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ASTP EXPERIMENT SUPPORT DATA PROCESSING

Mathematical Physics Branch

MISSION PLANNING AND ANALYSIS DIVISION

National Aeronautics and Space Administration

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1.0 INTRODUCTION

This internal note documents in detail the activities associated with the generation of ASTP experiment support data in the areas of spacecraft ephemeris and orientation and instrument pointing and field-of-view. The majority of this work is being performed for the Mathematical Physics Branch (MPB) by TRW engineers under contract NAS 9-13834, Task JSC/TRW 308. It is intended that this document represent a cradle-to-grave chronicle of these activities. To satisfy this intent while facilitating the ready dissemination of information, the document is being published twice. The first publication, scheduled for release prior to ASTP lift-off, includes all preflight phases of the experiment support activity in addition to those appendixes that do not pertain to any mission-specific data. The second publication will provide any required updates to the original documentation and will add all mission-specific data, including documentation of all postflight data processing activities and data archiving information.

It should be noted that the responsibilities of MPB and Task 308 are limited to the generation of spacecraft ephemeris, instrument pointing and field-of-view, and related experiment support data. The task is not involved in the retrieval of CSM orientation data, experiment sensor data, or any other such data from raw telemetry. In fact, the orientation data must be recovered by the IDSD of DSAD and delivered to MPB before generation of experiment support products can begin.

2.0 EXPERIMENT SUPPORT PLAN

The experiment support process can be divided into five distinct phases.

1. Requirements definition
2. Requirements implementation
3. Verification
4. Production
5. Archival

Each phase represents an important step in the experiment support process.

2.1 Requirements Definition

Requirement definition is one of the most important functions of the experiment support task. In past programs, numerous problems have arisen because of incorrect or insufficient definition of PI data requirements. Such problems have resulted in delayed delivery of PI data and/or delivery of data that were not correct or that were of no use to the PI. Many of these problems could have been avoided by more complete definition of PI requirements. To avoid repeating past mistakes, the initial function of MPB/TRW Task 308, together with the JSC task monitor, was to meet with ASTP PI's and/or their representatives for the purpose of obtaining detailed definitions of PI postflight data requirements defined in reference 6. These requirements were then documented by means of ASTP Postflight Requirements Forms (PRF's) and submitted to the PI's for review and concurrence and ultimate inclusion in the PI contracts. Definition and documentation of requirements were the major functions of Task 308 for its first 3 months, July through September, 1974, and were continued at a reduced level well into 1975.

2.2 Requirements Implementation

Following documentation of the postflight requirements and PI concurrence, the process of implementing the requirements began. In many cases, it was not necessary to go through a program design phase, which is normally required, since many of the parameters requested by PI's were available through existing software. In particular, the Houston Operations Predictor/Estimator (HOPE) orbit determination program and the Apollo Photo Evaluation (APE) photographic analysis program included software for computing many of the requested parameters. Certain other requested parameters, however, required new software. A new program, known as the Apollo-Soyuz Experiment Parameter (ASEP) program, was developed (designed, coded, and verified) to compute these new parameters and to act as an executive in the merging of all other output data onto a single PI output tape.

2.3 Verification

Following implementation of PI requirements, all ASEP outputs were verified, both through in-house verification and through a closed-loop PI verification utilizing simulated mission data. In-house verifications consisted of coding and logic checks and hand checks of all computer calculations. The PI verification data were generated on the basis of an ASTP reference trajectory and reference attitude time line (refs. 1 and 2). Each experiment for which data are to be provided was active at least once over the intervals chosen for test. Sample output data in the form of magnetic tapes, microfilm, and hard copies were shipped to each PI for verification of computer compatibility of magnetic tapes and of proper computation and display of all requested parameters.

2.4 Production

Experiment support data production can be divided up into four basic functions.

1. Trajectory data processing

2. Attitude data processing

3. Special processing

4. Output data generation

Of these functions, the first two can be further divided into the preprocessing and processing phases. Section 3 describes all the data processing and production functions in detail.

2.5 Archival

All important data required in the postflight experiment support effort will be archived for use by the current PI's, future scientific investigators, and other data users. In general, the archival will follow the guidelines enumerated below.

1. All raw data will be archived.

2. All master PI output products will be archived.

3. Intermediate data will be archived where appropriate and where no special processing is required for the archival.

4. Data will be archived at the National Space Sciences Data Center (NSSDC).

All data are being archived for the purpose of giving the PI the option of regenerating his support data at some future time. (JSC will have no ASTP support capability after January 1, 1976.) Since a probable reason for desiring a regeneration of data is a refinement of mission-specific constants and/or processing techniques, the attitude and tracking data are being archived in their raw, uncorrected form. Additionally, all spacecraft ephemeris and refined attitude data will be archived. This will allow for a relatively straightforward regeneration of experiment-specific parameters, should the PI refine his experiment-related constants (for example, instrument misalinements). Finally, all PI support products will be archived to ensure against loss of data and/or bad data tapes. It should be noted that the archived PI support tapes will be compatible with the Univac 1108 computing system at JSC. Any use of these tapes by PI's with other computing equipment will require reformatting of the tapes. Thus, current PI's should take it upon themselves to make certain that they maintain backup copies of the computer compatible tapes, to avoid later problems with tape conversions. For further information on archiving, see reference 8.

2.6 Schedules

The bar chart in figure 2-1 depicts the planned time line for the various experiment support functions described previously.

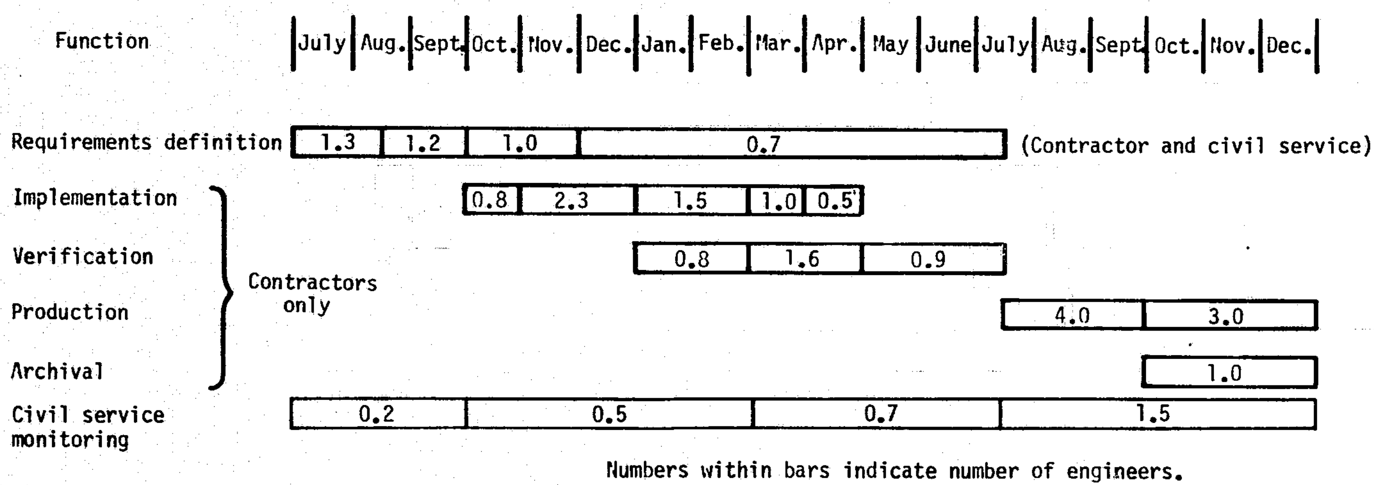


Figure 2-1.- Experiment support time line.

3.0 PRODUCTION PLAN

The purpose of this section is to delineate the experiment data generation process: identify the input data requirements, specify the required data processing functions and the associated software, describe the output data products, list archival products, and define a tentative data processing schedule.

3.1 Processing Overview

The data processing function has been divided into two operations: postflight data preprocessing and data processing. Refer to figure 3-1 for a detailed illustration of the general processing flow. The specific elements of these operations were developed by consideration of the following factors.

1. Maximize the use of existing software.

2. Standardize the processing functions and the output products.

3. Provide for quality control at each level of processing.

The preprocessing operation consists of processing, editing, interpolating (over short time intervals to fill data gaps), and merging the mission input data (telemetry data, tracking data, and camera shutter times) in order to produce a set of clean, time-ordered, master data files with the use of existing software (GREP, GEDIT, HOPE, and LOVE), with data quality checks at each processing step. This operation will account for approximately 75 percent of the processing effort with respect to labor and calendar time.

The processing operation consists of the assimilation of mission-specific data, the preparation of program control cards, and the generation of experiment support data tapes that contain the support parameters in a standard data record format. A nominal set of parameters (state vectors, Sun angles, and gimbal angles) will be generated on a one-for-one basis with the input ephemeris/attitude data, whereas special experiment-related parameters will be generated only during the specified operation periods associated with each individual experiment. This approach is considered the best way to standardize the production process and output products. Since the production program, Apollo-Soyuz Experiment Parameter (ASEP), must be developed from "scratch," the design of the program can be modified to reflect variations in the processing philosophy. Thus, there is more flexibility available for the modification of the production process. It is estimated that this operation will require about 25 percent of the labor resources.

There are five intermediate points in the overall data processing operation at which the quality and quantity of the data may be verified. All data listings and tapes for the intermediate steps will be retained until the support products have been delivered. The retention of these data will aid in the detection and isolation of data problems and facilitate the regeneration of data products.

