	TANANARIVE	3.27	46.18	
1256.74	ALASKA	5.76	29.81	-296.50
1315.04	TANANARIVE	10.20	52.54	
1350.01	ALASKA	9.80	24.77	-320.16
1444.07	ALASKA	10.26	84.26	-343.81
1538.23	ALASKA	8.67	83.90	-367.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 12.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.74	ALASKA	10.10		12.00
118.87	ALASKA	8.24	84.03	-11.65
212.59	ALASKA	5.62	85.48	-35.31
240.72	CARNARVON	8.08	22.51	
271.48	SANTIAGO	6.32	22.68	
290.23	ROSMAN	7.98	12.43	-58.96
304.86	ALASKA	4.96	6.65	
333.10	CARNARVON	9.43	23.29	
364.89	SANTIAGO	10.16	22.35	
382.71	ROSMAN	9.92	7.67	-82.62
395.67	ALASKA	7.28	3.04	
487.01	ALASKA	9.59	84.06	-106.27
522.06	TANANARIVE	9.02	25.46	
579.94	ALASKA	10.35	48.86	-129.93
615.79	TANANARIVE	8.28	25.50	
675.03	ALASKA	8.65	50.96	-153.58
998.52	SANTIAGO	9.94	314.84	-224.54
1029.48	CARNARVON	10.26	21.02	
1074.30	ROSMAN	9.41	34.57	-248.20
1093.02	SANTIAGO	7.57	9.31	
1126.79	CARNARVON	4.35	26.20	
1168.82	ROSMAN	8.84	37.67	-271.85
1256.85	ALASKA	5.42	79.20	-295.50
1315.01	TANANARIVE	10.28	52.74	
1350.04	ALASKA	9.72	24.76	-319.16
1444.09	ALASKA	10.28	84.33	-342.81
1538.25	ALASKA	8.76	83.87	-366.47

TABLE H2. - S-BAND TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 13.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.76	ALASKA	10.14		13.00
118.89	ALASKA	8.34	83.99	-10.65
212.65	ALASKA	5.72	85.41	-34.31
241.01	CARNARVON	7.70	22.65	
271.73	SANTIAGO	5.67	23.03	
290.48	ROSMAN	7.63	13.07	-57.96
305.00	ALASKA	4.91	6.89	
333.04	CARNARVON	9.63	23.14	
364.84	SANTIAGO	10.24	22.17	
382.67	ROSMAN	10.04	7.59	-81.62
395.83	ALASKA	7.16	3.12	
487.12	ALASKA	9.52	84.13	-105.27
522.28	TANANARIVE	8.73	25.64	
579.97	ALASKA	10.36	48.96	-128.93
615.65	TANANARIVE	8.63	25.31	
674.95	ALASKA	8.79	50.68	-152.58
998.67	SANTIAGO	9.81	314.93	-223.54
1029.51	CARNARVON	10.17	21.03	
1074.40	ROSMAN	9.20	34.72	-247.20
1092.86	SANTIAGO	7.96	9.26	
1126.37	CARNARVON	5.25	25.56	
1168.74	ROSMAN	9.08	37.12	-270.85
1256.99	ALASKA	5.05	79.17	-294.50
1314.99	TANANARIVE	10.33	52.96	
1350.08	ALASKA	9.63	24.76	-318.16
1444.11	ALASKA	10.31	84.40	-341.81
1538.27	ALASKA	8.86	83.85	-365.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 14.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.77	ALASKA	10.18		14.00
118.92	ALASKA	8.45	83.96	-9.65
212.70	ALASKA	5.82	85.34	-33.31
241.33	CARNARVON	7.26	22.81	
272.05	SANTIAGO	4.90	23.47	
290.76	ROSMAN	7.24	13.81	-56.96
305.14	ALASKA	4.86	7.14	
333.00	CARNARVON	9.80	23.00	
364.81	SANTIAGO	10.30	22.01	
382.65	ROSMAN	10.14	7.54	-80.62
395.99	ALASKA	7.05	3.21	
487.23	ALASKA	9.44	84.19	-104.27
522.52	TANANARIVE	8.41	25.84	
580.00	ALASKA	10.37	49.08	-127.93
615.53	TANANARIVE	8.94	25.16	
674.88	ALASKA	8.92	50.42	-151.58
998.83	SANTIAGO	9.65	315.03	-222.54
1029.54	CARNARVON	10.07	21.06	
1074.50	ROSMAN	8.96	34.89	-246.20
1092.72	SANTIAGO	8.30	9.25	
1126.04	CARNARVON	5.97	25.02	
1168.67	ROSMAN	9.29	36.66	-269.85
1257.14	ALASKA	4.64	79.18	-293.50
1314.98	TANANARIVE	10.36	53.21	
1350.11	ALASKA	9.54	24.77	-317.16
1444.13	ALASKA	10.33	84.48	-340.81
1538.29	ALASKA	8.95	83.83	-364.47

TABLE H2. - S-BAND TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 15.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.79	ALASKA	10.22		15.00
118.94	ALASKA	8.55	83.93	-8.65
212.75	ALASKA	5.92	85.27	-32.31
241.68	CARNARVON	6.76	23.00	
272.47	SANTIAGO	3.92	24.03	
291.06	ROSMAN	6.80	14.68	-55.96
305.27	ALASKA	4.83	7.41	
332.97	CARNARVON	9.95	22.87	
364.78	SANTIAGO	10.34	21.86	
382.64	ROSMAN	10.22	7.52	-79.62
396.16	ALASKA	6.93	3.30	
487.35	ALASKA	9.36	84.26	-103.27
522.79	TANANARIVE	8.04	26.07	
580.04	ALASKA	10.37	49.22	-126.93
615.43	TANANARIVE	9.21	25.02	
674.82	ALASKA	9.05	50.18	-150.58
999.01	SANTIAGO	9.48	315.14	-221.54
1029.59	CARNARVON	9.94	21.10	
1074.62	ROSMAN	8.70	35.09	-245.20
1092.60	SANTIAGO	8.61	9.28	
1125.76	CARNARVON	6.58	24.55	
1168.61	ROSMAN	9.48	36.27	-268.85
1257.31	ALASKA	4.18	79.22	-292.50
1314.98	TANANARIVE	10.37	53.49	
1350.15	ALASKA	9.45	24.79	-316.16
1444.15	ALASKA	10.34	84.56	-339.81
1538.31	ALASKA	9.04	83.82	-363.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 16.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.81	ALASKA	10.25		16.00
118.96	ALASKA	8.65	83.90	-7.65
212.80	ALASKA	6.03	85.19	-31.31
242.07	CARNARVON	6.19	23.24	
291.39	ROSMAN	6.32	43.13	-54.96
305.40	ALASKA	4.80	7.70	
332.96	CARNARVON	10.08	22.76	
364.76	SANTIAGO	10.36	21.73	
382.64	ROSMAN	10.28	7.51	-78.62
396.32	ALASKA	6.82	3.40	
487.47	ALASKA	9.28	84.33	-102.27
523.08	TANANARIVE	7.63	26.33	
580.09	ALASKA	10.37	49.38	-125.93
615.35	TANANARIVE	9.44	24.90	
674.76	ALASKA	9.17	49.97	-149.58
999.20	SANTIAGO	9.29	315.27	-220.54
1029.65	CARNARVON	9.79	21.16	
1074.75	ROSMAN	8.40	35.31	-244.20
1092.49	SANTIAGO	8.89	9.34	
1125.52	CARNARVON	7.11	24.14	
1168.56	ROSMAN	9.65	35.93	-267.85
1257.51	ALASKA	3.65	79.30	-291.50
1314.99	TANANARIVE	10.36	53.83	
1350.18	ALASKA	9.34	24.84	-315.16
1444.17	ALASKA	10.36	84.65	-338.81
1538.33	ALASKA	9.13	83.80	-362.47

TABLE H2. - S-BAND TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 17.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.83	ALASKA	10.28		17.00
118.98	ALASKA	8.75	83.88	-6.65
212.85	ALASKA	6.13	85.12	-30.31
242.51	CARNARVON	5.53	23.53	
291.76	ROSMAN	5.76	43.72	-53.96
305.53	ALASKA	4.77	8.01	
332.96	CARNARVON	10.18	22.65	
364.75	SANTIAGO	10.37	21.61	
382.65	ROSMAN	10.33	7.53	-77.62
396.48	ALASKA	6.70	3.51	
487.59	ALASKA	9.20	84.40	-101.27
523.40	TANANARIVE	7.15	26.61	
580.13	ALASKA	10.36	49.58	-124.93
615.29	TANANARIVE	9.65	24.79	
674.71	ALASKA	9.28	49.77	-148.58
772.67	ALASKA	3.41	88.68	-172.23
999.41	SANTIAGO	9.07	223.33	-219.54
1029.72	CARNARVON	9.61	21.24	
1074.89	ROSMAN	8.07	35.57	-243.20
1092.41	SANTIAGO	9.14	9.44	
1125.31	CARNARVON	7.57	23.77	
1168.52	ROSMAN	9.80	35.63	-266.85
1257.76	ALASKA	3.03	79.44	-290.50
1315.01	TANANARIVE	10.32	54.22	
1350.22	ALASKA	9.23	24.89	-314.16
1444.19	ALASKA	10.37	84.74	-337.81
1538.35	ALASKA	9.22	83.79	-361.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 18.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.85	ALASKA	10.30		18.00
119.01	ALASKA	8.84	83.85	-5.65
212.90	ALASKA	6.24	85.05	-29.31
243.03	CARNARVON	4.73	23.89	
292.17	ROSMAN	5.11	44.42	-52.96
305.65	ALASKA	4.76	8.37	
332.97	CARNARVON	10.26	22.55	
364.74	SANTIAGO	10.36	21.51	
382.67	ROSMAN	10.36	7.56	-76.62
396.65	ALASKA	6.59	3.63	
462.20	SANTIAGO	4.13	58.97	
487.72	ALASKA	9.11	21.39	-100.27
523.76	TANANARIVE	6.61	26.94	
580.18	ALASKA	10.35	49.81	-123.93
615.24	TANANARIVE	9.83	24.71	
674.66	ALASKA	9.39	49.59	-147.58
772.35	ALASKA	3.96	88.30	-171.23
999.63	SANTIAGO	8.83	223.31	-218.54
1029.80	CARNARVON	9.40	21.34	
1075.06	ROSMAN	7.70	35.85	-242.20
1092.34	SANTIAGO	9.36	9.58	
1125.13	CARNARVON	7.98	23.44	
1168.48	ROSMAN	9.93	35.37	-265.85
1315.04	TANANARIVE	10.26	136.63	-289.50
1350.26	ALASKA	9.12	24.96	-313.16
1444.21	ALASKA	10.37	84.84	-336.81
1538.37	ALASKA	9.30	83.79	-360.47

TABLE H2. - S-BAND TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 19.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.87	ALASKA	10.32		19.00
119.03	ALASKA	8.93	83.83	-4.65
212.94	ALASKA	6.36	84.98	-28.31
243.66	CARNARVON	3.70	24.36	
292.66	ROSMAN	4.34	45.30	-51.96
305.77	ALASKA	4.75	8.78	
332.99	CARNARVON	10.32	22.47	
364.74	SANTIAGO	10.33	21.43	
382.70	ROSMAN	10.37	7.62	-75.62
396.82	ALASKA	6.48	3.75	
461.81	SANTIAGO	4.98	58.52	
487.84	ALASKA	9.02	21.05	-99.27
524.17	TANANARIVE	5.98	27.31	
580.24	ALASKA	10.34	50.08	-122.93
615.21	TANANARIVE	9.98	24.64	
674.62	ALASKA	9.49	49.43	-146.58
772.08	ALASKA	4.45	87.97	-170.23
999.86	SANTIAGO	8.56	223.34	-217.54
1029.89	CARNARVON	9.17	21.47	
1075.24	ROSMAN	7.29	36.18	-241.20
1092.29	SANTIAGO	9.55	9.76	
1124.97	CARNARVON	8.34	23.14	
1168.45	ROSMAN	10.05	35.14	-264.85
1315.08	TANANARIVE	10.18	136.58	-288.50
1350.30	ALASKA	8.99	25.04	-312.16
1412.33	TANANARIVE	4.24	53.04	
1444.23	ALASKA	10.37	27.67	-335.81
1538.39	ALASKA	9.38	83.79	-359.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 20.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.89	ALASKA	10.34		20.00
119.05	ALASKA	9.03	83.82	-3.65
212.98	ALASKA	6.47	84.91	-27.31
293.25	ROSMAN	3.35	73.80	-50.96
305.89	ALASKA	4.75	9.29	
333.03	CARNARVON	10.35	22.39	
364.74	SANTIAGO	10.29	21.36	
382.74	ROSMAN	10.37	7.71	-74.62
396.98	ALASKA	6.36	3.88	
461.50	SANTIAGO	5.68	58.15	
480.46	ROSMAN	3.46	13.28	-98.27
487.97	ALASKA	8.93	4.06	
524.65	TANANARIVE	5.23	27.74	
580.29	ALASKA	10.32	50.42	-121.93
615.19	TANANARIVE	10.10	24.58	
674.58	ALASKA	9.58	49.28	-145.58
771.83	ALASKA	4.87	87.67	-169.23
1000.12	SANTIAGO	8.27	223.41	-216.54
1030.00	CARNARVON	8.90	21.62	
1075.45	ROSMAN	6.81	36.55	-240.20
1092.24	SANTIAGO	9.72	9.98	
1124.83	CARNARVON	8.67	22.86	
1168.43	ROSMAN	10.14	34.94	-263.85
1315.13	TANANARIVE	10.07	136.56	-287.50
1350.35	ALASKA	8.86	25.15	-311.16
1411.88	TANANARIVE	5.20	52.67	
1444.26	ALASKA	10.37	27.18	-334.81
1538.41	ALASKA	9.46	83.79	-358.47

TABLE H2. - S-BAND TELEMETRY COVERAGE PROFILES - Continued

EAST LONGITUDE,ASC. NODE (TIME=0) = 21.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.91	ALASKA	10.36		21.00
119.07	ALASKA	9.11	83.81	-2.65
213.02	ALASKA	6.58	84.84	-26.31
306.00	ALASKA	4.76	86.40	-49.96
333.08	CARNARVON	10.37	22.32	
364.76	SANTIAGO	10.22	21.31	
382.79	ROSMAN	10.35	7.81	-73.62
397.15	ALASKA	6.25	4.01	
461.23	SANTIAGO	6.27	57.83	
479.91	ROSMAN	4.52	12.41	-97.27
488.11	ALASKA	8.84	3.67	
525.21	TANANARIVE	4.29	28.27	
580.36	ALASKA	10.30	50.85	-120.93
615.19	TANANARIVE	10.20	24.54	
674.55	ALASKA	9.67	49.15	-144.58
771.60	ALASKA	5.26	87.39	-168.23
1000.39	SANTIAGO	7.94	223.53	-215.54
1030.12	CARNARVON	8.59	21.79	
1075.69	ROSMAN	6.27	36.97	-239.20
1092.22	SANTIAGO	9.87	10.26	
1124.70	CARNARVON	8.95	22.61	
1168.41	ROSMAN	10.22	34.76	-262.85
1315.20	TANANARIVE	9.93	136.56	-286.50
1350.39	ALASKA	8.72	25.26	-310.16
1411.52	TANANARIVE	5.97	52.41	
1444.28	ALASKA	10.36	26.79	-333.81
1538.43	ALASKA	9.53	83.79	-357.47