3.2 Detailed Processing Plan

The purpose of this section is to provide a more detailed explanation of the preprocessing and processing operations. Some of the techniques and procedures

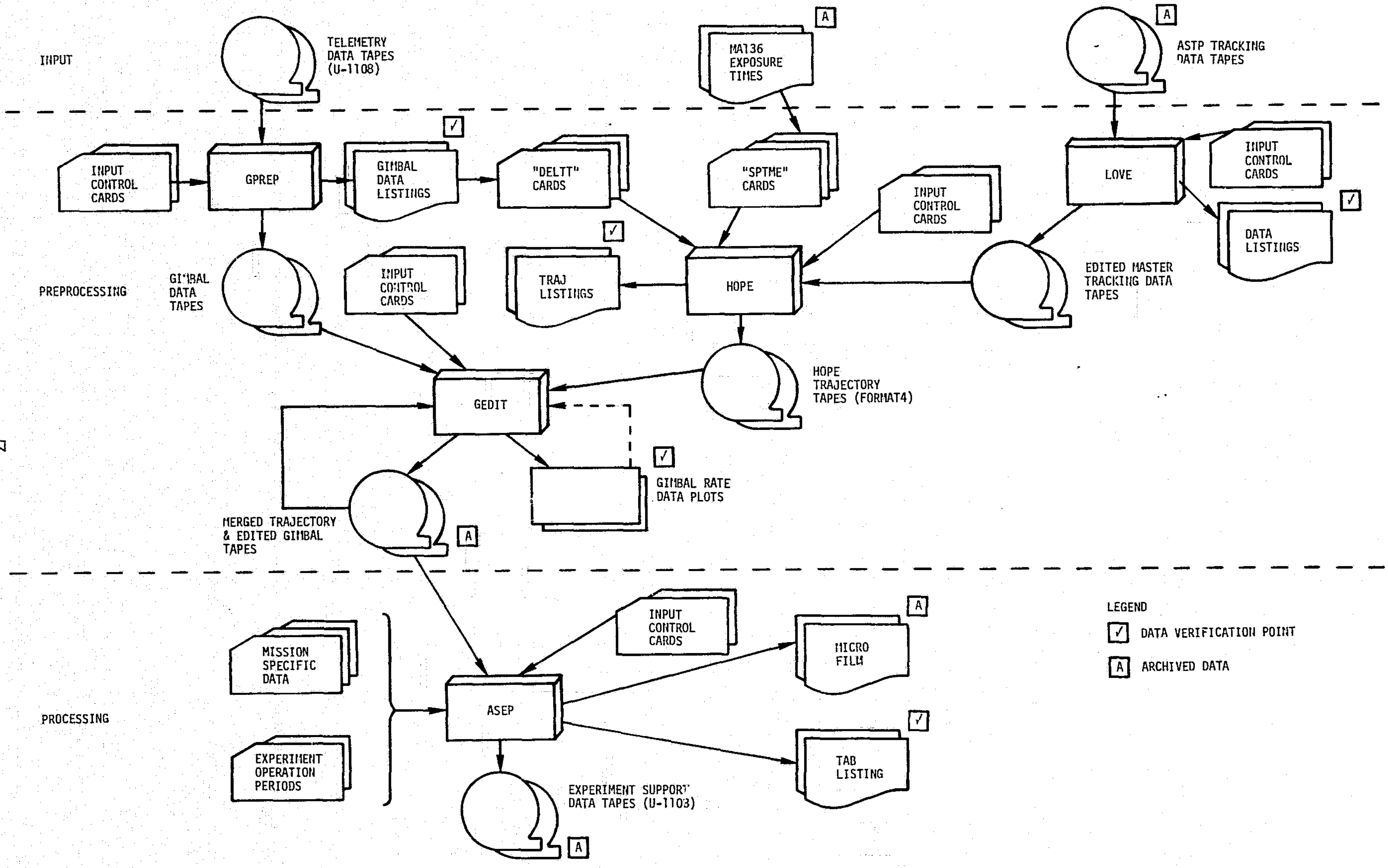


Figure 3-1.- General processing plan for experiment data support.

outlined below were originally developed during the Apollo Program for the generation of NASA Apollo Trajectory (NAT) tapes and Apollo Photograph Evaluation (APE) tapes, which provided ephemeris, attitude, pointing, and field-of-view data for numerous lunar orbital experiments. Some of the other techniques and procedures that will be used for the ASTP were developed for the reconstruction of SKYBET tapes, which provided ephemeris, attitude, and pointing data for Skylab orbital experiments. All existing software - GREP, GEDIT, HOPE, and LOVE - was developed during the Apollo Program but was utilized on both the Apollo and Skylab Programs to provide experiment support data. Thus, the support to be provided for ASTP will be based on proven techniques, procedures, and software.

3.2.1 Preprocessing.- The preprocessing operation is the most complex and time consuming of the two operations. The operation can be viewed as four distinct functions, as illustrated by figure 3-2. These functions are identified as follows.

1. Preprocess "raw" gimbal data.

2. Reconstruct a refined spacecraft trajectory as required.

3. Generate trajectory tapes.

4. Edit, interpolate, and merge trajectory and gimbal data tapes.

Detailed descriptions are presented below.

The purpose of function 1 is to strip time and gimbal words from the Univac 1108 input tapes, convert the time words into G.m.t. times, eliminate duplicate data points, create gimbal data "work" tapes, and list all the gimbal data. The listings provide for a check of the quality and quantity of the data, as well as the identification of missing data. Once data gaps are identified, the missing data may be re-requested or the gaps may be filled by interpolation or extrapolation, if possible. Finally, the DELTT cards - HOPE input trajectory control cards - may be derived from the data listings in preparation for the generation of trajectory tapes.

Function 2 consists of the preprocessing of the "raw" tracking data tapes for input to the orbit determination program. The orbit determination program will be used to reconstruct refined trajectories for all the experiments. Special techniques, devised by the Mathematical Physics Branch, will be used to reduce spacecraft position errors to 200 meters (1σ), unless there is excessive vehicle maneuvering.

Function 3 consists of the generation of trajectory data tapes for the total mission experimental period. There are two distinct modes. The first, a fixed frequency mode, generates trajectory data to match exactly the times associated with the preprocessed gimbal data. The second mode generates trajectory data at the MA-136 camera exposure times that have been converted to G.m.t. times. The DELTT trajectory control cards for the HOPE program are used for the first mode, whereas the SPTME trajectory control cards, derived from the listing of MA-136 exposure times, are used for the second mode. Refined state vectors will be used to generate the ephemerides for all experimental periods.

Function 4 consists of the editing, interpolating and merging of trajectory and gimbal data. For the fixed frequency mode, the gimbal times may be tested against the corresponding trajectory times to identify and edit "wild" gimbal time points. For short time intervals where gimbal data do not exist, interpolation

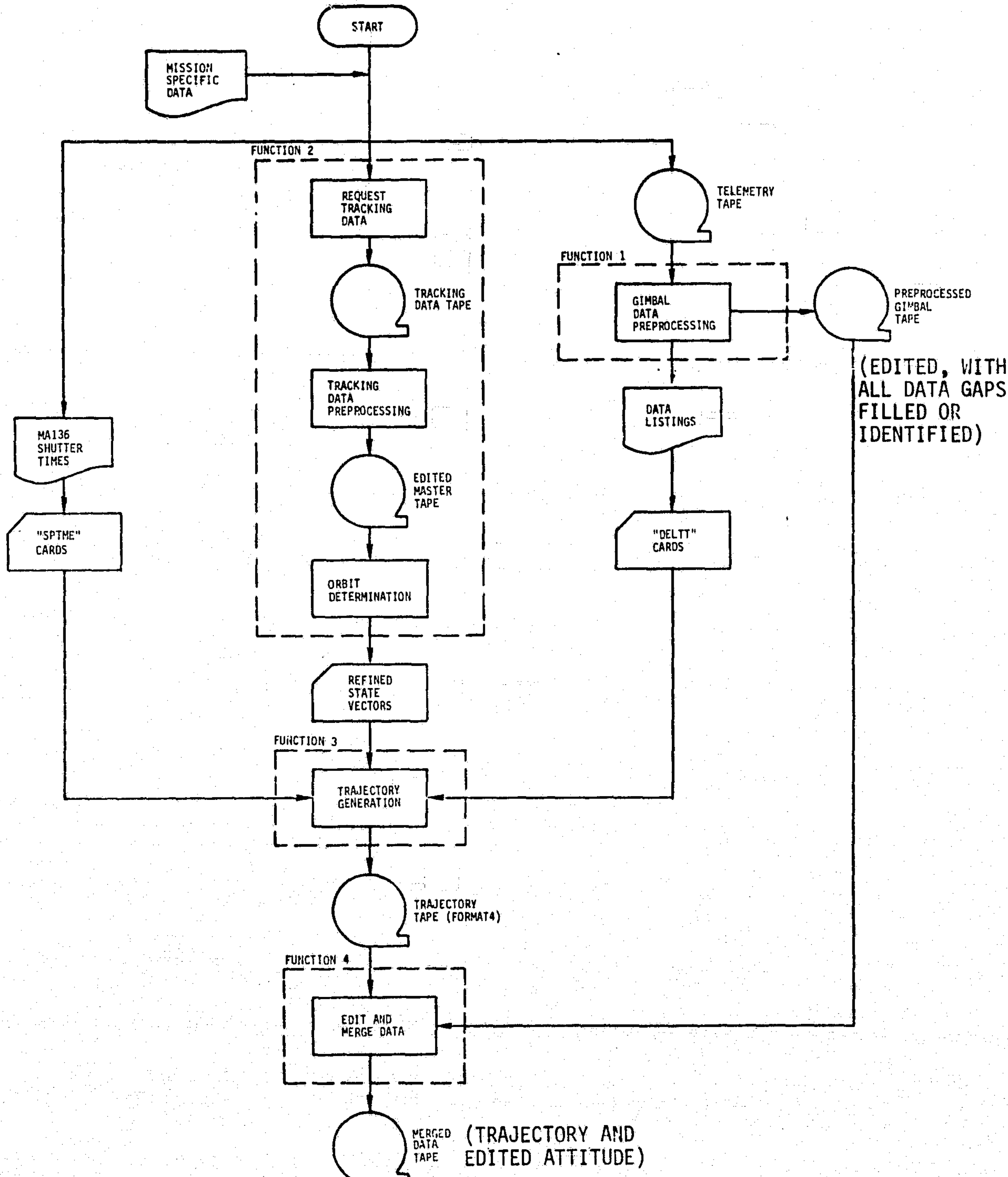


Figure 3-2.- Functional flow for the data preprocessing operation.

routines will be used to fill in these gaps and such data will be tagged accordingly. For the special time mode, the time and gimbal data are linearly interpolated in order to match the trajectory times that correspond to the camera exposure times. After all editing and interpolation is complete, the data will be merged onto master tapes in preparation for the next operation.

Figure 3-3 depicts the time phasing of these preprocessing functions. Initially, functions 1 and 2 may proceed in parallel, as well as some phases of function 3. Function 3, however, cannot be completed until all the data associated with functions 1 and 2 are generated. In particular, it should be noted that function 1 cannot even begin until raw attitude data tapes have been delivered by DSAD/IDSD. Function 4 is initiated after the completion of function 3 and proceeds until all merged master tapes are assembled.

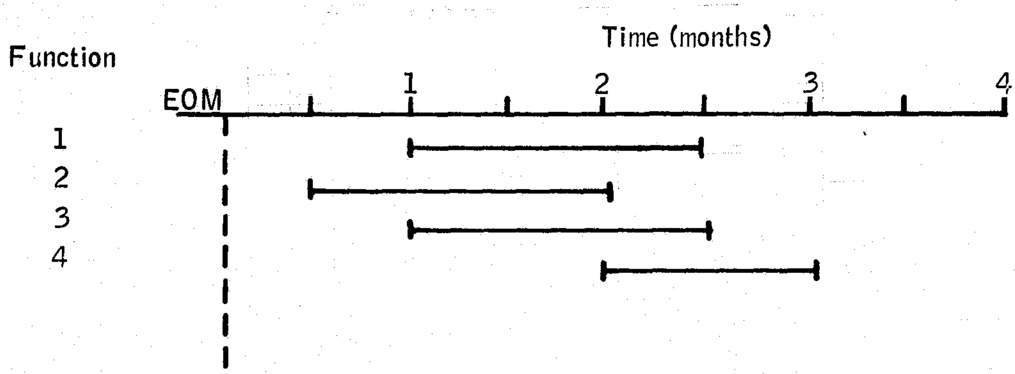


Figure 3-3.- Preprocessing operation time phasing.

3.2.2 Processing.- The processing operation consists of the computation of required ephemeris, attitude, and pointing parameters and the generation of required output products - tapes, listings, and microfilm. The operation is straightforward once the mission-specific data in the form of cards (see sec. 6.2.1) and the master input data tapes are available. The output tape will consist of header records of fixed length and data records of fixed length. A nominal set of parameters (state vectors, Sun angles, and gimbal angles) will be generated on a one-for-one basis with the input ephemeris/attitude data, whereas special experiment-related parameters will be generated only during the actual operation periods associated with each experiment (as specified at end-of-mission (EOM) by the responsible PI's). If gimbal angle data are not available at a specific time and cannot be reconstructed, only ephemeris-related parameters will be computed and all attitude and pointing parameters will be flagged with a code word to indicate that the gimbal data were missing. The output tape format is specified in section 6.2.4.

With regard to other output products, microfilm will be generated on a one-for-one basis with the output data, whereas tab listings will be printed at a frequency controlled by card input to the program. The format is specified in section 6.2.4.

3.2.3 Special processing requirements for MA-059.- To supplement the parameters provided by the Apollo-Soyuz Experiment Parameter (ASEP) program for the UV absorption experiment, MA-059, additional parameters will be generated from the reconstruction of the relative trajectory with use of the HOPE orbit determination program. Special purpose utility programs will be required to preprocess the relative tracking data used in the orbit determination process and to merge the HOPE parameters with the ASEP parameters. Figure 3-4 displays the required processing functions associated with this special support.

3.3 Computer Compatible Tape Conversions

The master output data tape generated by the ASEP program, as well as the special MA-059 data tape, must be converted to forms compatible with PI computational systems. These computer compatible tapes (CCT's) are the tapes that are shipped to PI's. Special purpose utility programs are used for these conversions. The tape formats are discussed in appendix C.

3.4 Archival

It is proposed that the output data tapes (Univac 1108) and associated microfilm, as well as the merged data tapes, be archived for possible future use. This archival function would have minimal impact with respect to labor and computer resources and delivery schedules if this function is specified before the data generation is actually initiated.

3.5 Schedule

A tentative schedule of data deliveries, based on a current understanding of MPAD, IDSD, and principal investigator commitments, is presented in table 3-I, where all delivery dates are referenced to the end of mission.

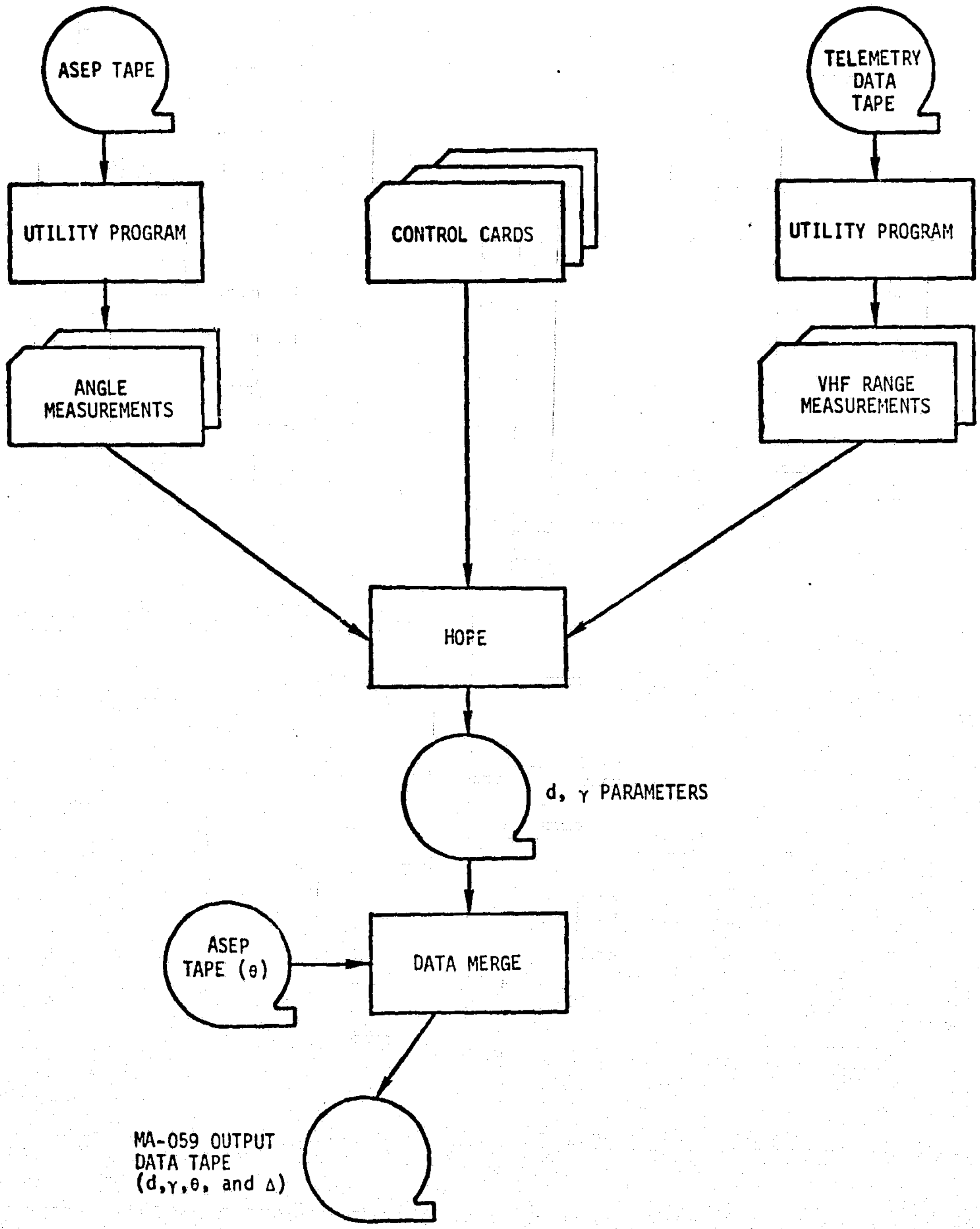


Figure 3-4.- Special-purpose processing functions for MA-059.

TABLE 3-I.- DATA PROCESSING SCHEDULE

Item	Responsible source (organization)	Delivery date[a]	Calandar date based on nominal mission
Experiment specific data	PI/S&AD	EOM	7/24/75
Mission specific data			
As-flown experiment time lines	PI/S&AD	EOM	7/24/75
Tracking data tapes	GDSD	2 weeks	8/7/75
Camera shutter times	IDSD	4-8 weeks	8/21-9/18
Telemetry data tapes	IDSD	4-8 weeks	8/21-9/18
Mission orbit determination	MPAD/TRW	6 weeks	9/4/75
Telemetry data rerun request	MPAD/TRW	9 weeks	9/25/75
Merged gimbal & trajectory tapes	MPAD/TRW	10 weeks	10/1/75
Experiment support data tapes	MPAD/TRW	14 weeks	11/1/75
Experiment support data rerun request	PI	18 weeks	11/29/75
Final experiment support data tapes	MPAD/TRW	23 weeks	12/31/75
Archival	MPAD	34 weeks	3/15/76
Final report	MPAD	34 weeks	3/15/76

[a]All dates referenced to the end of mission.

4.0 EXPERIMENT SUPPORT PARAMETER FORMULATIONS

The purpose of this section is to specify the equations for all the experiment support parameters that will be provided by JSC/TRW Task 308. The following subsections define the standard nomenclature for all formulations, define all required computational coordinate systems and associated transformations, and specify the equations for all the experiment support parameters.

4.1 Nomenclature

This section defines the nomenclature to be used for the specification of experiment parameter formulations. The units associated with the parameters are kilometers, seconds, and degrees unless otherwise specified. The coordinate system numeric designators are listed below. The coordinate systems are defined in section 4.2.

Definition	Numeric identifier
Mean of 1950.0	1
Ecliptic mean of 1950.0	2
True of date	3
Geographic (inertial)	4
IMU (nominal)	5
IMU (actual)	6
Navigation base	7
Instrument base (nominal)	8
Instrument base (actual)	9
UEN - up, east, north	10
Geomagnetic	11
Geographic (rotating)	12

A — 3×3 transformation matrix from the nominal instrument base (8) to the actual instrument base (9).

a — Semimajor axis of the Earth's reference ellipsoid.

AET — ASTP mission elapsed time from range zero.

Ai — Instrument field-of-view designator.

AL	Surface arc length between nadir and the principal point.
ALFi	Right ascension of the vehicle measured from the x-axis of the i^{th} coordinate system.
ALPHA	Angle between the camera z-axis and the projection of the local vertical (principal point) into the plane formed by the vector from the principal point to the Sun and the camera z-axis.
ALPH10, BETA10, PHI10	Three orientation angles that relate the spacecraft body axes to the UEN coordinate system.
ALT4	Geodetic altitude of the vehicle.
ALTR	Time rate of change of the altitude (inertial) of the spacecraft with respect to the principal point.
AZi	Azimuth of the velocity vector in the i^{th} coordinate system measured clockwise from the local north to the projection of the velocity vector in a plane normal to the local vertical.
B	3 × 3 transformation matrix from the geographical inertial coordinate system (4) to the geomagnetic coordinate system (11).
b	Semiminor axis of the Earth's reference ellipsoid.
Bi	Instrument field-of-view designator.
BMAG	Intensity of the Earth's magnetic field (gauss).
BTAi	Vertical flightpath angle measured from the local vertical to the velocity vector in the i^{th} coordinate system.
C	3 × 3 transformation matrix from the geographical inertial coordinate system (4) to the UEN coordinate system (10).
CDUX, CDUY, CDUZ	Outer, inner, and middle gimbal angles.
Ci	Instrument field-of-view designator.
CET	Onboard clock elapsed time for the CSM central timing equipment.
D	3 × 3 transformation matrix from the nominal IMU coordinate system (5) to the actual IMU coordinate system (6).
Di	Instrument field-of-view designator.