EAST LONGITUDE,ASC. NODE (TIME=0) = 22.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.93	ALASKA	10.36		22.00
119.09	ALASKA	9.20	83.80	-1.65
213.06	ALASKA	6.70	84.77	-25.31
306.11	ALASKA	4.77	86.35	-48.96
333.14	CARNARVON	10.37	22.26	
364.77	SANTIAGO	10.14	21.27	
382.85	ROSMAN	10.31	7.93	-72.62
397.32	ALASKA	6.14	4.15	
461.00	SANTIAGO	6.78	57.54	
479.50	ROSMAN	5.34	11.71	-96.27
488.24	ALASKA	8.75	3.41	
525.96	TANANARIVE	3.01	28.98	
580.42	ALASKA	10.27	51.45	-119.93
615.20	TANANARIVE	10.28	24.51	
674.52	ALASKA	9.75	49.04	-143.58
771.40	ALASKA	5.61	87.13	-167.23
1000.68	SANTIAGO	7.58	223.68	-214.54
1030.26	CARNARVON	8.24	22.00	
1075.97	ROSMAN	5.64	37.46	-238.20
1092.20	SANTIAGO	10.00	10.59	
1124.59	CARNARVON	9.21	22.39	
1168.40	ROSMAN	10.28	34.61	-261.85
1315.27	TANANARIVE	9.77	136.58	-285.50
1350.44	ALASKA	8.58	25.40	-309.16
1411.23	TANANARIVE	6.61	52.21	
1444.30	ALASKA	10.35	26.46	-332.81
1538.45	ALASKA	9.61	83.80	-356.47

TABLE H2. - S-BAND TELEMETRY COVERAGE PROFILES - Concluded

EAST LONGITUDE,ASC. NODE (TIME=0) = 23.00 DEG

TIME, MIN.	STATION	MINUTES IN SIGHT	MINUTES SINCE LAST CONTACT	LAST ASC.NODE E.LONG.,DEG.
24.95	ALASKA	10.37		23.00
119.11	ALASKA	9.29	83.79	-.65
213.10	ALASKA	6.81	84.71	-24.31
306.21	ALASKA	4.79	86.30	-47.96
333.21	CARNARVON	10.35	22.20	
364.80	SANTIAGO	10.04	21.24	
382.92	ROSMAN	10.26	8.08	-71.62
397.48	ALASKA	6.03	4.30	
460.80	SANTIAGO	7.24	57.29	
479.16	ROSMAN	6.01	11.12	-95.27
488.38	ALASKA	8.65	3.21	
580.49	ALASKA	10.25	83.46	-118.93
615.22	TANANARIVE	10.33	24.49	
674.49	ALASKA	9.83	48.94	-142.58
771.21	ALASKA	5.93	86.88	-166.23
1001.00	SANTIAGO	7.18	223.86	-213.54
1030.43	CARNARVON	7.85	22.25	
1076.31	ROSMAN	4.89	38.03	-237.20
1092.20	SANTIAGO	10.11	11.00	
1124.49	CARNARVON	9.43	22.18	
1168.40	ROSMAN	10.33	34.48	-260.85
1315.36	TANANARIVE	9.58	136.63	-284.50
1350.49	ALASKA	8.42	25.55	-308.16
1410.98	TANANARIVE	7.16	52.07	
1444.32	ALASKA	10.33	26.18	-331.81
1538.47	ALASKA	9.68	83.82	-355.47

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APPENDIX I
EFFECT OF COMPUTATIONAL ERRORS

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APPENDIX I
EFFECT OF COMPUTATIONAL ERRORS

To test the accuracy of the numerical solution of the differential equation, the solution as obtained by a numerical technique was compared to an analytical solution.

The analytical solution was obtained by assuming a torque-free unsymmetric body. For this case, the differential equations become

$$\dot{\theta} = d \sin\theta \sin\Psi \cos\Psi (1/A - 1/B)$$

$$\dot{\phi} = d (\sin^2\Psi/A + \cos^2\Psi/B)$$

$$\dot{\Psi} = d \cos\theta (1/C - \sin^2\Psi/A - \cos^2\Psi/B)$$

The analytic solution for small θ and a body which does not approximate a sphere-like body is given in reference 6 as:

$$\theta = \theta_a - \frac{\epsilon}{2} \tan\theta_a (1 + r) [\cos\alpha + \frac{\epsilon}{8} \sec^2\theta_a (1 + r)(\cos 2\alpha - \cos^2\theta_a)] + \ldots$$

$$\Psi = \Psi_a + \mu t + \epsilon p \sin a[1 + \frac{\epsilon}{8} (1 + r) \cos\alpha$$

$$x (\tan^2\theta_a + \frac{6 + 2\cos^2\theta_a}{1 + \cos^2\theta_\alpha})] + \ldots$$

$$\phi = \phi_a + \frac{d}{I_1} [1 + \epsilon^2 (1 - p)] t$$

$$-\frac{\epsilon}{2} (1 + r) \sec\theta_a \sin\alpha (1 + \epsilon p \cos\alpha) + \ldots$$

where

$$\alpha = 2(\mu t + \Psi_a),$$

$$\mu = -\frac{d}{(r + 1) I_1} \cos\theta_a \{1 + \frac{\epsilon^2}{2}(1 + r) [1 - r - 1/4 \tan^2\theta_a (1 + r)]\} + \ldots$$

$$I_1 = \frac{A + B}{2},$$

$$\epsilon = \frac{A - B}{A + B},$$

$$1 + r = \frac{2C}{2C - A - B},$$

Here, θ_a, Ψ_a; ϕ_a determine the initial conditions.

If we assume the initial conditions

$$\theta(0) = 5°$$

$$\Psi(0) = \phi(0) = 0$$

$$d = 31.41593 \text{ slug ft}^2/\text{second}$$

$$A = 40 \text{ slug ft}^2$$

$$B = 40.4 \text{ slug ft}^2$$

$$C = 60 \text{ slugs},$$

then the results plotted in Figure I1 are obtained.

Here, error in ϕ = analytic solution - numerical solution. Only errors in ϕ are shown, but the error in Ψ was similar to that of ϕ. Errors in θ were negligible.

The method used to obtain the numerical solution was a Runge-Kutta method. Two different word lengths were utilized. The first had a mantissa of 36 bits (CDC 3600), while the second had a mantissa of 48 bits (CDC 6500). The error is less than one second of arc after one orbital period if a 48 bit mantissa is utilized.

Two different step sizes were chosen in performing the computations with the 36-bit mantissa. For this case, the longer step size yields slightly better results.

The general conclusion which may be drawn from this graph is that if the differential equations are to be solved numerically, a 36-bit mantissa can only be used if the time interval is restricted to about one-third of an orbital period. However, a 48-bit mantissa yields negligible errors over an orbital period.

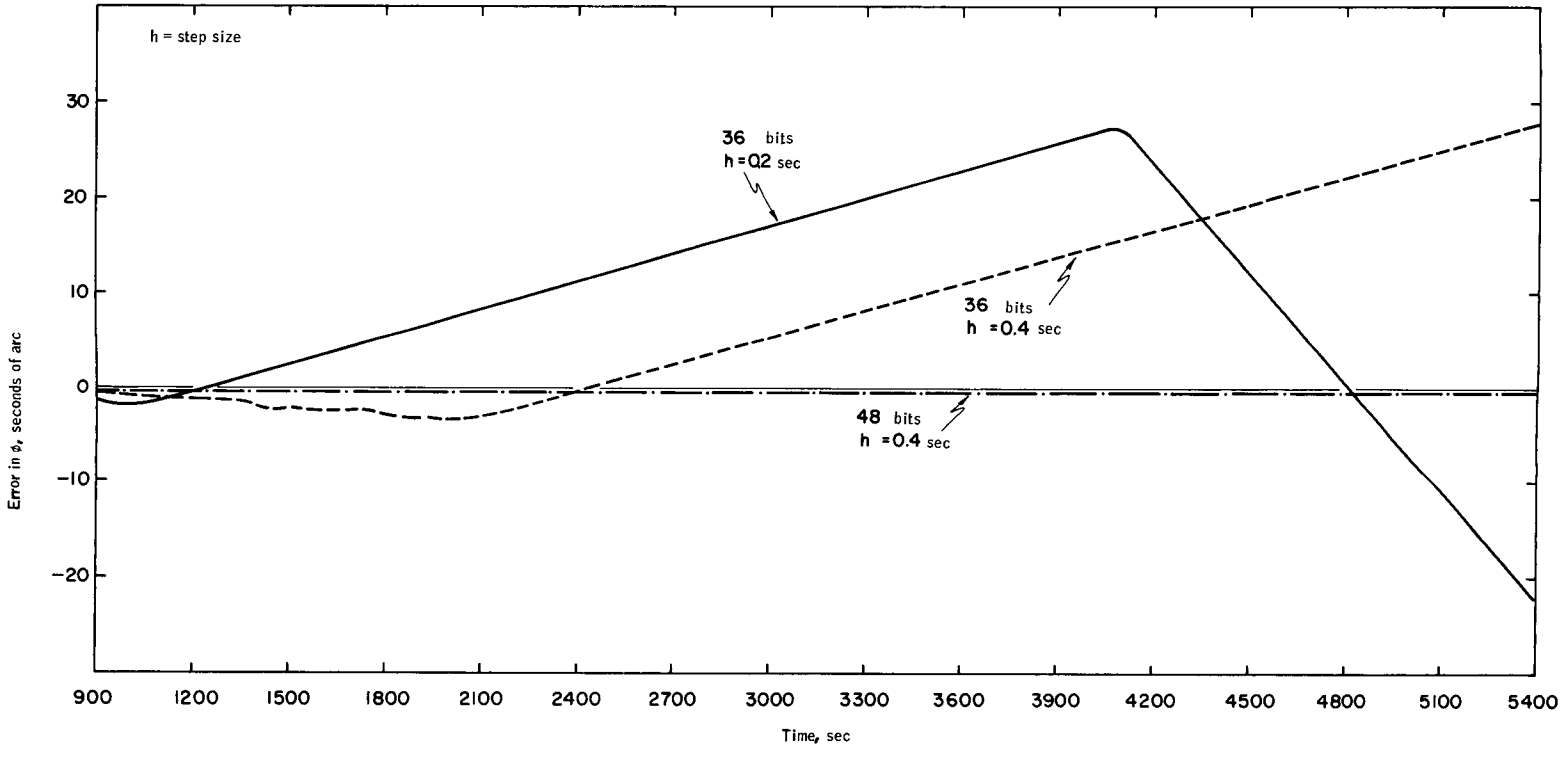

Figure I1. Error in Numerical Solutions of Differential Equations

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APPENDIX J

LEAST-SQUARES ATTITUDE DETERMINATION PROGRAM

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```
                PROGRAM HNYL (INPUT,OUTPUT,TAPE1,TAPE5=INPUT,TAPE9=OUTPUT,TAPE7)
000003          DIMENSION D(1174),PF(15 ),PG(15,16),VG(15),AV(16),BIM(3),EMA(3,3),
               1PFS(3,3),PEH(3,3),PET(3,3),BBM(3),PBS(3),PBH(3),PBT(3),CF(3,3),
               2PCE1(3,3),PCE2(3,3),PCE3(3,3),PFX(6,6),PMA(3,3),CMAT1(3,3),CMAT2(3
               32,3),BIL(5,3),SHAT(3),OUT(12),TP(6),BETGAM(2,5)
000003          EQUIVALENCE (D(1),DT),(D(2),TIME),(BBM(1),BBX),(BBM(2),BBY),(BBM(3
               1),BBZ),(SH1,SHAT(1)),(SH2,SHAT(2)),(SH3,SHAT(3)),(TP(1),OMX),(TP(2
               2),OMY),(TP(3),OMZ),(TP(4),PSI),(TP(5),PHI),(TP(6),THT)
               3,(VG(1),OMXZ),(VG(2),OMYZ),(VG(3),OMZZ),(VG(4),PSIZ),(VG(5),PHIZ),
               4 (VG(6),THTZ),(VG(7),A  ),(VG(8),C),(VG(9),FMXP),(VG(10),FMYP),
               5 (VG(11),FMZP),(VG(12),FKP),(VG(13),EP1),(VG(14),EP2),(VG(15),EP3)
000003          REWIND 1
          C
          CONSTANTS, ZERO ARRAYS, INITIAL CONDITIONS
          C
000005          READ (5,450) M1,M2,ISUN,IRIN,ITEST
000023      450 FORMAT (10I5)
000023          IEND = 0
000024          NS = 10
000025          IF (ISUN.NE.0) NS = 11
000027          DTMIN = 1.0E-12
000031          PI =  3.141592654
000032          TWOPI = 6.283185307
000034          CONVER = 1.E-05
000035          DTR = .0174532925
000037          RTD = 57.2957795
000040          DO 15 I=1,3
000042          PFS(I,3) = 0.
000043          PET(2,I) = 0.
000046          PCE1(I,3) = 0.
000047          PCE3(2,I) = 0.
000051          PFX(I+3,2) = 0.
000052       15 PFX(I+3,4) = 0.
000054          PFX(5,5) = 0.
000055          PFX(6,2) = 1.
          CONSTANTS FOR MAGNETIC FIELDS
000057          NMX = 8
000060          NMY = 1
000061          ALT = 500.
000062          TM = 1969.25
          CONSTANTS FOR DE ROUTINE
000064          ISW = 2
000065          JUMP = 0
000066          NDE= 78
          C READ INITIAL GUESS FROM CARD
000067          READ (5,7) ITAPE,NSF,(VG(I),I=1,6),EI1
000106          READ (5,205) EI2,EI3,EMX,EMY,EMZ,EK,EP1,EP2
000132          READ (5,205) EP3,DT,RATIOK
000144      205 FORMAT (8E10.8)
000144        7 FORMAT (2I5,7F10.7)
000144          DTSAVE = DT
000146          KOUNT = 0
000147          IF(IRIN.EQ.0) CALL STARED (ITAPE)
000151          REWIND ITAPE
          C READ AND WRITE FIRST RECORD FROM TAPE
000153          READ (ITAPE) ID,CI1,CI2,CI3,CMX ,CMY ,CMZ ,CK,R,FI,FNUZ,OMN,GMAZ,
               1OME,((BETGAM(I,J),I=1,2),J=1,5),CP1,CP2,CP3
000233          WRITE (9,5) ID,CI1,CI2,CI3,CMX,CMY,CMZ,CK,R,FI,FNUZ,OMN,GMAZ,
               1OME,((BETGAM(I,J),J=1,5),I=1,2),CP1,CP2,CP3
```

```
000314        5 FORMAT (1H1,5H ID =,I8//4H I =,3F16.8/4H M =,3F16.8/4H K =,F16.8/
             18H OMEGA =,F12.8/4H T =,F16.8/5H NU =,F15.8/ 8H OM NU =,F12.8/
             28H GMA O =,F12.8/7H OM E =,F13.8/7H RETA =,F13.8,4F16.8/8H GAMMA =
             3,F12.8,4F16.8/7H EPSI =,F13.8,2F16.8/)
        CONVERT ANGLES FROM DEGREES TO RADIANS
000314        DO 103 I = 1,2
000316        DO 103 J = 1,5
000317    103 BETGAM(I,J) = BETGAM(I,J)*DTR
000330        A = FI1
000331        C = FI2
000333        FMXP = FMX
000334        FMYP = FMY
000336        FMZP = FMZ
000337        FKP = FK
000341        R = R*DTR
000342        FI = FI *DTR
000343        FMUZ = FMUZ * DTR
000344        OMM = OMM*DTR
000345        GMAZ = GMAZ*DTR
000346        OME = OME*DTR
000350        FP1 = FP1 * DTR
000351        FP2 = FP2 * DTR
000352        FP3 = FP3 * DTR
000354        CP1 = CP1*DTR
000355        CP2 = CP2*DTR
000356        CP3 = CP3*DTR
000357        DO 14 I = 1,6
000360     14 VG(I) = VG(I) * DTR
        CALCULATE E ARRAY AND VALUES FOR INITIAL GUESS
000364        DO 101 I = 1,5
000366        CBI = SIN(BETGAM(1,I))
000372        BIL(I,1) = COS(BETGAM(1,I))
000400        BIL(I,2) =  SIN(BETGAM(2,I))*CBI
000407    101 BIL(I,3) =  -COS(BETGAM(2,I))*CBI
000417        CR = COS(R)
000421        SR = SIN(R)
000423        CI = COS(FI)
000425        SI = SIN(FI)
        C
        CODE TO HERE TO RESTART AFTER UPDATE, COMPUTE C MATRIS AND ITS PARTIALS
        C
000427     16 TR = 0.
000430        ICHCK = 0
000431        COST = 0.
000432        SEP1 = SIN(FP1)
000434        SEP2 = SIN(FP2)
000436        SEP3 = SIN(FP3)
000440        CEP1 = COS(FP1)
000442        CEP2 = COS(FP2)
000444        CEP3 = COS(FP3)
000446        TEMP = SEP3*SEP2
000450        CF(1,1) = CEP3*CEP1 - TEMP*SEP1
000453        CF(1,2) = CEP3*SEP1 + TEMP*CEP1
000456        CF(1,3) = -SEP3*CEP2
000460        CF(2,1) = -CEP2*SEP1
000462        CF(2,2) = CEP2*CEP1
000463        CF(2,3) = SEP2
000465        TEMP = CEP3*SEP2
000466        CF(3,1) = SEP3*CEP1 + TEMP*SEP1
000471        CF(3,2) = SEP3*SEP1 - TEMP*CEP1
```