DLTi	Declination of the vehicle in the i^{th} coordinate system.
DT	Time interval between adjacent photographs.
E	3 x 3 transformation matrix from the mean of 1950.0 coordinate system (1) to the ecliptic mean of 1950.0 coordinate system (2) (also denoted E_{ij}).
ECCi	Eccentricity of the orbit in the i^{th} coordinate system.
EMISS	Angle between the camera optical axis and the local vertical at the principal point.
ESLOS	Angle between the Earth-Sun vector and the SIM Bay sector 1 (MA-048, MA 083, MA-088) line-of-sight.
ESLOSS	Supplement of ESLOS.
F	3 × 3 transformation matrix from the navigation base coordinate system (7) to the nominal instrument base coordinate system (8).
f	Earth's flattening (unitless).
F3RHA1, F3DCA1	Right ascension and declination associated with the "A quadrant" of the MA-083 field-of-view in the mean of 1950.0 coordinate system (1).
F3RHB1, F3DCB1	Right ascension and declination associated with the "B quadrant" of the MA-083 field-of-view in the mean of 1950.0 coordinate system (1).
F3RHC1, F3DCC1	Right ascension and declination associated with the "C quadrant" of the MA-083 field-of-view in the mean of 1950.0 coordinate system (1).
F3RHD1, F3DCD1	Right ascension and declination associated with the "D quadrant" of the MA-083 field-of-view in the mean of 1950.0 coordinate system (1).
F8RHA1, F8DCA1	Right ascension and declination associated with the "A quadrant" of the MA-088 field-of-view in the mean of 1950.0 coordinate system (1).
F8RHB1, F8DCB1	Right ascension and declination associated with the "B quadrant" of the MA-088 field-of-view in the mean of 1950.0 coordinate system (1).
F8RHC1, F8DCC1	Right ascension and declination associated with the "C quadrant" of the MA-088 field-of-view in the mean of 1950.0 coordinate system (1).

F8RHD1, F8DCD1	Right ascension and declination associated with the "D quadrant" of the MA-088 field-of-view in the mean of 1950.0 coordinate system (1).
FL	Focal length of the camera lens.
FOV	Field-of-view.
G	3 × 3 transformation matrix from the actual IMU coordinate system (6) to the navigation base coordinate system (7).
GC	3 × 3 transformation matrix from the geographic coordinate system (4) to camera axes coordinate system.
GET	Ground elapsed time.
GHA	Angle between the vernal equinox and the Greenwich meridian.
GIMB	Gimbal data status flag.
GMT	Greenwich mean time (UTC).
HEAD	Angle, measured positive clockwise in the local-horizontal plane, from local north to the projection of the camera x-axis into the local-horizontal plane.
HV	Component of the spacecraft's velocity vector (inertial) that is colinear with the local-horizontal plane with respect to the principal point.
INCi	Inclination of the orbit plane with respect to the x-y plane in the i^{th} coordinate system.
L1AD1	Alinement corrected angle L1DEC1.
L1AR1	Alinement corrected angle L1RHA1.
L1AZ	Azimuth of the SIM Bay sector 1 (MA-048, MA-083, MA-088) line-of-sight in the UEN coordinate system (10).
L1DEC1	Declination of the SIM Bay sector 1 (MA-048, MA-083, MA-088) line-of-sight in the mean of 1950.0 coordinate system (1).
L1DEC2	Declination of the SIM Bay sector 1 (MA-048, MA-083, MA-088) line-of-sight in the ecliptic mean of 1950.0 coordinate system (2).
L1EL	Elevation of the SIM Bay sector 1 (MA-048, MA-083, MA-088) line-of-sight in the UEN coordinate system (10).

L1RHA1	Right ascension of the SIM Bay sector 1 (MA-048, MA-083, MA-088) line-of-sight in the mean of 1950.0 coordinate system (1).
L1RHA2	Right ascension of the SIM Bay sector 1 (MA-048, MA-083, MA-088) line-of-sight in the ecliptic mean of 1950.0 coordinate system (2).
LAT4	Geodetic latitude of the vehicle.
LATA, LONA	Geodetic latitude and longitude associated with the "A corner" of the MA-136 field-of-view.
LATB, LONB	Geodetic latitude and longitude associated with the "B corner" of the MA-136 field-of-view.
LATC, LONC	Geodetic latitude and longitude associated with the "C corner" of the MA-136 field-of-view.
LATD, LOND	Geodetic latitude and longitude associated with the "D corner" of the MA-136 field-of-view.
LATP, LONP	Geodetic latitude and longitude of the principal point.
LATS, LONS	Latitude and longitude of the intersection of the vector from the Earth's center to the Sun with the Earth's ellipsoid.
LH	3 × 3 transformation matrix from the geographic inertial coordinate system (4) to UEN coordinate system (10).
LMAG	Radius of the magnetic field "L shell" (Earth radii).
LON4	Geographic longitude of the vehicle.
LONS2	Longitude of the Sun in the ecliptic mean of 1950.0 coordinate system (2).
LOS	Line-of-sight.
LOSX, LOSY, LOSZ	Direction cosines for a vector from the vehicle to the principal point in the geographic inertial coordinate system (4).
ni	Subscript that designates the instrument line-of-sight or the camera optical axis in the i^{th} coordinate system.
NODi	Longitude of the ascending node, measured in the x-y plane from the x-axis in the i^{th} coordinate system.

OMGi	Argument of perifocus, measured in the orbit plane from the ascending node to the point of closest approach in the i^{th} coordinate system.
OPFLAG	Flag that designates which experiments are operating.
OVR	Ratio of the amount of overlap of the photograph frame dimension along the direction of the flightpath.
PET	Phase elapsed time.
PHASE	Angle between the camera optical axis and the vector from the principal point to the Sun.
PHI, KAPPA, OMEGA	Angles that rotate the camera axes coordinate system into the local-horizontal coordinate system, where ϕ = primary right-handed rotation about the camera y-axis. ω = secondary right-handed rotation about the intermediate x-axis. κ = final right-handed rotation about the local-vertical axis.
pi	Subscript that denotes a vector from the Earth's center to principal point in the i^{th} coordinate system.
PP	Principal point - point of intersection of the camera optical axis with the Earth's ellipsoid.
psi	Subscript that denotes a vector from the principal point to the Sun in the i^{th} coordinate system.
R	3 × 3 transformation matrix from the mean of 1950.0 coordinate system (1) to the nominal IMU coordinate system (5).
$\bar{r}$	Vehicle position vector.
REV	Vehicle rev. number.
RF	3 × 3 transformation matrix that relates the stable member axis or nominal IMU (5) system to the mean of 1950.0 coordinate system.
Ri	Magnitude of the position vector.
SAZ10	Azimuth of the Sun vector in the UEN coordinate system (10).
SAZP	Sun azimuth at the principal point - angle, measured positive clockwise, from local north to the projection

	of the vector from the principal point to the Sun into the local-horizontal plane.
SCSA	Angle between the Earth-centered vehicle position vector and the Earth-Sun vector.
SEL10	Elevation of the Sun vector in the UEN coordinate system (10).
SELP	Sun elevation at the principal point - angle, measured counterclockwise, between the vector from the principal point to the Sun and the local-horizontal plane at the principal point.
SF	Constant that relates film dimensions to surface dimensions.
si	Subscript that denotes a vector from the Earth to the Sun in the i^{th} coordinate system.
SMAi	Semimajor axis of the orbit in the i^{th} coordinate system.
SR	Slant range from the vehicle to the principal point.
SUNF	Sunrise/sunset designator.
SUNH, SUNM, SUNS	Sunrise/sunset time.
SWING	Angle, measured counterclockwise, between the camera y-axis and the projection of the local vertical into the camera x-y plane.
T	3×3 transformation matrix from the mean of 1950.0 coordinate system (1) to the true of date coordinate system (3) (also denoted T_{ij}).
TAi	True anomaly in the i^{th} coordinate system, measured in the orbit plane from the point of closest approach to the vehicle's position in the orbit.
THETA	Angle between the vehicle x-axis and the CSM velocity vector.
TILT	Angle between the camera optical axis and the local vertical.
TILTAZ	Angle, measured clockwise, between local north and the projection of the camera optical axis into the local-horizontal plane.
$\bar{v}$	Vehicle velocity vector.

Vi	Vehicle speed.
vi	Subscript that denotes a vector from the center of the Earth to the vehicle in the i^{th} coordinate system.
VDEC1	Declination of the vehicle velocity in the mean of 1950.0 coordinate system (1).
VDEC2	Declination of the vehicle velocity in the ecliptic mean of 1950.0 coordinate system (2).
VLOS	Angle between the vehicle velocity vector and the instrument line-of-sight.
VRHA1	Right ascension of the vehicle velocity in the mean of 1950.0 coordinate system (1).
VRHA2	Right ascension of the vehicle velocity in the ecliptic mean of 1950.0 coordinate system (2).
W	3 × 3 transformation matrix from the true of date coordinate system (3) to the geomagnetic inertial coordinate system (4).
$\bar{x}$	Denotes an instrument pointing vector.
Xi, Yi, Zi	Vehicle position in the i^{th} Cartesian coordinate system.
XANG	x-angle deviation of the vehicle-Sun vector with respect to the instrument line-of-sight.
XDi, YDi, ZDi	Vehicle velocity in the i^{th} Cartesian coordinate system.
XDSi,YDSi, ZDSi	Velocity of the Sun with respect to the Earth in the mean of 1950.0 coordinate system (1).
XSi, YSi, ZSi	Position of the Sun with respect to the Earth in the mean of 1950.0 coordinate system (1).
XTILT	Angle from the local-horizontal plane to the camera y-axis (lateral tilt).
YANG	y-angle deviation of the vehicle-Sun vector with respect to the instrument line-of-sight.
YTILT	Angle from the local-horizontal plane to the camera x-axis (longitudinal tilt).
α_1, α_2, α_3	Inner, middle, and outer gimbal angles.

4.2 Definition of Coordinate Systems

A total of 12 coordinate systems is involved in the computation of the required experiment support parameters. The purpose of this section is to define each required coordinate system.

4.2.1 Mean of 1950.0.- The x-axis of this inertial Cartesian coordinate system lies along the line of intersection of the mean celestial equator with the ecliptic plane at 1950.0 and points toward the vernal equinox. The z-axis is orthogonal to the mean celestial equator at the reference time, and the y-axis completes the right-handed system.

4.2.2 Ecliptic of 1950.0.- The x-axis for this inertial Cartesian coordinate system lies along the line of intersection of the mean celestial equator with the ecliptic plane at 1950.0 and points toward the vernal equinox. The z-axis is orthogonal to the ecliptic plane at the reference time, and the y-axis completes the right-handed system.