```
000474          CE(3,3) = CEP3*CEP2
000476          DO 26 I=1,3
000477          PCE1(I,1) = -CE(I,2)
000501          PCE1(I,2) =  CE(I,1)
000502          PCE3(1,I) = -CE(3,I)
000507          PCE3(3,I) =  CE(1,I)
000511          PCE2(1,I) =  CE(2,I)*SEP3
000513       26 PCE2(3,I) = -CE(2,I)*CEP3
000520          PCE2(2,1) = SEP2*SEP1
000522          PCE2(2,2) = -SEP2*CEP1
000524          PCE2(2,3) = CEP2
          COMPUTE PARAMETER DIFFERENCES AND WRITE OUT
000525          DELTA = A - CI1/CI2
000530          DELTC = C - CI3/CI2
000533          DELTMX= FMXP - CMX/CI2
000535          DELTMY= FMYP - CMY/CI2
000540          DELTMZ= FMZP - CMZ/CI2
000543          DELTK = FKP - CK/CI2
000545          DELTE1=(EP1 - CP1)*RTD
000550          DELTE2=(EP2 - CP2)*RTD
000553          DELTE3=(EP3 - CP3)*RTD
000556          WRITE (9,11)                                    DELTA,DELTC,DELTMX,
               2DELTMY,DELTMZ,DELTK,DELTE1,DELTE2,DELTE3
000603       11 FORMAT                                  (/6HDELTAS,12X,2H A,10X,2H C,
               410X,3H MX,9X,3H MY,9X,3H MZ,9X,2H K,10X,5H EPS1,7X,5H EPS2,7X,
               55H EPS3 / 12X,9F12.4)
000603          DO 102 I=1,158
000605      102 D(I)= 0.
000610          WRITE (9,1)
000614        1 FORMAT (//11X,4HTIME,12X,3HOMX,12X,3HOMY,12X,3HOMZ,12X,3HPSI,12X,
               1 3HPHI,12X,3HTHT,10X,4HCOST //)
          C READ TAPE FOR INITIAL CONDITIONS. SET UP FOR FIRST CALL TO DE ROUTINE
000614       18 READ (ITAPE) TIMS,ISLT,ALF,DEL,TIMA,(TP(I),I=1,6),WMAG
000641          TIMEZ = TIMA
000643          DT = DTSAVE
000644          D(2) = TIMA
000645          D(3) = OMXZ
000647          D(5) = OMYZ
000650          D(7) = OMZZ
000652          D(9) = PSIZ
000653          D(11)= PHIZ
000655          D(13)= THTZ
000656          DO 104 I=15,85,14
000660      104 D(I) = 1.0
000664          I = -NSF
000665          TEMP = 10.**I
000670          DO 106 I= 4,158,2
000672      106 D(I) = TEMP
000676          DO 108 I=1,15
000677          DO 108 J=1,16
000700      108 PG(I,J) = 0.
000710       69 ICIND = 6
000711            JOP = 1
000712            CALL SDAM    (1,NSF,0,IDE,NDE,ISW,TB)
          C
          COMPUTE RIGHT HAND SIDES
          C
000721       20 DTIME = TIME
          C ORBIT DATA LATITUDE AND LONGITUDE
000723          ENU = ENUZ + OMN*DTIME
```

```
000726          CNU = COS(FNU)
000730          SNU = SIN(FNU)
000732          CLCL = CP*CNU - CI*SP*SNU
000736          CLSL = SP*CNU + CI*CP*SNU
000741          SLAM = SI*SNU
000743          IF (CLCL) 200,202,200
000744      202 FL = PI*0.5
000746          GO TO 204
000747      200 FL = ATAN(ABS(CLSL/CLCL))
000754      204 IF(CLSL) 206,208,208
000756      208 IF (CLCL) 210,210,218
000760      210 FL= PI-FL
000762          GO TO 218
000763      206 IF (CLCL) 212,212,214
000765      212 FL = FL-PI
000767          GO TO 218
000770      214 FL = -FL
000771      218 DLAT = ASIN(ABS(SLAM))
000776          IF (SLAM) 220,222,222
000777      220 DLAT = -DLAT
001000      222 DLONG = FL - GMAZ - OMEGA*DTIME
001004          DLAD=DLAT*RTD
001006          DLOND=DLONG*RTD
        C MAGNETIC FIELD
001010          CALL FIELDG (DLAD,DLOND,ALT,TM,NMX,NMY,FX,FY,FZ,F)
        CONVERT B TO INERTIAL SPACE
001021          FX = FX * CONVER
001023          FY = FY * CONVER
001024          FZ = FZ * CONVER
001025          TEMP = FX*SLAM + FZ*COS(DLAT)
001032          BIN(1) = -FY*SIN(FL) - TEMP*COS(FL)
001041          BIN(2) =  FY*COS(FL) - TEMP*SIN(FL)
001051          BIN(3) =  FX*COS(DLAT) - FZ*SLAM
        COMPUTE E MATRIX AND ITS PARTIALS
001057       21 SPST = SIN(O(9))
001062          SPHI = SIN(O(11))
001064          STHT = SIN(O(13))
001066          CPST = COS(O(9))
001070          CPHI = COS(O(11))
001072          CTHT = COS(O(13))
001074          TEMP = STHT*SPHI
001076          EMA(1,1) = CTHT*CPSI - TEMP*SPSI
001101          EMA(1,2) = CTHT*SPSI + TEMP*CPSI
001104          EMA(1,3) = -STHT*CPHI
001106          EMA(2,1) = -CPHI*SPSI
001110          EMA(2,2) = CPHI*CPSI
001111          EMA(2,3) = SPHI
001113          TEMP = CTHT*SPHI
001114          EMA(3,1) = STHT*CPSI + TEMP*SPSI
001117          EMA(3,2) = STHT*SPSI - TEMP*CPSI
001122          EMA(3,3) = CTHT*CPHI
001124          DO 22 I=1,3
001125          PES(I,1) =-EMA(I,2)
001127          PES(I,2) = EMA(I,1)
001130          PET(1,I) =-EMA(3,I)
001135          PET(3,I) = EMA(1,I)
001137          PEH(1,I) = EMA(2,I)*STHT
001141       22 PEH(3,I) =-EMA(2,I)*CTHT
001146          PEH(2,1) = SPHI*SPSI
001150          PEH(2,2) = -SPHI*CPSI
```

```
001152          PEH(2,3) = CPHI
          C PSI DOT, PHI DOT, THETA DOT
001153          F4 = (-D(3)*STHT+D(7)*CTHT)/CPHI
001160          F5 = D(3)*CTHT + D(7)*STHT
001163          F6 = D(5)-F4*SPHI
001166          IF (JUMP) 45,45,46
          COMPUTE B BODY AND PARTIALS OF B
001170       45 DO 24 I =1,3
001172          PBS(I) = PES(I,1)*BIM(1) + PES(I,2)*BIM(2) + PES(I,3)*BIM(3)
001200          PBH(I) = PEH(I,1)*BIM(1) + PEH(I,2)*BIM(2) + PEH(I,3)*BIM(3)
001206          BBM(I) = EMA(I,1)*BIM(1) + EMA(I,2)*BIM(2) + EMA(I,3)*BIM(3)
001214       24 PBT(I) = PET(I,1)*BIM(1) + PET(I,2)*BIM(2) + PET(I,3)*BIM(3)
001224          T1 = OMX
001226          T2 = OMY
001227          T3 = OMZ
001231          OMX = D(3)
001232          OMY = D(5)
001233          OMZ = D(7)
001234          BTM1 = -(BBY*BBY+BBZ*BBZ)*OMX + BBX*(BBY*OMY+BBZ*OMZ)
001244          BTM2 = -(BBX*BBX+BBZ*BBZ)*OMY + BBY*(BBX*OMX+BBZ*OMZ)
001254          BTM3 = -(BBX*BBX+BBY*BBY)*OMZ + BBZ*(BBX*OMX+BBY*OMY)
          C OMEGA X DOT, OMEGA Y DOT, OMEGA Z DOT
001264          D(4) = (OMY*OMZ*(1.-C) + FMYP*BBZ     - FMZP*BBY     + FKP*BTM1)/A
001277          D(6) = OMX*OMZ*(C-A)+FMZP*BBX - FMXP*BBZ + FKP*BTM2
001311          D(8) = (OMX*OMY*(A-1.) + FMXP*BBY - FMYP*BBX + FKP*BTM3)/ C
001324          D(10) = F4
001325          D(12) = F5
001327          D(14) = F6
          COMPUTE P MATRIX
001330          TEMP = SPHI/CPHI
001332          PMA(1,1) = FKP*(BBY*OMY + BBZ*OMZ)/ A
001340          PMA(1,2) =(FKP*(BBX*OMY - 2.*BBY*OMX) - FMZP)/A
001347          PMA(1,3) =(FKP*(BBX*OMZ - 2.*BBZ*OMX) + FMYP)/A
001356          PMA(2,1) = FKP*(BBY*OMX - 2.*BBX*OMY) + FMZP
001364          PMA(2,2) = FKP*(BBX*OMX + BBZ*OMZ)
001370          PMA(2,3) = FKP*(BBY*OMZ - 2.*BBZ*OMY) - FMXP
001376          PMA(3,1) =(FKP*(BBZ*OMX - 2.*BBX*OMZ) - FMYP)/C
001405          PMA(3,2) =(FKP*(BBZ*OMY - 2.*BBY*OMZ) + FMXP)/C
001414          PMA(3,3) =(FKP*(BBX*OMX + BBY*OMY))/C
          COMPUTE PARTIAL OF F W/R/T X
001421          PFX(1,1) = -FKP*(BBY*BBY + BBZ*BBZ)/A
001425          PFX(1,2) =(OMZ*(1.-C) + FKP*BBX*BBY)/ A
001434          PFX(1,3) =(OMY*(1.-C) + FKP*BBX*BBZ)/ A
001442          PFX(2,1) = OMZ*(C-A) + FKP*BBX*BBY
001447          PFX(2,2) = -FKP*(BBX*BBX + BBZ*BBZ)
001452          PFX(2,3) = OMX*(C-A) + FKP*BBY*BBZ
001457          PFX(3,1) =(OMY*(A-1.) + FKP*BBZ*BBX)/C
001466          PFX(3,2) =(OMX*(A-1.) + FKP*BBZ*BBY)/C
001474          PFX(3,3) = -FKP*(BBX*BBX + BBY*BBY)/C
001500          PFX(4,1) = -STHT/CPHI
001502          PFX(5,1) =  CTHT
001504          PFX(6,1) =  STHT*TEMP
001506          PFX(4,3) = CTHT/CPHI
001507          PFX(5,3) = STHT
001510          PFX(6,3) = -CTHT*TEMP
001511          PFX(4,5) = D(10)*TEMP
001513          PFX(6,5) = -D(10)/CPHI
001514          PFX(4,6) = -D(12)/CPHI
001516          PFX(5,6) =  D(10)*CPHI
001517          PFX(6,6) =  D(12)*TEMP
```

```
101521          DO 28 I = 1,3
101522          PEX(I,4)= 0.
101523          PEX(I,5)= 0.
101524          PEX(I,6)= 0.
101525          DO 28 K = 1,3
101527          PEX(I,4)= PEX(I,4) + PMA(I,K) * PBS(K)
101535          PEX(I,5)= PEX(I,5) + PMA(I,K) * PBH(K)
101541       28 PEX(I,6)= PEX(I,6) + PMA(I,K) * PBT(K)
        C RIGHT HAND SIDES OF LINEARIZED DE
101550          K = 1
101551          DO 30 L = 1,12
101553          K = K + 12
101555          DO 30 I = 1,6
101556          M = K+1 + 2*I
101562          D(M) = 0.
101563          DO 30 J = 1,6
101565          N = K + 2*J
101570       30 D(M) = D(M) + PEX(I,J)*D(N)
        C ADD FORCING TERMS
101604          D( 88) = D( 88)   -D(4)/ A
101607          D( 90) = D( 90)   -OMX*OMZ
101612          D( 92) = D( 92)   +OMX*OMY/ C
101615          D(100) = D(100)   -OMY*OMZ/ A
101622          D(102) = D(102)   +OMX*OMZ
101625          D(104) = D(104)   -D(2) / C
101630          D(114) = D(114)   -BBZ
101632          D(116) = D(116)   +BBY / C
101634          D(124) = D(124)   +BBZ / A
101637          D(128) = D(128)   -BBX / C
101642          D(136) = D(136)   -BBY / A
101645          D(138) = D(138)   +BBX
101647          D(148) = D(148)   +BTM1/A
101652          D(150) = D(150)   +BTM2
101654          D(152) = D(152)   +BTM3/C
101657          OMX = T1
101660          OMY = T2
101661          OMZ = T3
101663          CALL SOLN    (2,NSE,D,IDE,NDE,ISW,TB)
        C
        C BRANCH TO PROPER CALCULATIONS AFTER ENTRY TO DE ROUTINE, CHECK SIZE OF ANGLES
        C
101671          GO TO (32,26,38), IDE
101700       32 IF (ICLOG) 36,36,36
101702       38 T1 = ABS(D(9))/D(9)
101704       52 IF (IDE) 42,42,40
101706       36 CONTINUE
        CO ROTE OUTPUT VALUES
101706       40 JOP = JOP + 1
101710          DO 57 I = 1,6
101712             = 2*I+1
101716       57 OUT(I) = D(M)*RTO
101722          DO 51 I = 4,6
101724          K = OUT(I)/360.
101727          T1 = K
101730       51 OUT(I) = OUT(I) - 360.*T1
101734          DO 56 I=1,6
101736       56 OUT(I+6) = (OUT(I)-TR(I))*3600.
101743          DO 96 I = 8,12
101745          IF (ABS(OUT(I))-10.) 96,95,95
101751       95 ICHCK = 7
```