4.2.3 True of date.- The x-axis of this inertial Cartesian coordinate system lies along the intersection of the true celestial equator of date and the ecliptic plane and points towards the vernal equinox of date. The z-axis is orthogonal to the true celestial equator of date, and the y-axis completes the right-handed system.

4.2.4 Geographic inertial.- The x-axis of this Cartesian coordinate system lies in the celestial equator of date through the Greenwich meridian of date. The z-axis is orthogonal to the celestial equator of date, and the y-axis completes the right-handed system.

4.2.5 IMU (nominal).- The CSM IMU Cartesian coordinate system is alined in inertial space to the mean of 1950.0 system through the Apollo REFSMMAT, which relates the stable member (SM) axis system to the mean of 1950.0 coordinate system. The nominal system is assumed to be error free; that is, no misalinements, drifts, et cetera.

4.2.6 IMU (actual).- The actual IMU coordinate system is related to the nominal IMU system by means of platform drifts.

4.2.7 Navigation base.- The navigation base coordinate system is a Cartesian system that corresponds to the vehicle-fixed x_v, y_v, and z_v coordinate system.

4.2.8 Instrument base (nominal).- For each instrument, as required, a Cartesian coordinate system is defined such that the z-axis is colinear with the nominal (perfectly alined) instrument LOS and orthogonal to the x-y plane. The specification of the x, y axes will be instrument dependent.

4.2.9 Instrument base (actual).- This Cartesian coordinate system is related to the nominal instrument base coordinate system by means of three-axes rotation matrix of misalinement angles.

4.2.10 Up, east, north (UEN).- The x-axis of this local-horizontal coordinate system is colinear with the position vector of the vehicle. The z-axis is directed towards local north in the geographic inertial system, and the y-axis (directed towards local east) completes the right-handed system.

4.2.11 Geomagnetic.- The z-axis of this Cartesian coordinate system is parallel to the extended axis of a "best fit" of a centered dipole to the Earth's actual magnetic field, the y-axis lies in the celestial equator of date, and the x-axis completes the right-handed system. The location of the intersection of the extended axis of the centered dipole with the Earth's surface is +69.5° west longitude and 78.5° north latitude.

4.2.12 Geographic rotating.- This Cartesian coordinate system is identical to the geographic inertial coordinate system except that it is rotating about the z-axis with angular speed ω_e, where ω_e is the rotation rate of the Earth.

4.2.13 Local vertical.- The local-vertical coordinate system, although not used directly in experiment support computations, is useful and often referenced for analysis purposes. This Cartesian system is Earth-centered. Its x-axis (radial axis) is directed radially outward along the vehicle position vector. The z-axis (crosstrack axis) is in the direction of $\bar{r} \times \bar{v}$, where $\bar{r}$ is the vehicle position vector and $\bar{v}$ is the velocity vector. The y-axis (downtrack axis) completes the right-handed system.

4.3 Coordinate System Transformations

To compute the required experiment support parameters, it will be necessary, in general, to transform vectors from any one of 12 possible coordinate systems, as defined in section 4.2, to any one of the remaining coordinate systems. The definition of these transformations can be simplified by the visualization of three "strings" of transformations that originate from the base system (mean of 1950.0). These strings of transformations include vehicle related transformations, true Earth equatorial related transformations, and the ecliptic mean of 1950.0 transformation, as illustrated in figure 4-1. Thus, any required transformation can be computed on the basis of the proper selection of matrix products as indicated in the figure.

The objective of this section is to specify the formulation for those transformations that must be computed or to identify the source of those transformations that will be defined by input (tape or card).

4.3.1 Mean of 1950.0 to nominal IMU.- The transformation R is specified by the REFSMMT matrix through card input.

4.3.2 Nominal IMU to actual IMU.- The transformation D is computed as follows, on the basis of the drifts that are defined in a right-handed sense about the x, y, and z axes.

$$D = \left\{ [I] - \frac{1}{d} \sin (d\ \Delta t)\ [H] + \frac{1}{d^2} [1 - \cos(d\ \Delta t)]\ [H]^2 \right\}$$

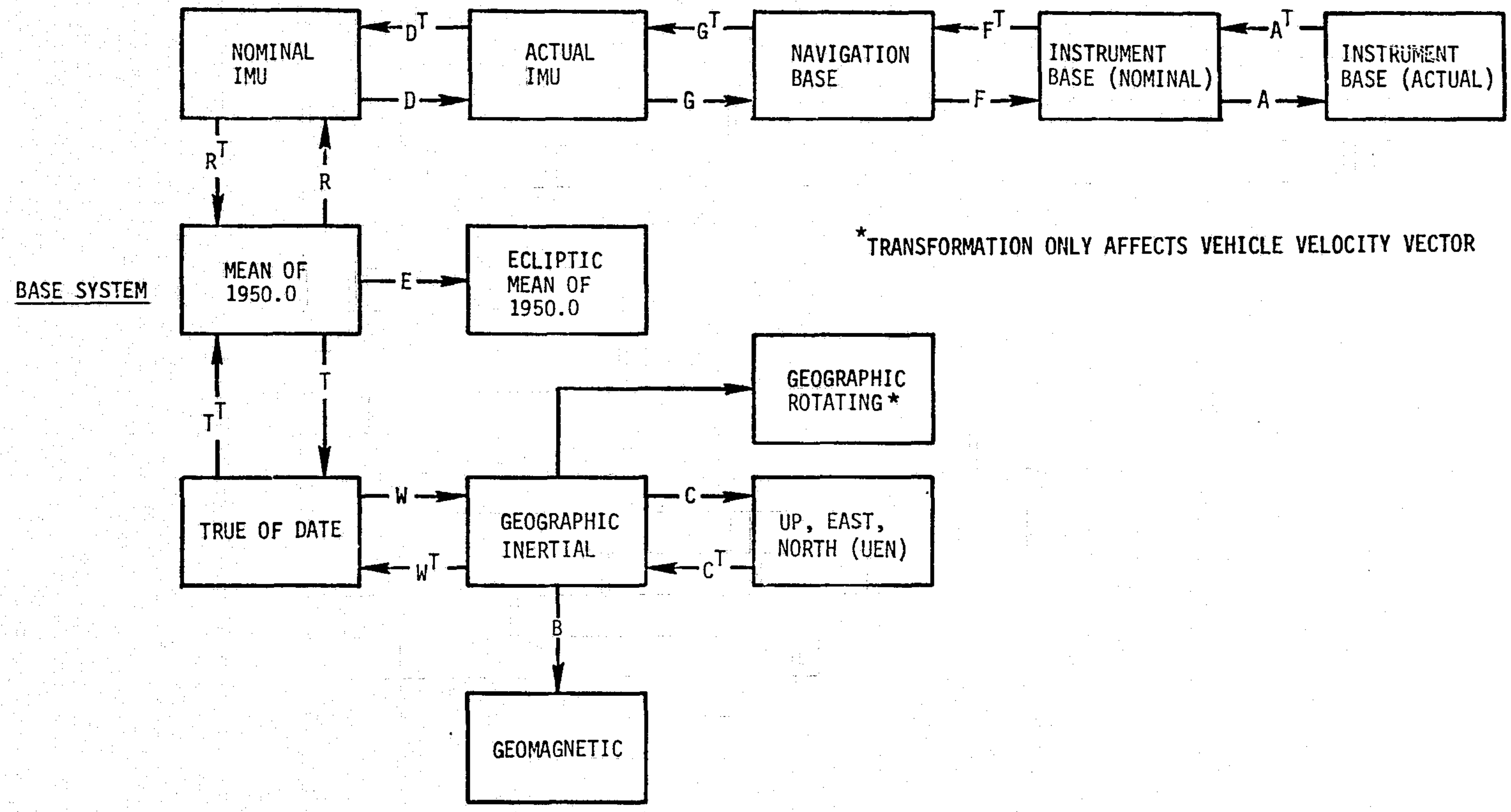


Figure 4-1.- Coordinate system transformation "tree."

where

$[I]$ = identity matrix, 3 × 3

$\bar{d}$: $(d_x, d_y, d_z)^T$ = drift about the IMU axes

$d = (\bar{d} \cdot \bar{d})^{1/2}$

Δt = time elapsed since alinement of the IMU

$$[H] = \begin{bmatrix} 0 & -d_z & d_y \\ d_z & 0 & -d_x \\ -d_y & d_x & 0 \end{bmatrix}$$

The values for d_x, d_y, and d_z are obtained through card input.

4.3.3 Actual IMU to navigation base.- The transformation G is a function of the inner (α_1), middle (α_2), and outer (α_3) gimbal angles, as follows.

$$G = [g_{ij}] \text{ ; } i,j = 1, 2, \text{ and } 3$$

$$g_{11} = \cos\alpha_1 \cos\alpha_2$$

$$g_{12} = \sin\alpha_2$$

$$g_{13} = -\sin\alpha_1 \cos\alpha_2$$

$$g_{21} = -\cos\alpha_1 \sin\alpha_2 \cos\alpha_3 + \sin\alpha_1 \sin\alpha_3$$

$$g_{22} = \cos\alpha_2 \cos\alpha_3$$

$$g_{23} = \sin\alpha_1 \sin\alpha_2 \cos\alpha_3 + \cos\alpha_1 \sin\alpha_3$$

$$g_{31} = \cos\alpha_1 \sin\alpha_2 \sin\alpha_3 + \sin\alpha_1 \cos\alpha_3$$

$$g_{32} = -\cos\alpha_2 \sin\alpha_3$$

$$g_{33} = -\sin\alpha_1 \sin\alpha_2 \sin\alpha_3 + \cos\alpha_1 \cos\alpha_3$$

The gimbal angles are available through tape input.

4.3.4 Navigation base to nominal instrument base.- The transformation F is instrument dependent; it is defined in section 4.4 as required.

4.3.5 Nominal instrument base to actual instrument base.- The transformation A is instrument dependent; it is defined in section 4.4 as required.

4.3.6 Mean of 1950.0 to ecliptic mean of 1950.0.- The transformation E is available through the tape input as computed by the HOPE program (see app. A).

4.3.7 Mean of 1950.0 to true of date.- The transformation T is available through the tape input as computed by the HOPE program (see app. A).

4.3.8 True of date to geographic inertial.- The transformation W is computed as follows.

$$W = (w_{ij}) \ ; \ i,j = 1, 2, \text{ and } 3$$

where

$$w_{11} = w_{22} = \cos \alpha$$

$$w_{21} = -w_{12} = -\sin \alpha$$

$$w_{31} = w_{13} = w_{32} = w_{23} = 0$$

$$w_{33} = 1$$

$$\alpha = \alpha_{go} + \omega_e \, \Delta t$$

α_{go} = right ascension of Greenwich, midnight day of epoch

ω_e = Earth's rotation speed

Δt = elapsed time since midnight day of epoch

The value for α_{go} is available by tape input.

4.3.9 Geographic inertial to up, east, north (UEN).- The transformation C is computed as follows.

$$C = (c_{ij}) \ ; \ i,j = 1, 2 \text{ and } 3$$

where

$$c_{11} = \cos \phi \cos \lambda$$

$$c_{12} = \cos \phi \sin \lambda$$

$$c_{12} = \sin \phi$$

$$c_{21} = -\sin \lambda$$

$$c_{22} = \cos \lambda$$

$$c_{23} = 0$$

$$c_{31} = -\sin \phi \cos \lambda$$

$$c_{32} = -\sin \phi \sin \lambda$$

$$c_{33} = \cos \phi$$

and where ϕ and λ are the computed geodetic latitude and longitude, respectively.

4.3.10 Geographic inertial to geomagnetic.- The transformation B is computed as follows.

$$B = (b_{ij}) \; ; \; i,j = 1, 2, \text{ and } 3$$

where

$$b_{11} = \cos \gamma \cos \lambda$$

$$b_{12} = \cos \gamma \sin \lambda$$

$$b_{13} = -\sin \gamma$$

$$b_{21} = -\sin \lambda$$

$$b_{22} = \cos \lambda$$

$$b_{23} = 0$$

$$b_{31} = \sin \gamma \cos \lambda$$

$$b_{32} = \sin \gamma \sin \lambda$$

$$b_{33} = \cos \gamma$$

and where $\lambda = -69.5°$ and $\gamma = 11.5°$, the longitude and colatitude, respectively, of the Earth's magnetic North Pole.

4.3.11 Geographic inertial to geographic rotating.- The transformation of a state vector from the geographic inertial coordinate system to the geographic rotating coordinate system is defined as follows.

$$\bar{r}_{12} = \bar{r}_4$$

$$\bar{v}_{12} = \bar{v}_4 - \bar{\omega} \times \bar{r}_4$$

$$\bar{\omega} = (0,\ 0,\ \omega_e)^T$$

ω_e = rotational speed of the Earth

4.4 Experiment Support Parameters

The objective of this section is to specify in detail the formulation for each experiment support parameter to be provided to ASTP principal investigators. There are two basic sets of parameters: the nominal ephemeris and pointing parameters and the experiment-specific (attitude, pointing, and field-of-view) parameters. Section 4.4.1 specifies the nominal parameters, whereas sections 4.4.2.1 through 4.4.2.8 specify the experiment-related parameters.

4.4.1 Nominal support parameters.- The set of nominal support parameters will be divided into four categories, as follows.

1. Time-related parameters.

2. Vehicle state vectors.

3. Vehicle-attitude-related parameters.

4. Miscellaneous support parameters.

These categories will be discussed in the above-mentioned order in the following subsections.

4.4.1.1 Time-related parameters: The six sets of time-related parameters are specified as follows.

1. G.m.t. - Greenwich mean time (UTC).

2. g.e.t. - Ground elapsed time. The base time for g.e.t. may be updated during the mission.

3. AET - ASTP mission elapsed time from range zero.

4. CET - Onboard clock elapsed time. All onboard computer parameters are tagged by CET.

5. PET - Phase elapsed time, which is used to designate special experiment phases.

6. OPFLAG - Flag to designate which experiments are operating.

All parameters will be displayed in terms of hours, minutes, and seconds from a base time.

The OPFLAG is a seven digit number used to designate experiment operation times. Each digit refers to a specific experiment, as follows.

Digit #	Experiment #	Experiment
1	1	MA-007
2	2	MA-048
3	3	MA-059
4	4	MA-083
5	5	MA-088
6	6	MA-106 and/or MA-107
7	7	MA-136

When an experiment is inactive, its digit in the OPFLAG will be zero. No experiment-specific parameters will be computed for that experiment. If the experiment is active, its digit in the OPFLAG will equal its experiment number as shown above. Thus, if MA-007 and MA-106 are active while all other experiments are off, the OPFLAG will be 1000060.E+00. Similarly, if MA-048, MA-083, and MA-088 are active, the OPFLAG will be 0204500.E+00.

4.4.1.2 Vehicle state vectors: The vehicle state vectors will be displayed in four reference coordinate systems and three different element sets, as designated below.

Coordinate systems	Element sets
Mean of 1950.0	Cartesian
Geographic rotating	
True of date	Spherical polar
Geographic inertial	Keplerian

The coordinate systems have been specified in section 3.4.2; the element sets are defined below.

Cartesian elements

The Cartesian elements x, y, z, $\dot{x}$, $\dot{y}$, and $\dot{z}$ are the components of the state vector $\vec{r}$, $\vec{v}$ of the vehicle at time t in the requested output coordinate system, with $\vec{r}$ and $\vec{v}$ represented by the column vectors.

$$\bar{r} = (x, y, z)^T$$

$$\bar{v} = (\dot{x}, \dot{y}, \dot{z})^T$$

The output elements are denoted X, Y, Z, XD, YD, and ZD.

Spherical elements

The spherical elements ALF, DLT, BTA, AZ, R, and V are determined from the state vector $\vec{r}$, $\vec{v}$ at time t as follows.

ALF is the right ascension of the vehicle measured from the x-axis in the i^{th} coordinate system.

$$ALF = \tan^{-1}\left(\frac{y}{x}\right) ; \; 0° \le ALF < 360°$$

DLT is the declination of the vehicle.

$$DLT = \tan^{-1}\left[\frac{z}{(x^2 + y^2)^{1/2}}\right] ; \; -90° \le DLT \le 90°$$

BTA is the vertical flightpath angle measured from the local vertical to the velocity vector $\vec{v}$.

$$BTA = \cos^{-1}\left(\frac{\vec{r}\cdot\vec{v}}{rv}\right) ; \; 0° \leq BTA \leq 180°$$

where $r = |\bar{r}|$ and $v = |\bar{v}|$.

AZ is the azimuth of the velocity vector measured clockwise from the projection of the reference z-axis to the projection of the velocity vector in a plane normal to the local vertical.

$$AZ = \tan^{-1}\left(\frac{x\dot{y} - y\dot{x}}{r\dot{z} - z\dot{r}}\right) ; \; 0° \leq AZ < 360°$$

where

$$\dot{r} = \frac{\vec{r}\cdot\vec{v}}{r}$$

R is the magnitude of the position vector $\vec{r}$.

$$R = \left(x^2 + y^2 + z^2\right)^{1/2}$$

V is the magnitude of the velocity vector $\vec{v}$.

$$V = \left(\dot{x}^2 + \dot{y}^2 + \dot{z}^2\right)^{1/2}$$

<u>Keplerian elements</u>

The Keplerian elements SMA, ECC, INC, NOD, OMG, and TA are determined from the state vector $\vec{r}$, $\vec{v}$ of the vehicle at the time t as follows.

SMA is the semimajor axis of the orbit.

$$\text{SMA} = \frac{\mu r}{2\mu - rv^2} \qquad \begin{array}{l} a > 0, \text{ elliptical orbit} \\ a < 0, \text{ hyperbolic orbit} \\ a = 0, \text{ parabolic orbit} \end{array}$$

where

$$\mu = \text{gravitational parameter of the Earth}$$

ECC is the eccentricity of the orbit.

$$\text{ECC} = (1 - p/a)^{1/2} \qquad \begin{array}{r l} 0 \leq & \text{ECC} < 1, \text{ elliptical} \\ & \text{ECC} < 1, \text{ hyperbolic orbit} \\ & \text{ECC} = 1, \text{ parabolic orbit} \end{array}$$

where

$$p = \frac{r^2 v^2 - (\bar{r} \cdot \bar{v})^2}{\mu}$$

INC is the inclination of the orbit plane with respect to the x-y plane in the i^{th} coordinate system.

$$\text{INC} = \tan^{-1} \left\{ \frac{\left[(y\dot{z} - z\dot{y})^2 + (z\dot{x} - x\dot{z})^2\right]^{1/2}}{(x\dot{y} - y\dot{x})} \right\} ; \; 0^\circ \leq \text{INC} < 180^\circ$$

NOD is the longitude of the ascending node measured in the x-y plane from the x-axis in the i^{th} coordinate system.

$$NOD = \tan^{-1}\left[\frac{y\dot{z} - z\dot{y}}{-(z\dot{x} - x\dot{z})}\right] \; ; \; 0 \leq NOD < 360^{\circ}$$

OMG is the argument of perifocus measured in the orbit plane from the ascending node to the point of closest approach.

$$OMG = \tan^{-1}\left[\frac{(\mu p)^{1/2} \; z}{y(y\dot{z} - z\dot{y}) - x(z\dot{x} - x\dot{z})}\right] - \nu \; ; \; 0^{\circ} \leq OMG < 360^{\circ}$$

where

$$\nu = \text{true anomaly}$$

TA is the true anomaly measured in the orbit plane from the point of closest approac . to the vehicle's position in the orbit.

$$TA = \tan^{-1}\left[\frac{(\vec{r}\cdot\vec{v})(\mu p)^{1/2}}{(\mu p - \mu r)}\right] ; \; 0^{\circ} \leq TA < 360^{\circ}$$

4.4.1.3 Vehicle-attitude-related parameters: The vehicle-attitude-related parameters are specified as follows.

1. RF(REFSMMAT) - A 3 × 3 matrix that relates the orientation of the IMU stable member axes system to the mean of 1950 coordinate system. This matrix is available by means of card input.

2. CDUX, CDUY, CDUZ - The inner, middle, and outer gimbal angles that relate the vehicle navigation base coordinate system to the IMU stable member axes system. These angles are available by means of tape input.

3. GIMB - Gimbal data quality flag that denotes the status of the parameters CDUX, CDUY, and CDUZ.

$$GIMB = \begin{cases} 0 & \text{Good data} \\ 1 & \text{Interpolated data} \\ 2 & \text{No data} \\ 3 & \text{Bad data} \\ 4 & \text{Premission attitude reference data (MA-048 only)} \end{cases}$$

This flag is available through tape input. When no gimbal data are available or the data are bad, the value of all attitude, pointing, and FOV parameters is

0.77777770+7. For the MA-136 experiment, a value of 0.88888888+8 for the geodetic location of an FOV corner point(s) or the principle point indicates that the associated line-of-sight is "above the horizon." If this is the case, then any other parameter that depends on the principle point or the FOV corner point(s) will be set equal to 0.88888888+8.