```
001752      96 CONTINUE
001754         IF (JOP-2) 44,50,50
        C SET UP FOR STAR TRACKER TIME BREAK
001757      44 TB = TIMS
001761         IOP =  -5
001762         GO TO 60
        C
        COMPUTE AV VECTOR AND UPDATE PG ARRAY, COST
        C
001762      42 JUMP = 5
001763         GO TO 21
001764      46 JUMP = 0
001765         DO 48 I=1,3
001767         CMAT1(1,I) = 0.
001772         DO 48 K=1,3
001774      48 CMAT1(1,I) = CMAT1(1,I) + BIL(ISLT,K)*CE(K,I)
002012         DO 70 I=1,3
002013         CMAT2(1,I) = 0.
002016         CMAT2(2,I) = 0.
002020         DO 70 K=1,3
002021         CMAT2(2,I) = CMAT2(2,I) + CMAT1(1,K)*(PES(K,I)*F4     + PEH(K,I)*
              1F5     + PET(K,I)*F6    )
002041      70 CMAT2(1,I) = CMAT2(1,I) + CMAT1(1,K)*FMA(K,I)
        COMPUTE H AND H DOT
002054         HTL = CMAT2(1,1)*SHAT(1) + CMAT2(1,2)*SHAT(2) + CMAT2(1,3)*SHAT(3)
002062         HTLD= CMAT2(2,1)*SHAT(1) + CMAT2(2,2)*SHAT(2) + CMAT2(2,3)*SHAT(3)
002070         HTLD = 1.
002071         DO 72 I =1,3
002073         DO 71 J =1,12
002074      71 CMAT2(J,I) = 0.
002102         DO 72 K =1,3
002103         CMAT2( 1,I) = CMAT2( 1,I) + CMAT1(1,K)*(PES(K,I)*D( 21)+PEH(K,I)*
              1 D( 23) + PET(K,I)*D( 25))
002123         CMAT2( 2,I) = CMAT2( 2,I) + CMAT1(1,K)*(PES(K,I)*D( 33)+PEH(K,I)*
              1 D( 35) + PET(K,I)*D( 37))
002141         CMAT2( 3,I) = CMAT2( 3,I) + CMAT1(1,K)*(PES(K,I)*D( 45)+PEH(K,I)*
              1 D( 47) + PET(K,I)*D( 49))
002157         CMAT2( 4,I) = CMAT2( 4,I) + CMAT1(1,K)*(PES(K,I)*D( 57)+PEH(K,I)*
              1 D( 59) + PET(K,I)*D( 61))
002175         CMAT2( 5,I) = CMAT2( 5,I) + CMAT1(1,K)*(PES(K,I)*D( 69)+PEH(K,I)*
              1 D( 71) + PET(K,I)*D( 73))
002213         CMAT2( 6,I) = CMAT2( 6,I) + CMAT1(1,K)*(PES(K,I)*D( 81)+PEH(K,I)*
              1 D( 83) + PET(K,I)*D( 85))
002231         CMAT2( 7,I) = CMAT2( 7,I) + CMAT1(1,K)*(PES(K,I)*D( 93)+PEH(K,I)*
              1 D( 95) + PET(K,I)*D( 97))
002247         CMAT2( 8,I) = CMAT2( 8,I) + CMAT1(1,K)*(PES(K,I)*D(105)+PEH(K,I)*
              1 D(107) + PET(K,I)*D(109))
002265         CMAT2( 9,I) = CMAT2( 9,I) + CMAT1(1,K)*(PES(K,I)*D(117)+PEH(K,I)*
              1 D(119) + PET(K,I)*D(121))
002303         CMAT2(10,I) = CMAT2(10,I) + CMAT1(1,K)*(PES(K,I)*D(129)+PEH(K,I)*
              1 D(131) + PET(K,I)*D(133))
002321         CMAT2(11,I) = CMAT2(11,I) + CMAT1(1,K)*(PES(K,I)*D(141)+PEH(K,I)*
              1 D(143) + PET(K,I)*D(145))
002337      72 CMAT2(12,I) = CMAT2(12,I) + CMAT1(1,K)*(PES(K,I)*D(153)+PEH(K,I)*
              1 D(155) + PET(K,I)*D(157))
002361         ODHTLD = 1.0/HTLD
        COMPUTE AV(1)-AV(12)
002363         DO 74 I=1,12
002364      74 AV(I) = ODHTLD *(CMAT2(I,1)*SH1+CMAT2(I,2)*SH2+CMAT2(I,3)*SH3)
002400         DO 76 I=1,3
```

```
002401          CMAT1(1,I) = 0.
002404          CMAT1(2,I) = 0.
002406          CMAT1(3,I) = 0.
002407          DO 76 K=1,3
002410          CMAT1(1,I) = CMAT1(1,I) + BIL(ISLT,K)*PCE1(K,I)
002421          CMAT1(2,I) = CMAT1(2,I) + BIL(ISLT,K)*PCE2(K,I)
002427       76 CMAT1(3,I) = CMAT1(3,I) + BIL(ISLT,K)*PCE3(K,I)
002437          DO 78 I=1,3
002441          DO 78 J=1,3
002442          CMAT2(I,J) = 0.
002445          DO 78 K=1,3
002447       78 CMAT2(I,J) = CMAT2(I,J) + CMAT1(I,K) * EMA(K,J)
          COMPUTE AV(13)-AV(16)
002467          AV(13) = DOHILD*(CMAT2(1,1)*SH1+CMAT2(1,2)*SH2+CMAT2(1,3)*SH3)
002476          AV(14) = DOHILD*(CMAT2(2,1)*SH1+CMAT2(2,2)*SH2+CMAT2(2,3)*SH3)
002505          AV(15) = DOHILD*(CMAT2(3,1)*SH1+CMAT2(3,2)*SH2+CMAT2(3,3)*SH3)
002514          AV(16) = HIL*DOHILD
002515          DO 80 I=1,15
002517          PG(I,16) = PG(I,16) -AV(I)*AV(16)
          C UPDATE PG(I,J) MATRIX
002522          DO 80 J=I,15
002524       80 PG(I,J) = PG(I,J) + AV(I)*AV(J)
          C UPDATE COST
002537          COST = COST + AV(16)*AV(16)
002541          JOP = JOP + 1
002543          IF (IOP) 82,40,82
002544       82 IF (JOP-2) 84,50,50
          C SET UP FOR ACTUAL TIME TIME BREAK
002547       84 TB = TIMA
002551          IOP = 5
002552       40 CALL SDAX    (3,HSF,0,IDE,NDE,ISW,TB)
002561          GO TO 20
          C
          C OUTPUT SECTION
          C
002562       50 WRITE (9,3) TIMA,(OUT(I),I=7,12),COST
002600          IF (ICIND) 600,62,600
002601      600 ICIND = 0
002602          WRITE (9,2) (OUT(I),I=1,6)
002614        2 FORMAT (6F15.0)
002614        3 FORMAT (7F15.4,F15.5)
          C READ NEXT RECORD FROM TAPE,CONVERT TO RADIANS,COMPUTE NEW S HAT VECTOR, SET UP
          C  FOR CORRECT TIME BREAK
002614       62 READ (TTAPE) TIMS,ISLT,ALF,DEL,TIMA,(TP(I),I=1,6),WMAG
002681       64 ALF = ALF * DTR
002643          DEL = DEL * DTR
002644       68 IF (TIMS) 86,88,88
002646       86 REWIND TTAPE
002650          GO TO 100
002651       88 COEL = COS(DEL)
002654          SH1 = COEL * COS(ALF)
002657          SH2 = COEL * SIN(ALF)
002662          SH3 = SIN(DEL)
002664          JOP = 0
002665          IF (TIMS-TIMA) 90,92,94
002670       92 TB = TIMS
002672          IOP = 0
002673          GO TO 60
002673       94 TB = TIMA
002675          IOP = 5
```

```
002676          DO 1 I = [illegible]
002676      90  TN = 51.[illegible]
002700          IP = -5
002701          GO TO [illegible]
          C
          C PERFORM FIRST, CHECK FOR CONVERGENCE, WRITE OUT VALUES, UPDATE INITIAL CONDITION
          C  IF CONVERGENCE OF FAILS
          C
002701      100 NCVR = -15
002703          NCVR = -[illegible]
002704          WRITE (9,2) (PG(I),I=1,6)
002715          WRITE (9,[illegible]) (PG(I),I = 7,12),DFLTF1,DFLTF2
002733      421 FORMAT (8F11.4)
002733          DO 130 I = 1,15
002735          PF(I) = 1./SQRT(PG(1,I))
002746      130 PG(1,16) = PG(1,16)*PF(I)
002747          DO 132 I = 1,15
002751          DO 132 J = 1,15
002752      132 PG(I,J) = PG(I,J) *PF(I)*PF(J)
002766          DO 150 I = 1,15
002766          DO 150 J=1,15
002767      150 PG(J,I) = PG(I,J)
003001          IF (ITEST.GT.0) CALL SICHCK (PG,PF)
003004          IF (ITEST.GT.0) GO TO 112
003007      620 DO 500 I = 1,15
003011      500 PG(I,2) = PG(I,16)
003021          IF (ISOL) 452,454,452
003022      452 DO 456 I = 4,[illegible]
003026          DO 456 J = 1,[illegible]
003035      456 PG(I,J) = PG(I+1,J)
003040          J = [illegible] - 1
003041          DO 458 I = 4, 2
003043          DO 458 J = 1, [illegible]
003044      458 PG(J,I) = PG(J,I+1)
003057          [illegible] = [illegible] - 1
003060          NCVR = -[illegible]
003061      454 CALL SHIFT (ISOL,IDSOL,J),NCVR,PG,15,KHA,DFT)
003071          IF(ISOL) 460,462,460
003072      460 DO 464 I = 4,[illegible]
003074          J = [illegible]+5
003077      464 PG(J, 2) = PG(J+1,[illegible])
003106          PG(6,2) = 0.
003110          J = J +1
003111      462     136 I = 1,[illegible]
003113      136 PG(I,2) = PG(I,2) *PF(I)
003123          ISOL = (ISOL + 1)*ISOL
003125          IF (ISOL-2) 110,112,110
003127      110 WRITE (9,4) ISOL,IDSOL,DFT
003141        4 FORMAT (1H0 ERROR IN SHIFT, 2I4,F16.4)
003141          STOP 22
003143      112 WRITE (9,4) PG,(PG(I,2),I=1,15)
003161        8 FORMAT (/8X,X,1,=,1,8F11.4/7X,5F11.4//5H DY =,2X,10E11.4/7X,5F11.4)
003161          II = 15
003162          JJ = 26
003163      116 DO 116 I = 11,JJ,2
003165          J = I+[illegible]
003167      114 WRITE (9,5) (PG(K),K=I,J,12)
003204        5 FORMAT (5F16.[illegible])
003204          IF (II-15) 113,113,115
003206      113 II = 57

003207          JJ = 57
003210          WRITE (9,7) II
003214          GO TO 116
003217      115 IF (IC-[illegible]) 635,635,122
003221      635 IF (IC-[illegible]) 120,[illegible],120
003222      [illegible] IC = 7
003223          GO TO 122
003224      120 WRITE (9,10)
003230       10 FORMAT (15H MATL CONVERGED)
003230          STOP 11
003232      122 DO 124 I=1,[illegible]
003234      124 PG(I) = PG(I) + PG(I,2)
003245          [illegible] = [illegible] + 1
003246          IF (NC-[illegible],3) STOP 33
003252          WRITE (ITAPE) IC,(PG(I),I=1,26)
003265          GO TO 16
003266          END
```

```
                SUBROUTINE SHIMVR(ISOL,IDSOL,NR,NC,A,MRA,KWA,DET)
00011           DIMENSION A(1),KWA(1)                                    001
00011           IR=NR                                                    002
00012           ISOL =1                                                  003
00013           IDSOL=1                                                  004
00014           CALLDVCHK(IVF)
00025           CALL OVERFL(IVF)
00036           IF(NR) 61,61,11
00040        11 IF(IR-MRA)12,12,61                                       007
00042        12 IC=IABS(NC)
00044           IF(IC-IR) 13,14,14                                       009
00046        13 IC=IR                                                    010
00050        14 IRMP=1                                                   011
00051           JRMP=MRA                                                 012
00052           KRMP=JRMP+IRMP                                           013
00054           IFS=IR*JRMP                                              014
00056           NET=IC*JRMP                                              015
00060           IF(NC)  15,61,16                                         016
00061        15 MDIV=JRMP+1                                              017
00063           IRIC=IR-IC                                               018
00065           GO TO 17                                                 019
00066        16 MDIV=1                                                   020
00067        17 MDD =MDIV                                                021
00071           MSER=1                                                   022
00072           KSER=IR                                                  023
00073           NZ  =1                                                   024
00074           DET=1.0                                                  025
00076        18 PIV=0.0                                                  026
00077           I=MSER                                                   027
00101        19 IF(I-KSER)          20,20,23                             028
00104        20 IF(ABS(A(I))-PIV)22,22,21
00111        21 PIV=ABS(A(I))
00114           IP=I                                                     031
00115        22 I=I+IRMP                                                 032
00117           GO TO 19                                                 033
00117        23 IF(PIV)  24,62,24                                        034
00120        24 IF(NC)  26,25,25                                         035
00122        25 I=IP-((IP-1)/JRMP)*JRMP                                  036
00130           J=MSER-((MSER-1)/JRMP)*JRMP                              037
00136           JJ=MSER/KRMP+1                                           038
00141           II=JJ+(IP-MSER)                                          039
00143           KWA(JJ)=II                                               040
00146           GO TO 27                                                 041
00147        26 I=IP                                                     042
00151           J=MSER                                                   043
00152        27 IF(IP-MSER) 61,31,28                                     044
00155        28 IF(J-NET)  29,29,30                                      045
00160        29 PSTO=A(I)                                                046
00163           A(I)=A(J)                                                047
00167           A(J)=PSTO                                                048
00172           I=I+JRMP                                                 049
00173           J=J+JRMP                                                 050
00174           GO TO 28                                                 051
00174        30 DET=-DET                                                 052
00176        31 PSTO=A(MSER)                                             053
00201           DET=DET*PSTO                                             054
00202           CALL OVERFL(IVF)
00213           GO TO (34,33),IVF
00221        33 GO TO 35
```

```
00222      34 ISOL = 2
00223      35 PSI(0)=1.-PSI(1)                                          058
00225         CALL OVFL(IVF)
00235         GO TO (600,601),IVF
00243     600 ISOL = 3
00244         ISOL = 2
00245         GO TO 65
00246     601 CONTINUE
00246         A(MSEQ)=1.0                                              059
00252         I=NOIN                                                   060
00256      36 IF(I-NFT)    37,37,39                                    061
00257      37 A(I)=A(I)*PSI(0)                                          062
00262         I=I+JN-2                                                 063
00263         GO TO 36                                                 064
00266      39 IF(NZ-NSEQ) 40,41,45                                     065
00267      40 IF(NZ-NSEQ) 41,44,41                                     066
00271      41 I=NAD                                                    067
00273         J=NOIN                                                   068
00274         PSI0=A(NZ)                                               069
00277         IF(PSI0) 142,44,142                                      070
00300     142 A(NZ)=0.0                                                071
00303      42 IF(J-NFT)    43,41,44                                    072
00306      43 A(I)=A(I)-A(J)*PSI(0)                                     073
00313         J=J+JN-2                                                 074
00315         I=I+JN-2                                                 075
00316         GO TO 42                                                 076
00316      44 NAD=NAD+INCR                                             077
00320         NZ=NZ+INCR                                               078
00321         GO TO 39                                                 079
00321      45 CALL OVFL(IVF)
00332         GO TO (63,165),IVF
00340     145 MSEQ=MSEQ+JNCR                                           081
00342         IF(MSEQ-NFS) 46,46,53                                    082
00346      46 MSEQ=MSEQ+NCR                                            083
00346         IF(NC) 48,47,47                                          084
00347      47 NSIV=NSIV+INCR                                           085
00351         NZ=((MSEQ-1)/JN-NC)*JNCR+1                               086
00356         NAD=1                                                    087
00357         GO TO 39                                                 088
00360      48 NSIV=NSIV+NCR                                            089
00362         IF(I-NC) 50,49,50                                        090
00363      49 NSEQ=MSEQ+INCR                                           091
00365         GO TO 51                                                 092
00366      50 NZ=((MSEQ-1)/JN-NC)*JNCR+1                               093
00374      51 NAD=NZ+INCR                                              094
00376      52 GO TO 39                                                 095
00377      53 IF(NC) 55,54,54                                          096
00401      54 JN=IN                                                    097
00403      55 IF(JN) 61,65,56                                          098
00405      56 IF(K-(JN-1)-JN) 61,60,57                                 099
00411      57 K=(JN-1)*JNCR                                            100
00415         J=K+IN                                                   101
00417         L=(K-(JN-1)-1)*JNCR+IN                                   102
00424      58 IF(J-K)    61,61,59                                      103
00427      59 PSI0=A(L)                                                104
00432         A(L)=A(J)                                                105
00436         A(J)=PSI0                                                106
00441         J=J-INCR                                                 107
00443         L=L-INCR                                                 108
00444         GO TO 58                                                 109

00444      60 JN=JN-1                                                  110
00446         GO TO 55                                                 111
00448      61 ISOL=3                                                   112
00447         GO TO 65                                                 113
00450      62 IFT=0.0                                                  114
00451         ISOL=2
00452         ISOL=1
00453         GO TO 65
00454      63 ISOL = 2
00455         ISOL = 2
00456      65 RETURN                                                   116
00457         END                                                      117
```