4.4.1.4 Miscellaneous support parameters: The miscellaneous parameters that are to be computed are described below.

Sun angles

The Sun angles are defined to be the azimuth and elevation of the vector from the subvehicle point to the Sun ($\bar{r}'_{10}$) with respect to the UEN coordinate system.

$$\bar{r}'_{10} = C(WT\bar{r}_{s1} - \bar{r}'_4)$$

$$SEL10 = \tan^{-1}\left[x'_{10}/(y'^{2}_{10} + z'^{2}_{10})^{1/2}\right] \; ; \; -90^\circ \leq SEL10 \leq 90^\circ$$

$$SAZ10 = \tan^{-1}\left(y'_{10}/z'_{10}\right) \; ; \; 0^\circ \leq SAZ10 < 360^\circ$$

$$\bar{r}'_4 = \text{subvehicle vector} = (r_a \cos\lambda \cos\phi,\ r_a \sin\lambda \cos\phi,\ r_a \sin\phi)^T$$

$$r_a = \bar{r}_{v4} - ALT$$

Subvehicle point

The subvehicle location is defined as follows.

LAT is the geodetic latitude of the vehicle defined by the projection of the vehicle's position perpendicular to the reference ellipsoid.

$$LAT = \tan^{-1}\left[\frac{z_4}{(x_4^2 + y_4^2)^{1/2}(1 - f)^2}\right] ; \; -90^\circ \leq LAT \leq 90^\circ$$

LON is the longitude of the vehicle.

$$LON = \tan^{-1}(y_4/x_4) \; ; \; 0^\circ \leq LON < 360^\circ$$

ALT is the altitude above the reference ellipsoid for the Earth.

$$ALT = r - \frac{a(1 - f)}{\left[1 - f(2 - f)\,\frac{x_4^2 + y_4^2}{r^2}\right]^{1/2}}$$

where

r = magnitude of the position vector of the vehicle

$f = 1 - b/a$, flattening of the Earth

a = semimajor axis of the Earth's reference ellipsoid

b = semiminor axis of the Earth's reference ellipsoid

x_4, y_4, z_4 = geographic inertial Cartesian position coordinates of the vehicle

Greenwich hour angle

The angle between the vernal equinox and the Greenwich meridian in the true of date coordinates at midnight of base day is available through tape input.

Sun position and velocity

The Cartesian coordinates of the Sun with respect to the Earth (XS1, YS1, ZS1, XDS1, YDS1, and ZDS1) in the mean of 1950.0 are available through tape input.

Coordinate transformations

Two required coordinate transformations that are computed by the HOPE program and that are available through tape input are as follows.

T - Mean of 1950.0 to true of date transformation (3 × 3 matrix).

E - Mean of 1950.0 to ecliptic mean of 1950.0 transformation (3 × 3 matrix).

Rev. number

The revolution number of the vehicle is computed with reference to the launch longitude.

$$REV = REVI + n$$

where REVI (integer) is the initial rev. number input by card and n is the number of times the vehicle has passed the launch longitude since REVI (not to be confused with orbit number, which is based on ascending node crossings).

4.4.2 Experiment-specific support parameters.- The formulations for the experiment-specific parameters are discussed in the following order.

1. MA-007 - Stratospheric Aerosol Measurement
2. MA-048 - Soft X-Ray
3. MA-059 - UV Absorption
4. MA-083 - Extreme-UV Survey
5. MA-088 - Helium Glow
6. MA-106 - Light Flash
7. MA-107 - Biostack
8. MA-136 - Earth Observations

For a definition of each experiment-specific support parameter, refer to section 4.1.

The matrix F, the navigation base coordinate system to the nominal instrument base coordinate system transformation, is required for three experiments - MA-007, MA-083, and MA-136. The formulations for these experiment-specific matrices will be specified in the appropriate section. For all other experiments, F is assumed to be the identity matrix. It is also assumed that the matrix A, the nominal to actual instrument base transformation, is the identity matrix for all experiments unless other data are provided by the PI.

4.4.2.1 Support parameters for the stratospheric aerosol measurement experiment (MA-007): The additional support parameters for the stratospheric aerosol measurement experiment are defined below. Since the MA-007 experiment requires line-of-sight angular deviations, it is necessary to define the navigation base to nominal instrument base coordinate transformation F. The transformation F for MA-007 is defined as follows.

$$F = \begin{bmatrix} \hat{x}^T \\ \hat{y}^T \\ \hat{z}^T \end{bmatrix}$$

where

$$\hat{z} = (\cos\theta,\ \sin\theta\ \sin\phi,\ -\sin\theta\ \cos\phi)^T$$

$$\bar{y} = \hat{z} x\ (1,\ 0,\ 0)^T$$

$$\hat{y} = \bar{y}/|\bar{y}|$$

$$\hat{x} = \hat{y} \times \hat{z}$$

The nominal values for θ and ϕ are 57.5° and 58.9°, respectively. Refer to figure 4-2 for an illustration of the nominal instrument base coordinate system.

Sunrise/sunset time (SUNH, SUNM, and SUNS)

The vehicle, Earth, and Sun geometry associated with the sunrise/sunset calculation is depicted, on an exaggerated scale, in figure 4-3. The procedure is to test for the approximate conditions of sunrise/sunset (within 0.25 second) with the use of a mean radius of the Earth (r_{em}). The final calculation is based on the proper geodetic Earth radius, r_e. The effects of refraction will not be considered.

From the figure, the angles β and S_r can be approximated as follows.

$$\beta_m = \cos^{-1}(r_{em}/|\bar{r}_{vl}|)$$

$$\Delta S_r{}' = \tan^{-1}[(S_r - r_{em})/r_s]$$

S_r = radius of the Sun

r_{em} = mean radius of the Earth

r_s = mean distance to the Sun

where β_m is accurate to within 0.0164 degree and $\Delta S_r{}'$ is accurate to within 0.25×10^{-3} degree. The condition for sunrise or sunset is

$$\theta = \beta + \Delta S_r \doteq \beta_m + \Delta S_r{}'$$

Thus, when

$$\theta_i = \pi/2 - \cos^{-1}(-\hat{r}_{sl} \cdot \bar{r}_{vl}/|\bar{r}_{vl}|) \leq \theta \leq \theta_{i+1}$$

where

$\hat{r}_{sl} = \bar{r}_{sl}/|\bar{r}_{sl}|$

i = designates time t_i

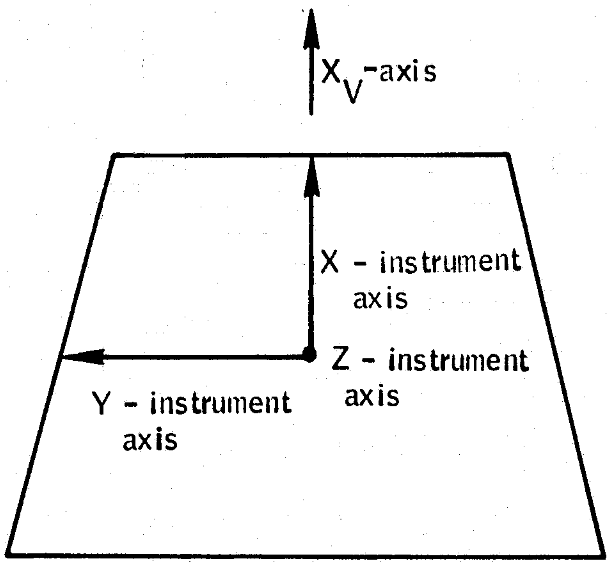


Figure 4-2.- MA-007 coordinate system for the right side window.

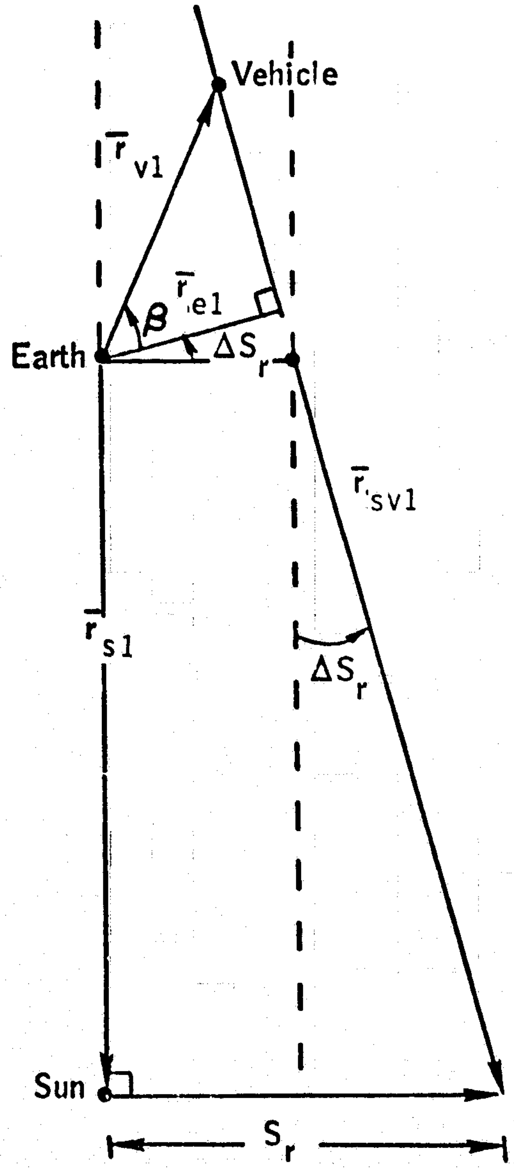


Figure 4-3.- Geometry for the sunrise and sunset computation.

then the sunset time may be calculated as follows.

$$t_s = t_{i+1} - \left(\theta_{i+1} - \theta\right) / \dot{\theta}_i$$

$$\dot{\theta}_i = \left(\theta_{i+1} - \theta_i\right) / \left(t_{i+1} - t_i\right)$$

$$\theta = \beta + \Delta S_r$$

$$\beta = \cos^{-1} \left[r_e / |\bar{r}_{v1} \, (t_{i+1})| \right]$$

$$\Delta S_r = \tan^{-1} \left[(S_r - r_e) / |\bar{r}_{s1}(t_{i+1})| \right]$$

where r_e is computed as presented below.