```
      SUBROUTINE SOA (J,NSF,D,I,N,ISW,TB)
      DIMENSION D(1300)
      IF(J)105,105,211
  211 IF(J-4)212,104,105
  212 GO TO (100,101,103,104),J
  101 GO TO 10,(1,10,21,25,26,27,28,33)
  103 GO TO 12, (9,34)
  100 DO 107 JJ=1,N
         K = 4*N + 3 + JJ
  107    D(K) = D(2*JJ+2)
  104 IXP = 2*N + 2
      IX  = 3*N + 3
      IPX = 4*N + 3
      IY2 = 5*N + 3
      IY3 = 6*N + 3
      I7 =  7*N + 4
      I6 =  8*N + 4
      I5 =  9*N + 4
      I4 = 10*N + 4
      I3 = 11*N + 4
      I2 = 12*N + 4
      I1 = 13*N + 4
      I7 = 14*N + 4
         B = 10.**(-NSF)
  200 IXP = 0
    4 IX = 0
    5 ASSIGN 1 TO IP
      I = 2
      RETURN
    1 ASSIGN 9 TO IP
      I = 1
      RETURN
    9 D(IK) = D(2)
      DO 108 JJ=1,N
         K = IK + JJ
  108    D(K) = D(2*JJ+1)
      IX = I
      IF (IAN) 111,110,111
  110 IF (ISW-1) 112,113,114
  114 IF (ISW-3) 115,116,117
  112 IF (ISW-1) 118,119,120
  118 DO 121 JJ=1,N
         K = I3 + JJ
  121    D(K) = D(2*JJ+2)
      IY = I3
      GO TO 122
  119 DO 123 JJ=1,N
         K = I2 + JJ
  123    D(K) = D(2*JJ+2)
      IY = I2
      GO TO 122
  120 DO 124 JJ=1,N
         K = I1 + JJ
  124    D(K) = D(2*JJ+2)
      IY = I1
      GO TO 122
  115 DO 125 JJ=1,N
         K = I7 + JJ
  125    D(K) = D(2*JJ+2)
```

```
00251          IY = I7
00252      122 ASSIGN 2 TO II
00253          GO TO 1000
00254        2 ASSIGN 3 TO IR
00255          GO TO 2000
00256        3 IF (ISW-1) 126,117,127
00260      126 IF (IRK-2) 128,129,130
00263      128 IRK = IRK + 1
00265          GO TO 5
00265      129 IAM = 1
00266      127 GO TO 5
00267      116 DO 138 JJ=1,N
00271              K = T5 + JJ
00273      138     D(K) = D(2*JJ+2)
00303          IY = T5
00304          GO TO 135
00305      113 IF (IRK-1) 131,130,132
00310      131 DO 133 JJ=1,N
00312              K = T4 + JJ
00314      133     D(K) = D(2*JJ+2)
00324          IY = T4
00325          GO TO 135
00326      132 DO 134 JJ=1,N
00330              K = T2 + JJ
00332      134     D(K) = D(2*JJ+2)
00342          IY = T2
00343      135 IYO = IY
00345          ASSIGN 7 TO II
00346          GO TO 1000
00346        7 ASSIGN 11 TO IR
00347          GO TO 2000
00350       11 ASSIGN 10 TO 10
00351          I = 2
00352          RETURN
00353       10 IF (ISW-2) 139,117,140
00355      140 DO 141 JJ=1,N
00357              K = T4 + JJ
00361      141     D(K) = D(2*JJ+2)
00371          IY = T4
00372          GO TO 142
00373      139 IRK = IRK + 1
00375          IF (IRK-2) 143,130,144
00377      143 DO 145 JJ=1,N
00401              K = T3 + JJ
00403      145     D(K) = D(2*JJ+2)
00413          IY = T3
00414          GO TO 142
00415      144 DO 146 JJ=1,N
00417              K = T1 + JJ
00421      146     D(K) = D(2*JJ+2)
00431          IY = T1
00432      142 D(I7) = D(2)
00436          DO 147 JJ=1,N
00440              K = T7 + JJ
00442      147     D(K) = D(2*JJ+1)
00452          IX = T7
00453          ASSIGN 12 TO II
00454          GO TO 1000
00455       12 ASSIGN 13 TO I4
00456          GO TO 2000
```

```
000457      13 ASSIGN 33 TO IO
000460         I= 2
000461         RETURN
000462      33 DO 31 JJ=1,M
000464            K2 = IXP + JJ
000466            K  = IK  + JJ
000467            L  = IYO + JJ
000471            L1 = IY  + JJ
000472      31    D(K2) = D(K) + D(1)/3.*(D(L)+4.*D(L1)+D(2*JJ+2))
000515         ASSIGN 14 TO IC
000516         GO TO 4000
000516      14 IF (IF) 148,149,148
000517     149 IF (IOB) 150,151,150
000520     151 D(1) =2.*D(1)
000522         IQK = 0
000523         GO TO 1
000523     150 IF (ISM-2) 152,117,153
000525     153 IQK = 0
000526         GO TO 1
000527     152 IF (IBK-3) 154,155,130
000532     154 IQK = IQK + 1
000534         GO TO 1
000534     155 IAM = 1
000535         GO TO 1
000536     148 D(1) = .5*D(1)
000540         IX = IK
000541         IF (ISM-2) 157,117,158
000543     158 IY = IS
000545         GO TO 32
000545     157 IF (IBK-2) 159,130,160
000550     159 IY = I4
000552         GO TO 32
000552     160 DO 161 JJ=1,M
000554         K = I2 + JJ
000556         L = I4 + JJ
000557     161    D(L) = D(K)
000566         IY = I4
000567      32 IQK = 0
000570         IX = IK
000572         GO TO 7
000572     111 DO 162 JJ=1,M
000574            K = I7 + JJ
000576     162    D(K) = D(2*JJ+2)
000606         IY = I7
000607         ASSIGN 17 TO II
000610         GO TO 1000
000611      17 DO 163 JJ=1,M
000613            K  = IK  + JJ
000615            K1 = IXP + JJ
000616            L  = I7  + JJ
000620            L1 = I1  + JJ
000621            L2 = I2  + JJ
000623            L3 = I3  + JJ
000625            A = 55.*D(L) - 59.*D(L1) + 37.*D(L2) - 9.*D(L3)
000644            D(K1) = D(K) + D(1)*A / 24.
000653     163    D(2*JJ+1) = D(K1)
000663         D(2) = D(IK) + D(1)
000667         ASSIGN 25 TO IO
000670         I = 2
000671         RETURN
```

```
000672      28 DO 164  JJ=1,N
000674            K = TK + JJ
000676            L = IZ + JJ
000677            L1 = I1 + JJ
000701            L2 = I2 + JJ
000702            A = 9.*D(2*JJ+2) + 19.*D(L) - 5.*D(L1) + D(L2)
000722     164    D(2*JJ+1) = D(K) + D(1)*A / 24.
000735         IF (IS*) 117,165,166
000737     165 IT = I3
000741         I3 = I2
000742         I2 = I1
000743         I1 = IZ
000744         IZ = IT
000745         GO TO 5
000745     166 ASSIGN 18 TO IC
000746         GO TO 4000
000747      18 IF (IE) 167,168,167
000750     168 IF (IDB) 169,170,169
000751     169 IAM = IAM + 1
000753         IT = I7
000754         I7 = I6
000755         I6 = I5
000756         I5 = I4
000757         I4 = I3
000760         I3 = I2
000761         I2 = I1
000762         I1 = IZ
000763         IZ = IT
000764         GO TO 5
000765     170 IF (IAM-5) 169,171,171
000770     171 IAM = 1
000771         D(1) = 2.*D(1)
000773         IT = I2
000774         I2 = I3
000775         I3 = I5
000776         I5 = IT
000777         IT = I7
001000         I7 = I4
001001         I4 = IT
001002         GO TO 5
001003     167 D(1) = .5*D(1)
001005         IAM = 1
001006         DO 172 JJ=1,N
001007             K  = I6 + JJ
001011             K1 = I5 + JJ
001012            L  = IZ + JJ
001014            L1 = I1 + JJ
001015            L2 = I2 + JJ
001017            L3 = I3 + JJ
001021            L4 = I4 + JJ
001022            D(K) = -.0390625*D(L) + .46875*D(L1) + .703125*D(L2)
             X           - .15625*D(L3) + .0234375*D(L4)
001050     172    D(K1) = .2734375*D(L) + 1.09375*D(L1) - .546875*D(L2)
             X           + .21875*D(L3) - .039063*D(L4)
001101         IT = I1
001102         I1 = I5
001103         I5 = I3
001104         I3 = I6
001105         I6 = I4
001106         I4 = I2
```

```
001107          T2 = TT                                                  00240
001110          GO TO 17                                                 00241
001111     2000 M=1                                                      00242
001112          HALFDT = .5*D(1)                                         00243
001114          D(2) = D(TX) + HALFDT                                    00244
001121          DO 2001 JJ=1,N                                           00245
001122             K = TX + JJ                                           00246
001124             L = TY + JJ                                           00247
001125     2001    D(2*JJ+1) = D(K) +HALFDT*D(L)                         00248
001140          ASSIGN 25 TO IP                                          00249
001141          I = 2                                                    00250
001142          RETURN                                                   00251
001142       25 DO 2002 JJ=1,N                                           00252
001144             K = TY2 + JJ                                          00253
001146             D(K) = D(2*JJ+2)                                      00254
001154             L = TX + JJ                                           00255
001155     2002    D(2*JJ+1) = D(L) + HALFDT*D(K)                        00256
001167          ASSIGN 26 TO IP                                          00257
001170          I = 2                                                    00258
001171          RETURN                                                   00259
001171       26 DO 2003 JJ=1,N                                           00260
001173             K = TY3 + JJ                                          00261
001175             D(K) = D(2*JJ+2)                                      00262
001203             L = TX + JJ                                           00263
001204     2003    D(2*JJ+1) = D(L) + D(1)*D(K)                          00264
001216          D(2) =D(TX) + D(1)                                       00265
001222          ASSIGN 27 TO IP                                          00266
001223          I = 2                                                    00267
001224          RETURN                                                   00268
001225       27 DO 2004 JJ=1,N                                           00269
001227             K = TX + JJ                                           00270
001231             L1 = TY + JJ                                          00271
001232             L2 = TY2 + JJ                                         00272
001234             L3 = TY3 + JJ                                         00273
001235     2004    D(2*JJ+1)=D(K) +(D(1)/6.)*(D(L1)+2.*D(L2)+2.*D(L3)+D(2*JJ+2))  00274
001267          GO TO 12, (3,11,13,20)                                   00275
001272     4000 IF = 0                                                   00276
001273          IDR = 0                                                  00277
001274          DO 33 JJ=1,N                                             00278
001275          KF=TFX+JJ                                                00279
001277             KP = TXP + JJ                                         00280
001300             KC = 2*JJ + 1                                         00281
001304             DELTA = ABSF(D(KC) - D(KP))                           00282
001311             XP = ABSF(D(KP))                                      00283
001313             XC = ABSF(D(KC))                                      00284
001316          M=5                                                      00285
001317          IF(DELTA-D(KF))4001,4001,4002                            00286
001323     4002    IF (XC - XP) 4003,4004,4004                           00287
001326     4003    DENOM = XP                                            00288
001330             GO TO 4005                                            00289
001330     4004    DENOM = XC                                            00290
001332     4005    ETA = DELTA/DENOM                                     00291
001334             IF (ETA - H) 4006,4006,4007                           00292
001336     4006    IF (IDR) 4015,4016,4015                               00293
001337     4015    GO TO 30                                              00294
001340     4007    IF = 1                                                00295
001341             IDR = 1                                               00296
001342     4021 GO TO (6, (14,18)                                        00297
001346     4001    IF (IDR) 4008,4009,4008                               00298
001347     4008    GO TO 33                                              00299
```

```
001350    4009  IF (32.*DELTA - D(XF)) 4010,4010,4011
001355    4011    GO TO 30
001356    4011    IF (XC - XP) 4012,4013,4013
001361    4012    DENOM = XP
001363            GO TO 4014
001363    4013    DENOM = XC
001365    4014    ETA = DELTA/DENOM
001367    4016    IF (32.*ETA - H) 4017,4017,4018
001373    4017    GO TO 30
001374    4018    IOB = 1
001375      30    CONTINUE
001400          GO TO 4020
001400    1000 IF (TB - D(2)) 19,19,1002
001403    1002 IF(TB-D(2)-1.01*D(1)) 1003,1003,19
001410    1003 SAVEDT = D(1)
001412         TBOLD=TB
001413         TSAVE=D(2)
001415         D(1) = TB - D(2)
001420         ASSIGN 20 TO IB
001421         GO TO 2000
001422      20 D(1) = SAVEDT
001425    1004 ASSIGN 21 TO IB
001426         I = 2
001427         RETURN
001430      21 ASSIGN 34 TO IB
001431         I = 3
001432         RETURN
001433      34 D(2)=TSAVE
001436         IF(TB-TBOLD)19,19,1000
001441      19 GO TO IT, (2,7,12,17)
001445     105 STOP 1
001447     117 STOP 2
001451     130 STOP 3
001453         END
```

```
                SUBROUTINE FIELDG (DLAT,DLONG,ALT,TM,NMX,L,X,Y,Z,F)
000013          EQUIVALENCE (SHMIT,TG)
000013          COMMON /COEFFS/TG(18,18)
000013          COMMON /FLDCOM/ST,CT,SPH,CPH,R,NMAX,RT,RP,RR,R
000013          DIMENSION G(18,18),GT(18,18),SHMIT(18,18),AID(11)
000013            DIMENSION GTT(18,18)
000013          DATA (A = 0.)
000013          IF(A.EQ.6378.165) GO TO 30
000015          A=6378.165
000016          FLAT=1.-1./298.3
000021          A2=A**2
000022          A4=A**4
000023          B2=(A*FLAT)**2
000025          A2B2=A2*(1.-FLAT**2)
000030          A4B4=A4*(1.-FLAT**4)
000032          IF (L) 14,14,2
000034       30 IF(L) 19,1,2
000036    1     IF (TM-TLAST) 17,19,17
000041    2     READ (5,3) J,K,TZERO,(AID(I),I=1,11)
000071    3     FORMAT (2I1,1X,F6.1,10A6,A3)
000071          L=0
000071          WRITE (9,4) J,K,TZERO,(AID(I),I=1,11)
000121    4     FORMAT (2I3,5X6HEPOCH=,F7.1,5X10A6,A3)
000121          MAXN=0
000122          TEMP=0.
000123    5     READ (5,6) N,M,GNM,HNM,GTNM,HTNM,GTTNM,HTTNM
000153    6     FORMAT (2I3,6F11.4)
000153          IF (N.LE.0) GOTO7
000154          MAXN=(MAX0(N,MAXN))
000157          G(N,M)=GNM
000164          GT(N,M)=GTNM
000170          GTT(N,M)=GTTNM
000174          TEMP=AMAX1(TEMP,ABS(GTNM))
000202          IF (M.EQ.1) GOTO5
000204          G(M-1,N)=HNM
000210          GT(M-1,N)=HTNM
000214          GTT(M-1,N)=HTTNM
000220          GO TO 5
000221    7     WRITE (9,8)
000231    8     FORMAT (6H0 N  M,6X1HG,10X1HH,9X2HGT,9X2HHT,8X3HGTT8X3HHTT//)
000231          DO 12 N=2,MAXN
000232          DO 12 M=1,N
000233          MI=M-1
000235          IF (M.EQ.1) GOTO10
000236          WRITE (9,9) N,M,G(N,M),G(MI,N),GT(N,M),GT(MI,N),GTT(N,M),GTT(MI,N)
000327    9     FORMAT (2I3,6F11.4)
000327          GO TO 12
000327   10     WRITE (9,11) N,M,G(N,M),GT(N,M),GTT(N,M)
000372   11     FORMAT (2I3,F11.4,11X,F11.4,11XF11.4)
000372   12     CONTINUE
000377          WRITE (9,13)
000407   13     FORMAT (1H1)
000407          IF (TEMP.EQ.0.) L=-1
000411   14     IF (K.NE.0) GOTO17
000412          SHMIT(1,1)=-1.
000414          DO 15 N=2,MAXN
000415          SHMIT(N,1)=SHMIT(N-1,1)*FLOAT(2*N-3)/FLOAT(N-1)
000426          SHMIT(1,N)=0.
000433          JJ=2
```

```
000434          DO 15 M=2,N                                                92
000436          SHMIT(N,M)=SHMIT(N,M-1)*SQRT(FLOAT((N-M+1)*JJ)/FLOAT(N+M-2))  93
000463          SHMIT(M-1,N)=SHMIT(N,M)                                    94
000471    15    JJ=1                                                       95
000476          DO 15 N=2,MAXN                                             96
000500          DO 15 M=1,N                                                97
000501          G(N,M)=G(N,M)*SHMIT(N,M)                                   98
000510          GT(N,M)=GT(N,M)*SHMIT(N,M)                                 99
000514          GTT(N,M)=GTT(N,M)*SHMIT(N,M)
000520          IF (M.EQ.1) GOTO16                                        100
000522          G(M-1,N)=G(M-1,N)*SHMIT(M-1,N)                            101
000527          GT(M-1,N)=GT(M-1,N)*SHMIT(M-1,N)
000533          GTT(M-1,N)=GTT(M-1,N)*SHMIT(M-1,N)
000537    16    CONTINUE
000544    17    T=TM-TZERO                                                103
000546          DO 18 N=1,MAXN                                            104
000550          DO 18 M=1,N                                               105
000551          TG(N,M)=G(N,M)+T*(GT(N,M)+GTT(N,M)*T)
000570          IF (M.EQ.1) GOTO18                                        107
000572          TG(M-1,N)=G(M-1,N)+T*(GT(M-1,N)+GTT(M-1,N)*T)
000610    18    CONTINUE                                                  109
000615          TLAST=TM                                                  110
000616    19    SINLA=SIN(DLAT/57.2957795)                                111
000625          RLONG=DLONG/57.2957795                                    112
000627          CPH=COS(RLONG)                                            113
000634          SPH=SIN(RLONG)                                            114
000642          IF (J.EQ.0) GOTO20                                        115
000643          R=ALT+6371.2                                              116
000645          CT=SINLA                                                  117
000647          GO TO 21                                                  118
000647    20    SINLA2=SINLA**2                                           119
000651          COSLA2=1.-SINLA2                                          120
000653          DEN2=A2-A2B2*SINLA2                                       121
000655          DEN=SQRT(DEN2)                                            122
000663          FAC=(((ALT*DEN)+A2)/((ALT*DEN)+B2))**2                    123
000667          CT=SINLA/SQRT(FAC*COSLA2+SINLA2)                          124
000702          R=SQRT(ALT*(ALT+2.*DEN)+(A4-A4B4*SINLA2)/DEN2)            125
000720    21    ST=SQRT(1.-CT**2)                                         126
000730          NMAX=MIN0(NMX,MAXN)                                       127
000733          CALL FIELD                                                128
000743          Y=BP
000745          F=B
000747          IF (J) 22,23,22                                           129
000750    22    X=-BT                                                     130
000752          Z=-BR                                                     131
000754          RETURN                                                    132
        C       TRANSFORMS FIELD TO GEODETIC DIRECTIONS                   133
000755    23    SIND=SINLA*ST-SQRT(COSLA2)*CT                             134
000766          COSD=SQRT(1.0-SIND**2)                                    135
000776          X=-BT*COSD-BR*SIND                                        136
001003          Z=BT*SIND-BR*COSD                                         137
001005          RETURN                                                    138
001006          END                                                       139
```

```
                SUBROUTINE FIELD
000002          COMMON /COEFFS/G(18,18)
000002          COMMON/FLUCOM/ST,CT,SPH,CPH,R,NMAX,BT,BP,BR,B
000002          DIMENSION P(18,18),DP(18,18),CONST(18,18),SP(18),CP(18),FN(18),FM(
               1 18)
000002          IF (P(1,1).EQ.1.0) GO TO 3
000004    1     P(1,1)=1.
000006          DP(1,1)=0.
000007          SP(1)=0.
000010          CP(1)=1.
000011          DO 2 N=2,18
000012          FN(N)=N
000014          DO 2 M=1,N
000016          FM(M)=M-1
000021    2     CONST(N,M)=FLOAT((N-2)**2-(M-1)**2)/FLOAT((2*N-3)*(2*N-5))
000045    3     SP(2)=SPH
000047          CP(2)=CPH
000050          DO 4 M=3,NMAX
000052          SP(M)=SP(2)*CP(M-1)+CP(2)*SP(M-1)
000060    4     CP(M)=CP(2)*CP(M-1)-SP(2)*SP(M-1)
000067          ADR=6371.2/R
000071          AR=ADR**2
000072          BT=0.
000073          BP=0.
000074          BR=0.
000075          DO 8 N=2,NMAX
000076          AR=AR*AR
000100          DO 8 M=1,N
000101          IF (N-M) 6,5,6
000102    5     P(N,N)=ST*P(N-1,N-1)
000111          DP(N,N)=ST*DP(N-1,N-1)+CT*P(N-1,N-1)
000120          GO TO 7
000120    6     P(N,M)=CT*P(N-1,M)-CONST(N,M)*P(N-2,M)
000133          DP(N,M)=CT*DP(N-1,M)-ST*P(N-1,M)-CONST(N,M)*DP(N-2,M)
000150    7     PAR=P(N,M)*AR
000156          IF (M.EQ.1) GO TO 9
000160          TEMP=G(N,M)*CP(M)+G(N-1,M)*SP(M)
000170          BP=BP-(G(N,M)*SP(M)-G(M-1,N)*CP(M))*FM(M)*PAR
000204          GO TO 10
000205    9     TEMP=G(N,M)*CP(M)
000213          BP=BP-(G(N,M)*SP(M))*FM(M)*PAR
000222   10     BT=BT+TEMP*DP(N,M)*AR
000231    8     BR=BR-TEMP*FN(N)*PAR
000241          BP=BP/ST
000243          B=SQRT(BT*BT+BP*BP+BR*BR)
000251          RETURN
000251          END
```

```
                SUBROUTINE RANDOM (RANDO,AMEAN,SIGMA,IR)
00006           IR=29*IR+1
00011           IR=IR-(IR/104857)*104857
00015           R=IR
00016           U1=R/104857.
00020           IR=29*IR+1
00023           IR=IR-(IR/104857)*104857
00027           R=IR
00030           U2=R/104857.
00032           RANDO=SQRT(-2.*ALOG(U1))*COS(6.283185*U2)*SIGMA+AMEAN
00056           RETURN
00056           END
```

```
                SUBROUTINE STAMED (ITA)
)0003           DIME SI[illegible] AR(60),AB(12,60),IA(60)
)0003         1 FORMAT (I10,4F15.7/(5F15.7))
)0003         2 FORMAT (F15.7,I5,4F15.7)
)0003         3 FORMAT (5F15.7,F5.2)
)0003         4 FORMAT (5HFD00[illegible],I6)
)0003         5 FORMAT (F10.3,I10,4F15.7)
)0003           IC = 1
)0004           IRD = -7
)0005           NCOUNT = 4
)0006           NCOUNT = 2
)0007           NCOUNT = 5
)0010           READ (5,5) TIME,I[illegible],XMEAN,SIGMA
)0025           READ (5,3) T1,T2,T3
 0040           READ INPUT TAPE 7,1, TD,(AR(I),I=1,26)
 0056           WRITE (9,1) TD,(AR(I),I=1,26)
 0074           WRITE (7,1) TD,(AR(I),I=1,26)
 0112       101 READ INPUT TAPE 7,2,  (AB(I,IC),I=1,6)
 0130           READ INPUT TAPE 7,3, (AB(I,IC),I=7,12)
 0146           IF (AB(1,IC).NE.T1) GO TO 101
 0153           WRITE (9,2) (AB(J,IC),J=1,6    )
 0170           WRITE (9,3) (AB(J,IC),J=7,12)
 0206           WRITE (7,2)(AB(J,IC),J=1,12)
 0224        10 READ INPUT TAPE 7,2,  (AB(I,IC),I=1,6)
 0242           IF(EOF,7)8890,8892
 0245      8890 IC = IC + 1
 0247      8900 AB(1,IC)=-1.
 0253           DO 8901 IJKL=2,12
 0255      8901 AB(IJKL,IC)=0.
 0263           GO TO 9[illegible]
 0263      8902 CONTINUE
 0263           READ INPUT TAPE 7,3, (AB(I,IC),I=7,12)
 0301      8903 CONTINUE
 0301           IF (AB(1,IC).LT.T2) GO TO 10
 0306           IF (AB(1,IC).EQ.T3) GO TO 8890
 0311        50 IF (AB(1,IC)) 15,11,11
 0315        11 IF (AB(1,IC)-TIME - 5.) 12,14,14
 0323        12 TIMT = AB(1,IC)
 0327           IC = IC + 1
 0330           GO TO 10
 0331        15 IRD = 7
 0332        14 TIMT = AB(1,IC)
 0336           IC = IC - 1
 0337           IC = IC
 0340           WRITE (9,1) IR
 0347        17 IF (IC - 3*NCOUNT) 33,30,16
 0353        16 DO 18 I=1,IC
 0355           AR(I) = AB(12,I)
 0362        18 IA(I) = I
 0365           DO 22 K = 1,NCOUNT
 0367           TEMP = 1000.
 0371           DO 20 I=1,IC
 0372           IF (AR(I)-TEMP) 1[illegible],20,20
 0375        19 TEMP = AR(I)
 0400           IS = I
 0401        20 CONTINUE
 0404           DO 40 I = IS,IC
 0406           IF (AB(3,IS)-AB(3,I)) 40,36,40
 0414        35 IF (AB(4,IS)-AB(4,I))40,38,40
```

```
0423        38 IA(I) = 7
0426           AR(I) = 1000.
0430        40 CONTINUE
0433        22 CONTINUE
0435           IP = 0
0436           DO 24 I=1,IC
0437           IF (IA(I)) 24,24,23
0441        23 IP = IP + 1
0443           DO 21 J = 1,12
0444        21 AR(J,IP) = AR(J,I)
0456        24 CONTINUE
0461           IF (IP.GE.3*COUNT) WRITE (9,4) IP
0473        30 DO 32 I=1,IP
0475           CALL RNDIZ (RANDOM,AMEAN,STGMA,IR)
0502           AR(1,I) = AR(1,I) + RANDO
0507           WRITE (9,2) (AR(J,I),J=1,6    )
0524           WRITE (9,3) (AR(J,I),J=7,12)
0542        32 WRITE (TTA) (AR(J,I),J=1,12)
0563           IC=IC + 1
0564           DO 34 I=1,12
0566        34 AR(I,1) = AR(I,IC)
0576           IC = 2
0577           IF (TAB) 10,10,99
0600        99 WRITE (9,2) (AR(J,1),J=1,6    )
0614           WRITE (9,3) (AR(J,1),J=7,12)
0630           WRITE (TTA) (AR(J,1),J=1,12)
0644           WRITE (9,1) IR
0653           END FILE TTA
0655           RETURN
0656           END
```

```
                SUBROUTINE STCHCK (P,PE)
000004          DIMENSION PG(15,16),P(15,16),PE(15) ,KD(6),PS(15,16),PROD(15)
               1,DF(15)
000004          M1=14
000005          M2=15
000006          KSUB = 1
000007          KD(1) = 6
000010          KD(2) = 0
000011          KD(3)=0
000012          KD(4)=0
000013          KD(5)=0
000014          KD(6)=0
000015       19 DO 20 I = 1,15
000017          DO 20 J = 1,16
000020       20 PG(I,J) = P(I,J)
000034          DO 599 I = 1,15
000035          PE(I) = PE(I)
000040      599 PG(I,M2) = PG(I,16)
000046       50 DO 42 I = 1,KSUB
000050          K = KD(I)
000052       44 DO 43 L=K,M1
000054          PE(L) = PE(L+1)
000056          DO 43 J = 1,M2
000060       43 PG(J,L) = PG(J,L+1)
000074          DO 120 L = K,M1
000076          DO 120 J = 1,M2
000077      120 PG(L,J) = PG(L+1,J)
000113       42 CONTINUE
000116          M1 = M1 - KSUB
000117          M2 = M2 - KSUB
000117       48 NCVR = -M2
000121          DO 52 I = 1,15
000122          DO 52 J = 1,16
000123       52 PS(I,J) = PG(I,J)
000137          CALL SHIMVR (ISOL,IDSOL,M1,NCVR,PG,15,KWA,DFT)
000151          DO 72 I = 1,M1
000152          PROD(I) = 0.
000154          DO 72 J = 1,M1
000155       72 PROD(I) = PROD(I) + PG(J,M2)*PS(I,J)
000173          DO 134 I = 1,M1
000175      134 PG(I,M2) = PG(I,M2) *PE(I)
000205          P(1,15) = PG(1,M2)
000212          P(2,15) = PG(2,M2)
000214          P(3,15) = PG(3,M2)
000217          P( 4,15) = PG( 4,M2)
000221          P( 5,15) = PG( 5,M2)
000224          P( 6,15) = 0.
000225          P( 7,15) = PG( 6,M2)
000227          P( 8,15) = PG( 7,M2)
000232          P( 9,15) = PG( 8,M2)
000234          P(10,15) = PG( 9,M2)
000237          P(11,15) = PG(10,M2)
000241          P(12,15) = PG(11,M2)
000244          P(13,15) = PG(12,M2)
000244          P(14,15) = PG(13,M2)
000251          P(15,15) = 0.
000252          ISOOL = ISOL + IDSOL
000254          IF (ISOOL-2) 110,112,110
000256      110 WRITE (9,6) ISOL,IDSOL,DFT

000272        6 FORMAT (16H ERROR IN SHIMVR, 2I4,F16.8)
000272          GO TO 60
000272      112 GO TO 60
000273       60 RETURN
000274          END
```

APPENDIX K

A METHOD FOR DETERMINING THE OFF-SET ANGLE ϵ_3

APPENDIX K

A METHOD FOR DETERMINING THE OFF-SET ANGLE ϵ_3

It was stated in the test that it is difficult, during simulations, to distinguish between the initial condition θ_o and the off-set angle ϵ_3. The reason for this is that the two partials

$$\frac{\partial H}{\partial \theta_o}, \quad \frac{\partial H}{\partial \epsilon_3}$$

are nearly equal at observation instants. Thus, the matrix

$$G = \frac{\partial H}{\partial y} \tag{K1}$$

has two columns which are approximately equal. This causes difficulties on the computer, because of finite word length, although it may be possible to determine both θ_o and ϵ_3.

The method considered here replaces $\frac{\partial H}{\partial \epsilon_3}$ with the difference between the two columns. Thus, the resultant columns are well distinguished, although one of them may be close to the zero vector (it is possible for the column to be the zero vector. In this case, ϵ_3 may be set to zero, for it is unimportant so far as the solution is concerned.)

For convenience, the differential equations are rewritten in the form

$$\left.\begin{aligned} \dot{x} &= f\ (x,\ \theta,\ a) \\ \dot{\theta} &= g\ (x,\ \theta) \end{aligned}\right\} \tag{K2}$$

where the vector x has components (ω_x, ω_y, ω_z, ψ, ϕ), and θ is the usual pitch angle. The parameter vector a is unimportant here, but is included for completeness.

The constraint equation in the test has the form

$$A_1\ (\beta,\ \gamma)\ C\ (\epsilon_1,\ \epsilon_2,\ \epsilon_3)\ E(\psi,\ \phi, \theta)\ S(\alpha, \delta) = 0. \tag{K3}$$

The problem occurs when $\epsilon_1 = \epsilon_2 = 0$, for then θ and ϵ_3 are additive rotations. The additivity is emphasized here by redefining the order of rotations for the ϵ's as

ϵ_3 about the body y axis

ϵ_2 about the new x axis

ϵ_1 about the new z axis

Then (K3) may be redefined as

$$A_1(\beta,\gamma)\ D(\epsilon_1,\epsilon_2)\ E(\psi,\phi,\xi)\ S\ (\alpha,\delta) = 0 \tag{K4}$$

where the new angle is defined

$$\xi = \theta + \epsilon_3. \tag{K5}$$

Matrix D takes the place of C, and E has the same form as before, except that argument θ is replaced by $\theta + \epsilon_3$.

The form of the solution of (K2) is

$$\left.\begin{aligned} x &= x(t,\ x_o, \theta_o, a)\ ,\quad x(0) = x_o \\ \theta &= \theta(t,\ x_o, \theta_o, a)\ ,\quad \theta(0) = \theta_o. \end{aligned}\right\} \tag{K6}$$

Then the partial derivatives of interest for (K4) are

$$\left.\begin{aligned} \frac{\partial H}{\partial \theta_o} &= A_1\ D\left[\frac{\partial E}{\partial \psi}\frac{\partial \psi}{\partial \theta_o} + \frac{\partial E}{\partial \phi}\frac{\partial \phi}{\partial \theta_o} + \frac{\partial E}{\partial \xi}\frac{\partial \theta}{\partial \theta_o}\right] S \\ \frac{\partial H}{\partial \epsilon_3} &= A_1 D\ \frac{\partial E}{\partial \xi}\ S. \end{aligned}\right\} \tag{K7}$$

During simulations, it was found that $\frac{\partial \psi}{\partial \theta_o}$ and $\frac{\partial \phi}{\partial \theta_o}$ were close to zero, and that $\frac{\partial \theta}{\partial \theta_o}$ was approximately unity. Thus, (K7) and (K8) are nearly equal.

Now suppose that (K5) is inserted into (K2) to change variables from θ to ξ. Then the differential equations are changed to

$$\left.\begin{aligned} \dot{x} &= f(x, \xi - \epsilon_3, a) \\ \xi &= g(x, \xi - \epsilon_3, a) \end{aligned}\right\} \qquad \text{(K9)}$$

and the solutions have the form

$$\left.\begin{aligned} x &= x(t, x_o, \xi_o - \epsilon_3, a) \\ \xi &= \theta(t, x_o, \xi_o - \epsilon_3, a) + \epsilon_3. \end{aligned}\right\} \qquad \text{(K10)}$$

Comparison of (K6) and (K10) shows that

$$\left.\begin{aligned} \frac{\partial x}{\partial x_o} &= \frac{\partial x}{\partial x_o}, \quad \frac{\partial \theta}{\partial x_o} = \frac{\partial \xi}{\partial x_o} \\ \frac{\partial x}{\partial \xi_o} &= \frac{\partial x}{\partial \theta_o}, \quad \frac{\partial \theta}{\partial \theta_o} = \frac{\partial \xi}{\partial \xi_o} \end{aligned}\right\} \qquad \text{(K11)}$$

Thus, the variational equations for both systems are the same, and yield the same solutions. However, from (K10-K11), one finds

$$\left.\begin{aligned} \frac{\partial x}{\partial \epsilon_3} &= -\frac{\partial x}{\partial \theta_o} = -\frac{\partial x}{\partial \xi_o} \\ \frac{\partial \xi}{\partial \epsilon_3} &= 1 - \frac{\partial \theta}{\partial \theta_o} = 1 - \frac{\partial \xi}{\partial \xi_o} \end{aligned}\right\} \qquad \text{(K12)}$$

From (K11-K12), it then follows that

$$\frac{\partial H}{\partial \xi_o} = \frac{\partial H}{\partial \theta_o} \qquad \text{(K13)}$$

$$\frac{\partial H}{\partial \epsilon_3} = A_1 D \frac{\partial E}{\partial \xi} S - \frac{\partial H}{\partial \xi_o} \qquad \text{(K14)}$$

Equation (K13) is the same as (K7), so the change of variable does not affect that column of matrix G. However, comparison of (K8) and (K14) shows that (K14) is the difference between (K7) and (K8). Thus, the new G matrix has a difference column. The partials on the right-hand side of (K12) come from treating ϵ_3 as a parameter in the differential equations, whereas the one in the last of (K12) corresponds to the original change at the observation point.

If (K14) is very small over the time interval of interest, then ϵ_3 cannot be determined. In this case it is set to zero, and a reduced dimensional problem is solved.

From a numerical standpoint, it is not good to work with the difference between two numbers that are close together. Thus, it is advisable to integrate the variational equations to obtain (K12), rather than to use the solutions (K11) in equation (K12). The variational equations have the form

$$\left.\begin{aligned} \frac{d}{dt}\frac{\partial x}{\partial \epsilon_3} &= \frac{\partial f}{\partial x}\frac{\partial x}{\partial \epsilon_3} + \frac{\partial f}{\partial \theta}\left[\frac{\partial \xi}{\partial \epsilon_3} - 1\right], \quad \frac{\partial x}{\partial \epsilon_3}(0) = 0 \\ \frac{d}{dt}\frac{\partial \xi}{\partial \epsilon_3} &= \frac{\partial g}{\partial x}\frac{\partial x}{\partial \epsilon} + \frac{\partial g}{\partial \theta}\left[\frac{\partial \xi}{\partial \epsilon_3} - 1\right], \quad \frac{\partial \xi}{\partial \epsilon_3}(0) = 0. \end{aligned}\right\} \quad \text{(K15)}$$

Since $\frac{\partial \xi}{\partial \epsilon_3}$ is generally small, the bracketted term in (K15) is well defined, so the solutions should be well behaved.

APPENDIX L
EFFECT OF INSTRUMENT ERRORS - TORQUE-FREE CASE

APPENDIX L

EFFECT OF INSTRUMENT ERRORS - TORQUE-FREE CASE

Suppose that stars may be observed in the time interval $0 \leq t \geq 1419$ seconds and only the sun is observed in the time interval $1419 \leq t \leq 4731$ seconds. Observations of this type are expected, for it may not be possible to observe the stars if sunlight impinges on the spacecraft.

Utilize the notation as defined in reference 7, and investigate the effect of errors in the transit times. The following assumptions are made.

1. The body is torque-free.

2. $\theta = 5°$ (cone angle)

   $\phi_o = \Psi_o = 0 \equiv \epsilon_1 \equiv \epsilon_2$

   $\Psi = -8.9487°/\text{second}$ (spin rate)

   $\dot{\phi} = 26.8462°/\text{second}$ (precision rate)

   $\xi = \Omega = 68°$

   $\tau = i = 97.38°$

The rates $\dot{\Psi}$ and $\dot{\phi}$ were derived by assuming a spacecraft whose moments of inertia are given by $A = B = 40$ slug ft^2, $C = 60$ slug ft^2, and whose nominal spin period is 20 seconds.

3. Three crossed slits of the form ✱ are utilized when observing star transits. The parameters which define these slits are given by

$$\gamma_1 = 20.3° = -\gamma_3$$

$$\beta_1 = 27.5° = -\beta_3$$

$$\lambda_2 = \beta_2 = 0$$

The definition of the angles γ and β are given on page 11 of reference 7.

4. The sun is assumed to be a point target, and two slits of the form V are utilized when observing sun transits. The parameters which specify these slits are defined by

$$\gamma_4 = \gamma_5 = 0$$

$$\beta_4 = -\beta_5 = 10°$$

5. During the time interval over which stars are observable, $0 \leq t \leq 1419$ seconds, only stars within 110° of the spacecraft's instantaneous zenith can be utilized. Moreover, only stars of visual magnitude 2.5 and brighter are utilized. The instrument stellar field of view is chosen as 20°.

6. For both the sun and stars, data is gathered over three consecutive scans and then no data is gathered on the next seven consecutive scans. This pattern is repeated.

7. The distributions of each time measurement are independent. The mean of each distribution is the true value, and the second moments exist. Moreover, $\sigma(\delta t_i) = 0.155 \times 10^{-3}$ second. Also, the input errors are small enough so that each output error is a linear combination of the input errors.

8. All data is reduced by a least-squares method. Stellar and sun transits are weighted equally.

Of all the above assumptions, (1) is the most severe. In the presence of torques, it may not be possible to utilize data gathered over a long time duration. Thus, the numerical results obtained by use of the above assumptions can only be considered as a lower bound to the accuracy of the system. Nevertheless, it is important to obtain some knowledge of the accuracy of the system for the case when only the sun is observable for long time intervals.

Because of (8), it is possible to write

$$\delta \overline{X} = A \, \overline{\delta t}$$

where

$\delta \overline{X}$ is a 7 x 1 matrix such that

$$\overline{\delta X^T} = (\delta\theta, \delta\Psi_o, \delta\dot{\Psi}, \delta\dot{\phi}_o, \delta\dot{\phi}, \delta\xi, \delta\tau),$$

A = 7 x n matrix, where n is the number of observations,

$\overline{\delta t}$ = n x 1 matrix whose elements are the transit time errors.

Thus, the covariance matrix of the random variable, $\overline{\delta X}$, is given by

$$E(\overline{\delta X}\,\overline{\delta X}^T) = A\,E\,(\overline{\delta t}\,\overline{\delta t}^T)\,A^T = \sigma^2(\delta t)\,A\,A^T$$

In the time interval over which stars were observed, 376 stellar transits of eight stars were obtained. Note that the cone angle of θ =5° has the effect of increasing the effective field of view. However, not all stars were observed on every scan. Ninety-nine sun transits were obtained.

With these assumptions, we compute the standard deviation of the seven unknowns with and without use of the sun transits; the results are shown in Table L1.

TABLE L1. -- STANDARD DEVIATION OF UNKNOWNS (ANGLES MEASURED IN SECTIONS OF ARC, AND TIME IN SECONDS.)

	With sun	Without sun
$\sigma(\delta\,\theta)$	3.59	3.65
$\sigma(\delta\phi_o)$	53.57	80.32
$\sigma(\delta\dot{\phi})$	0.0260	0.107
$\sigma(\delta\Psi_o)$	52.99	79.22
$\sigma(\delta\dot{\Psi})$	0.0262	0.104
$\sigma(\delta\xi)$	3.82	4.03
$\sigma(\delta\tau)$	4.01	4.18

Note that the sun observations have improved all the unknowns, but the largest improvement is in the rates.

The quantities shown in Table L1 are not those of primary interest. Of more interest are the errors in the declination of the $\hat{i}_6$ axis. This axis passes from near the North Pole to near the South Pole.

Now, one may write

$$\delta a = B \; \delta \overline{X}$$

where

δa = error in the declination of the $\hat{i}_6$ axis

B = a 1 x 7 matrix where elements are functions of t.

Hence,

$$\sigma^2(\delta a) = B \; E(\delta X \; \delta X^T) \; B^T$$

Results are plotted in Figure L1 for two ten-second time intervals. The first time interval is immediately after losing the stars, the second immediately after losing the sun. The effect of the sun observation is also shown in Figure L1.

Because assumption (7) was utilized in obtaining Table L1 and Figure L1, the nonlinear effects of the problem were assumed to be negligible. These additional effects were investigated by a Monte Carlo technique. To the true times, errors were added which were generated by randomly choosing a number from a gaussian distribution whose mean is zero and whose standard deviation is 0.155×10^{-3}.

If only star transits are utilized, the results are

$\delta\theta$ = 0.148 second

$\delta\phi_o$ = 1.775 seconds

$\delta\dot{\phi}$ = 0.0072 second/second

$\delta\Psi_o$ = -1.710 seconds

$\delta\dot{\Psi}$ = 0.0110 second/second

$\delta\xi$ = 0.587 second

$\delta\tau$ = 0.850 second

These results then imply an error in the declination of $\hat{i}_6$ similar to those shown in Figure L1.

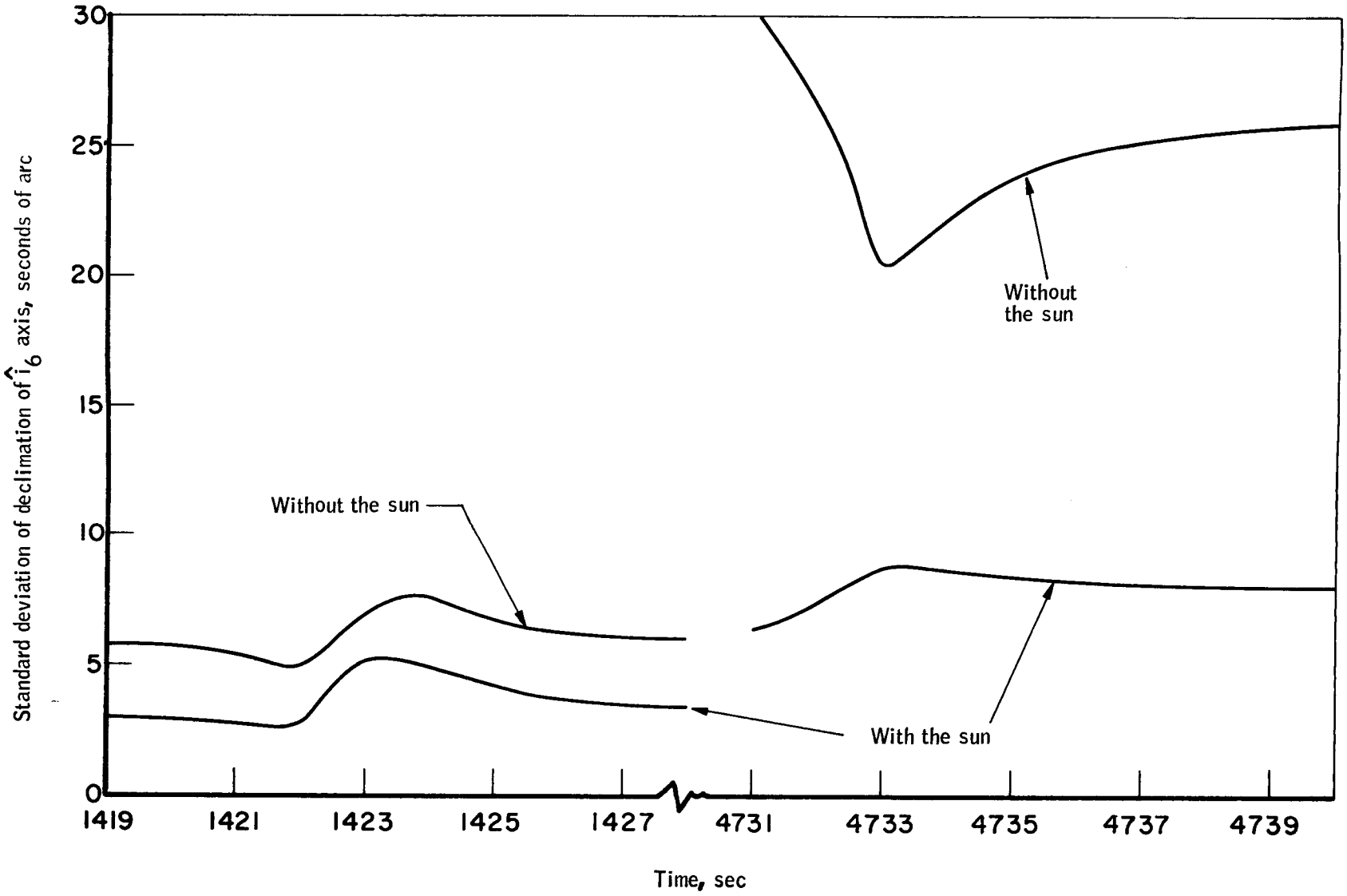

Figure L1. Error in Declination of Pitch Axis in Two Time Intervals with and without Sun, Torque-Free Case

In summary, it has been shown that if star transits are observed followed by a period with only sun transits, then the torque-free model does produce errors within the allowed ranges. However, these errors must be considered only as a lower bound of the true errors.

APPENDIX M
LEAST-SQUARES SOLUTION TESTING PROGRAM

```
IFN        EFN          PROGRAM:  SICHCK                JOB:    HDMPESTI-ECKART

0001            DIMENSION PG(15,16),P(15,16),PF(15) ,KD(6),PS(15,16),PROD(15)
               1,PE(15)
0002            READ (5,4) P,PE
0003          4 FORMAT (4E20.12)
0004            WRITE (9,40) PE,P
0005         40 FORMAT (8E15.7/7E15.7//(8E15.7/7E15.7))
0006         18 READ (5,2) M1,M2,KSUB,KD
0007          2 FORMAT (9I5)
0010            IF (M1) 99,99,19
0011         19 DO 20 I = 1,15
0012            DO 20 J = 1,16
0013         20 PG(I,J) = P(I,J)
0014            WRITE (9,2) M1,M2,KSUB,KD
0015            DO 599 I = 1,15
0016            PF(I) = PE(I)
0017        599 PG(I,M2) = PG(I,16)
0020            IF (KSUB) 18,48,50
0021         50 DO 42 I = 1,KSUB
0022            K = KD(I)
0023         44 DO 43 L=K,M1
0024            PF(L) = PF(L+1)
0025            DO 43 J = 1,M2
0026         43 PG(J,L) = PG(J,L+1)
0027            DO 120 L = K,M1
0030            DO 120 J = 1,M2
0031        120 PG(L,J) = PG(L+1,J)
0032         42 CONTINUE
0033            M1 = M1 - KSUB
0034            M2 = M2 - KSUB
0035         48 NCVR = -M2
0036            DO 52 I = 1,15
0037            DO 52 J = 1,16
0040         52 PS(I,J) = PG(I,J)
0041            CALL SHINAD (ISOL,IDSOL,M1,NCVR,PG,15,KWA,DET)
0042            DO 72 I = 1,M1
0043            PROD(I) = 0.
0044            DO 72 J = 1,M1
0045         72 PROD(I) = PROD(I) + PG(J,M2)*PS(I,J)
0046            DO 134 I = 1,M1
0047        134 PG(I,M2) = PG(I,M2) *PF(I)
0050            ISDOL = ISOL + IDSOL
0051            IF (ISDOL-2) 110,112,110
0052        110 WRITE (9,6) ISOL,IDSOL,DET
0053          6 FORMAT (16H ERROR IN SHINVR, 2I4,F16.8)
0054            GO TO 60
0055        112 WRITE (9,8)     (PG(I,M2),I=1,15)
0056          8 FORMAT (                                //3H DY =,2X,10E11.4/7X,5F11.4)
0057            WRITE (9,4) DET
0060            WRITE (9,74) (PS(I,M2),PROD(I),I=1,M1)
0061         74 FORMAT (5HCHECK/(6E16.8))
0062            DO 54 I = 1,15

0063            DO 54 J = 1,16
0064         54 PG(I,J) = PS(I,J)
0065         60 CALL CJM (15,M1,15,PS,IERR)
0066            CALL RANK (15,M1,40,IRANK,DET,PG)
0067            WRITE (9,70) IRANK,DET
0070         70 FORMAT (6HRANK = ,I8,24HDET =  ,E16.8)
0071            IF (IERR) 56,58,56
0072         56 WRITE (9,40) PS
0073            GO TO 18
0074         58 WRITE (9,40) (PS(I,I),I=1,M1 )
0075            GO TO 18
0076         99 STOP 11
0077            END
```

```
IFN        EFN          PROGRAM:  PROG0*                JOB:    HDMPESTI-ECKART

0001          SUBROUTINE RANK(NNK,N,IRE,IRANK,DET,S)
0002          DIMENSION ERR(15,15),S1(15),S2(15)
0003          DIMENSION S(NNK,NNK)
0004          IS=0
0005          B=1./.6931471806
0006          IB=0
0007          JB=0
0010          NM1=N-1
0011          DO 1 I=1,N
0012          DO 1 J=1,N
0013          IF(S(I,J))21,20,21
0014       20 JRE=0
0015          GOTO 27
0016       21 JRE=B*ALOG(ABSF(S(I,J)))
0017       27 KRE=JRE-IRE
0020        1 ERR(I,J)=2.**KRE
0021          DO 100 K=1,NM1
0022          IB=IB+1
0023          JB=JB+1
0024          KK=IB
0025          LL=JB
0026          BIG=ABSF(S(IB,JB))
0027          DO 4 I=IB,N
0030          DO 4 J=JB,N
0031          IF(BIG-ABSF(S(I,J)))3,4,4
0032        3 KK=I
0033          LL=J
0034          BIG=ABSF(S(I,J))
0035        4 CONTINUE
0036          IF(BIG)22,23,22
0037       23 IRANK=0
0040          DET=0
0041          RETURN
0042       22 IF(LL-JB)5,7,5
0043        5 IF(IS)30,31,30
0044       30 IS=0
0045          GOTO 32
0046       31 IS=1
0047       32 DO 6 I=1,N
0050          S1(I)=S(I,JB)
0051          S2(I)=ERR(I,JB)
0052          S(I,JB)=S(I,LL)
0053          ERR(I,JB)=ERR(I,LL)
0054          S(I,LL)=S1(I)
0055        6 ERR(I,LL)=S2(I)
0056        7 IF(KK-IB)8,10,8
0057        8 IF(IS)33,34,33
0060       33 IS=0
0061          GOTO 35
0062       34 IS=1
0063       35 DO 9 J=1,N
```

```
IFN        EFN          PROGRAM:  RANK                    JOB:    HDMPESTI-ECKART

0064            S1(J)=S(IB,J)
0065            S2(J)=ERR(IB,J)
0066            S(IB,J)=S(KK,J)
0067            ERR(IB,J)=ERR(KK,J)
0070            S(KK,J)=S1(J)
0071          9 ERR(KK,J)=S2(J)
0072         10 I1=IB+1
0073            J1=JB+1
0074            KEND=0
0075            DO 11 I=I1,N
0076            DO 11 J=J1,N
0077            E1=ABSF(S(IB,IB))
0100            E2=ABSF(ERR(I,J)*S(IB,IB))
0101            E3=2.*(ABSF(ERR(IB,IB)*S(I,J)))
0102            E4=ABSF(ERR(IB,IB)*ERR(I,J))
0103            E5=ABSF(ERR(IB,J)*S(I,JB))
0104            E6=ABSF(ERR(I,JB)*S(IB,J))
0105            E7=ABSF(ERR(IB,J)*ERR(I,JB))
0106            E8=ABSF(ERR(IB,IB)*S(IB,J)*S(I,JB))
0107            E9=E1*(E1+ABSF(ERR(IB,IB)))
0110            S(I,J)=S(I,J)-(S(I,JB)/S(IB,IB))*S(IB,J)
0111            IF(S(I,J))25,24,25
0112         24 JRE=0
0113            GOTO 26
0114         25 JRE=B*ALOG(ABSF(S(I,J)))
0115         26 KRE=JRE-IRE
0116            ERR(I,J)=(E1*(E2+E3+E4+E5+E6+E7)+E8)/(E9)+2.**KRE
0117            IF(ABSF(S(I,J))-ERR(I,J))11,11,12
0120         12 KEND=1
0121         11 CONTINUE
0122            DO 13 I=I1,N
0123         13 S(I,JB)=0.0
0124            IF(KEND)100,14,100
0125         14 IRANK=IB
0126            RETURN
0127        100 CONTINUE
0130            IRANK=N
0131            DET=1.0
0132            DO 15 I=1,N
0133         15 DET=DET*S(I,I)
0134            IF(IS)36,37,36
0135         36 DET=-DET
0136         37 RETURN
0137            END
```

```
IFN        EFN          PROGRAM:  PROGO"                JOB:    HDMPESTI-ECKART

0001            SUBROUTINE CJM(NN,N,KK,P,IERR)
          C  SOLVES FOR THE EIGEN VALUES OF A REAL SYMETRIC MATRIX BY THE JACOBI METHOD
0002            DIMENSION P(NN,NN)
0003            NM1=N-1
0004            IERR = 0
0005            ICNT = 0
0006        150 DO 100 I=1,NM1
0007            IP1=I+1
0010            DO 100 J=IP1,N
0011            IF(P(I,J))80,100,81
0012         80 IS=1
0013            GO TO 82
0014         81 IS=2
0015         82 DDE=P(I,I)-P(J,J)
0016            IF(DDE)84,83,84
0017         83 GOTO(60,65),IS
0020         84 A=.5*(ATAN(2.*P(I,J)/DDE))
0021            IF(ABS(A)-.78539816)90,90,70
0022         70 IF(A)60,60,65
0023         60 A=-.78539816
0024            GOTO 90
0025         65 A=+.78539816
0026         90 CA=COS(A)
0027            SA=SIN(A)
0030            S2A=SIN(2.*A)
0031            PII=    P(I,I)*CA*CA+P(I,J)*S2A+P(J,J)*SA*SA
0032            PJJ=P(I,I)*SA*SA-P(I,J)*S2A+P(J,J)*CA*CA
0033            P(I,I)=PII
0034            P(J,J)=PJJ
0035            DO 7 L=1,N
0036            IF(L-I)4,7,4
0037          4 IF(L-J)6,5,6
0040          5 P(I,L)=0.
0041            P(L,I)=0.
0042            GOTO 7
0043          6 RI=P(I,L)*CA+P(J,L)*SA
0044            RJ=P(J,L)*CA-P(I,L)*SA
0045            P(I,L)=RI
0046            P(J,L)=RJ
0047            P(L,I)=RI
0050            P(L,J)=RJ
0051          7 CONTINUE
0052        100 CONTINUE
0053            SSD=P(N,N)*P(N,N)
0054            SSOD=0.
0055            DO 9 K=1,NM1
0056            KP1=K+1
0057            SSD=SSD+P(K,K)*P(K,K)
0060            DO 9 L=KP1,N
0061            IF(ABS(P(K,L))-1.E-30)10,10,11
0062         10 P(K,L)=0.

0063            P(L,K)=0.
0064            GOTO 9
0065         11 SSOD=SSOD+2.*P(K,L)*P(K,L)
0066          9 CONTINUE
0067            IF(SSOD/SSD-(1./(10.**KK)))25,25,40
0070         40 ICNT = ICNT + 1
0071            IF (ICNT-10) 150,150,42
0072         42 IERR = -7
0073         25 RETURN
0074            END
```

```
IFN        EFN          PROGRAM: PROGO                JOB:    HDMPESTI-ECKART

0001              SUBROUTINE SHINAD(ISOL,IDSOL,NR,NC,A,MRA,KWA,DET)
0002              DIMENSION A(1),KWA(1)                                    001
0003              IR=NR                                                    002
0004              ISOL =1                                                  003
0005              IDSOL=1                                                  004
0006              CALLDVCHK(IVF)
0007              CALL OVERFL(IVF)
0010              IF(NR) 61,61,11
0011           11 IF (IR-MRA) 12,12,61
0012           12 IC=IABS(NC)
0013              IF(IC-IR) 13,14,14                                       009
0014           13 IC=IR                                                    010
0015           14 IBMP=1                                                   011
0016              JBMP=MRA                                                 012
0017              KBMP=JBMP+IBMP                                           013
0020              NES=IR*JBMP                                              014
0021              NET=IC*JBMP                                              015
0022              IF(NC)  15,61*16                                         016
0023           15 MDIV=JBMP+1                                              017
0024              IRIC=IR-IC                                               018
0025              GO TO 17                                                 019
0026           16 MDIV=1                                                   020
0027           17 MAD =MDIV                                                021
0030              MSER=1                                                   022
0031              KSER=IR                                                  023
0032              M7  =1                                                   024
0033              DET=1.0                                                  025
0034           18 PIV=0.0                                                  026
0035              I=MSER                                                   027
0036           19 IF(I-KSER)          20,20,23                             028
0037           20 IF(ABS(A(I))-PIV)22,22,21
0040           21 PIV=ABS(A(I))
0041              IP=I                                                     031
0042           22 I=I+IBMP                                                 032
0043              GO TO 19                                                 033
0044           23 IF(PIV)  24,62,24                                        034
0045           24 IF(NC)  26,25,25                                         035
0046           25 I=IP-((IP-1)/JBMP)*JBMP                                  036
0047              J=MSER-((MSER-1)/JBMP)*JBMP                              037
0050              JJ=MSER/KBMP+1
0051              II=JJ+(IP-MSER)                                          039
0052              KWA(JJ)=II                                               040
0053              GO TO 27                                                 041
0054           26 I=IP                                                     042
0055              J=MSER                                                   043
0056           27 IF(IP-MSER) 61,31,28                                     044
0057           28 IF(J-NET)  29,29,30                                      045
0060           29 PSTO=A(I)                                                046
0061              A(I)=A(J)                                                047
0062              A(J)=PSTO                                                048
0063              I=I+JBMP                                                 049
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0064          J=J+JBMP                                                  050
0065          GO TO 28                                                  051
0066       30 DET=-DET                                                  052
0067       31 PSTO=A(MSER)                                              053
0070          WRITE (9,100)  PSTO,I9
0071      100 FORMAT (E16.8,I5)
0072          DET=DET*PSTO                                              054
0073          CALL OVERFL(IVF)
0074          GO TO (34,33),IVF
0075       33 GO TO 35
0076       34 IDSOL = 2
0077       35 PSTO=1.0/PSTO                                             058
0100          CALLDVCHK(IVF)
0101          GO TO (600,601),IVF
0102      600 IDSOL = 3
0103          ISOL =2
0104          GO TO 65
0105      601 CONTINUE
0106          A(MSER)=1.0                                               059
0107          I=MDIV                                                    060
0110       36 IF(I-NET)   37,37,39                                      061
0111       37 A(I)=A(I)*PSTO                                            062
0112          I=I+JBMP                                                  063
0113          GO TO 36                                                  064
0114       39 IF(MZ-KSER) 40,40,45                                      065
0115       40 IF(MZ-MSER) 41,44,41                                      066
0116       41 I=MAD                                                     067
0117          J=MDIV                                                    068
0120          PSTO=A(MZ)                                                069
0121          IF(PSTO) 142,44,142                                       070
0122      142 A(MZ)=0.0                                                 071
0123       42 IF(J-NET)   43,43,44                                      072
0124       43 A(I)=A(I)-A(J)*PSTO                                       073
0125          J=J+JBMP                                                  074
0126          I=I+JBMP                                                  075
0127          GO TO 42                                                  076
0130       44 MAD=MAD+IBMP                                              077
0131          MZ=MZ+IBMP                                                078
0132          GO TO 39                                                  079
0133       45 CALL OVERFL(IVF)
0134          GO TO (63,145),IVF
0135      145 KSER=KSER+JBMP                                            081
0136          IF(KSER-NES) 46,46,53                                     082
0137       46 MSER=MSER+KBMP                                            083
0140          IF(NC) 48,47,47                                           084
0141       47 MDIV=MDIV+IBMP                                            085
0142          MZ=((MSER-1)/JBMP)*JBMP+1                                 086
0143          MAD=1                                                     087
0144          GO TO 52                                                  088
0145       48 MDIV=MDIV+KBMP                                            089
0146          IF(IRIC) 50,49,50                                         090
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IFN        EFN          PROGRAM:  SHINAD                JOB:    HDMPESTI-ECKART

0147        49 MZ=MSER+IBMP                                                  091
0150           GO TO 51                                                      092
0151        50 MZ=((MSER-1)/JBMP)*JBMP+1                                     093
0152        51 MAD=MZ+JBMP                                                   094
0153        52 GO TO 18                                                      095
0154        53 IF(NC) 65,54,54                                               096
0155        54 JR=IR                                                         097
0156        55 IF(JR) 61,65,56                                               098
0157        56 IF(KWA(JR)-JR) 61,60,57                                       099
0160        57 K=(JR-1)*JBMP                                                 100
0161           J=K+IR                                                        101
0162           L=(KWA(JR)-1)*JBMP+IR                                         102
0163        58 IF(J-K)   61,60,59                                            103
0164        59 PSTO=A(L)                                                     104
0165           A(L)=A(J)                                                     105
0166           A(J)=PSTO                                                     106
0167           J=J-IBMP                                                      107
0170           L=L-IBMP                                                      108
0171           GO TO 58                                                      109
0172        60 JR=JR-1                                                       110
0173           GO TO 55                                                      111
0174        61 ISOL=3                                                        112
0175           GO TO 65                                                      113
0176        62 DET=0.0                                                       114
0177           ISOL=2
0200           IDSOL=1
0201           GO TO 65
0202        63 ISOL = 2
0203           IDSOL = 2
0204        65 RETURN                                                        116
0205           END                                                           117
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