In a similar manner, the sunrise time may be computed as

$$t_s = t_{i+1} - \left(\theta_{i+1} - \theta\right) / \dot{\theta}_i$$

where

$$\theta_{i+1} \leq \theta \leq \theta_i$$

The geodetic radius r_e may be computed in the following manner.

$$\hat{r}_{s1} = \bar{r}_{s1} / |\bar{r}_{s1}|$$

$$\hat{r}_{v1} = \bar{r}_{v1} / |\bar{r}_{v1}|$$

$$\hat{n}_s = \hat{r}_{s1} \times \hat{r}_{v1} / \, |\hat{r}_{s1} \times \hat{r}_{v1}|$$

$$\hat{n}_r = \hat{n}_s \times \hat{r}_{s1}$$

$$S_r{}^* = \begin{cases} -S_r \text{ if } \hat{r}_{v1} \cdot \hat{n}_r < 0 \\ \ \ S_r \text{ if } \hat{r}_{v1} \cdot \hat{n}_r > 0 \end{cases}$$

$$\bar{r}_{sv1} = \bar{r}_{s1} + S_r{}^* \hat{n}_r - \bar{r}_{v1}$$

$$\hat{r}_{sv1} = \bar{r}_{sv1}/|\bar{r}_{sv1}|$$

$$\hat{r}_{e1} = \bar{r}_e/|\bar{r}_e| = \hat{n}_s \times \hat{r}_{sv1} \; [\text{SIGN } (S_r{*})]$$

$$\hat{r}_{e4} = WT \; \hat{r}_{e1}$$

If $\hat{r}_{e4}$ is given, the geodetic radius may be computed directly.

$$r_e = \frac{a_e(1 - f)}{[1 - f(2 - f)\;(x^2 + y^2)]^{1/2}}$$

where

a_e = Earth's equatorial radius

f = Earth's flattening

$\hat{r}_{e4} = (x, y, z)^T$

<u>Sunrise/sunset flag (SUNF)</u>

A flag to denote whether the listed time is associated with the vehicle sunrise time or the vehicle sunset time is included in the parameter list. The flag will be defined as follows.

$$\text{SUNF} = \begin{cases} 0 & \text{Not being used} \\ 1 & \text{Sunrise} \\ 2 & \text{Sunset} \end{cases}$$

<u>Line-of-sight angular deviations (XANG and YANG)</u>

The computations for the required angles are as follows.

$$\bar{r}_{vs1} = \bar{r}_{s1} - \bar{r}_{v1}$$

$$\hat{r}_{vs1} = \bar{r}_{vs1}/|\bar{r}_{vs1}|$$

$$\hat{r}_{vs9} = \text{AFGDR } \hat{r}_{vs1}$$

$$\text{XANG} = \tan^{-1}\left(\hat{x}_{vs9}/|\hat{z}_{vs9}|\right) \quad ; -90^{\circ} \leq \text{XANG} \leq 90^{\circ}$$

$$\text{YANG} = \tan^{-1}\left(\hat{y}_{vs9}/|\hat{z}_{vs9}|\right) \quad ; -90^{\circ} \leq \text{YANG} \leq 90^{\circ}$$

4.4.2.2 Support parameters for the soft X-ray experiment (MA-048): The additional support parameters for the soft X-ray experiment are identical to those of the extreme-UV survey experiment. The only exception is that MA-048 does not require any field-of-view computations. Refer to section 4.4.2.4 for a detailed definition of the parameters.

4.4.2.3 Support parameters for the UV absorption experiment (MA-059): In the nominal mode of operation, only one parameter (THETA) will be computed in support of the UV absorption experiment. In addition, other parameters will be obtained from the reconstruction of the relative trajectory (Apollo vs. Soyuz) with use of the HOPE orbit determination program, on the basis of available relative tracking data. Special purpose utility programs will be used to merge THETA with the HOPE derived parameters d and γ, where d is the relative distance between the CSM and the Soyuz and γ is the angle between the relative position vector and the CSM velocity vector. Figure 4-4 illustrates these parameters.

THETA

The parameter THETA is computed as follows.

$$\bar{x}_x = R^T D^T G^T \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$\text{THETA} = 90^{\circ} - \cos^{-1}\left(\frac{\bar{x}_x \cdot \bar{v}_{v1}}{|\bar{x}_x| \; |\bar{v}_{v1}|}\right); \; -90^{\circ} \leq \text{THETA} \leq 90^{\circ}$$

4.4.2.4 Support parameters for the extreme-UV survey experiment (MA-083): The additional support parameters that are required to support the extreme-UV survey are specified below. These parameters also pertain to the MA-048 and MA-088 experiments.

Since the MA-083 and MA-088 experiments require field-of-view computations, it is necessary to define the navigation base to nominal instrument base coordinate transformation F. The required transformation is defined as follows.

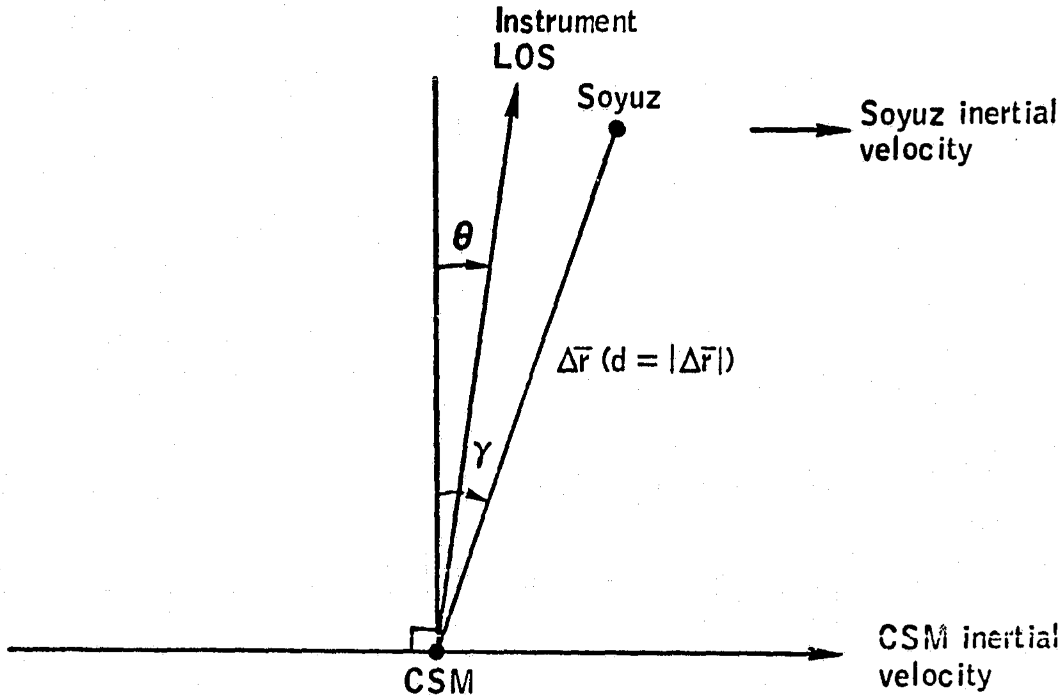


Figure 4-4.- MA-059 support parameters.

$$F = \begin{bmatrix} \hat{x}^T \\ \hat{y}^T \\ \hat{z}^T \end{bmatrix}$$

where

$$\hat{z} = (\cos\theta,\ \sin\theta\ \sin\phi,\ -\sin\theta\ \cos\phi)^T$$

$$\bar{y} = \hat{z} \times (1,\ 0,\ 0)^T$$

$$\hat{y} = \bar{y}/|\bar{y}|$$

$$\hat{x} = \hat{y} \times \hat{z}$$

The nominal values for θ and ϕ are 90.0° and 37.75°, respectively.

Geomagnetic position

The geomagnetic position vector (designated X11, Y11, and Z11) is computed as follows.

$$\bar{r}_{v11} = B\ \bar{r}_{v4}$$

SCSA

The angle between the Earth-centered spacecraft position vector and the Earth-Sun vector, SCSA, is computed in the following manner.

$$\theta = \cos^{-1}\left(\frac{\bar{r}_{s1}\cdot\bar{r}_{v1}}{|\bar{r}_{s1}|\ |\bar{r}_{v1}|}\right)$$

$$\hat{n} = \bar{r}_{s1} \times \bar{r}_{v1}/|\bar{r}_{s1} \times \bar{r}_{v1}|$$

$$\hat{s} = \hat{n} \times \hat{r}_{s1},\ \text{where}\ \hat{r}_{s1} = \bar{r}_{s1}/|\bar{r}_{s1}|$$

$$SCSA = \begin{cases} \theta & \text{if}\ \hat{s}\cdot\bar{r}_{v1} \geq 0 \\ -\theta & \text{if}\ \hat{s}\cdot\bar{r}_{v1} < 0 \end{cases} ;\ -180^\circ \leq SCSA < 180^\circ$$

ALF2 and DLT2

The right ascension and declination of the vehicle in the ecliptic mean of 1950.0 system is specified as follows.

$$\bar{r}_{v2} = E\,\bar{r}_{v1}$$

$$ALF2 = \tan^{-1}(y_{v2}/x_{v2}) \;;\; 0^\circ \leq ALF2 < 360^\circ$$

$$DLT2 = \sin^{-1}(z_{v2}/|\bar{r}_{v2}|) \;;\; -90^\circ \leq DLT2 \leq 90^\circ$$

LOS and FOV orientation angles

The computation of the instrument line-of-sight and field-of-view orientation angles is specified below for the following coordinate systems.

1. Mean of 1950.0

2. Ecliptic mean of 1950.0

3. Up, east, north

Note that the instrument alinement corrections are applied to the part 1 computations and the FOV computations.

1. $$\bar{x}_{n1} = R^T D^T G^T F^T A^T \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$L1RHA1 = \tan^{-1}(y_{n1}/x_{n1}) \qquad 0^\circ \leq L1RHA1 < 360^\circ$$

$$L1DEC1 = \sin^{-1}(z_{n1}) \qquad -90^\circ \leq L1DEC1 \leq 90^\circ$$

$$L1AR1 = L1RHA1 + \Delta A1 \qquad 0^\circ \leq L1AR1 < 360^\circ$$

$$L1AD1 = L1DEC1 + \Delta D1 \qquad -90^\circ \leq L1AD1 \leq 90^\circ$$

where $\Delta A1$ and $\Delta D1$ are the alinement corrections.

For the field-of-view computations, replace the $[0, 0, 1]^T$ vector with the MA-083 field-of-view pointing vectors ($\bar{x}_{A9}$, $\bar{x}_{B9}$, $\bar{x}_{C9}$, $\bar{x}_{D9}$) or the corresponding MA-088 field-of-view pointing vectors, and compute

F3RHA1, F3DCA1 - right ascension and declination for the "A" quadrant for MA-083

F3RHB1, F3DCB1 - right ascension and declination for the "B" quadrant for MA-083

.
.
.

F8RHD1, F8DCD1 - right ascension and declination for the "D" quadrant for MA-088

with the alinement corrections included in the computations. The essential difference between the MA-083 FOV and the MA-088 FOV is the angular width, 2 degrees versus 15 degrees, respectively.

2. $\bar{x}_{n2} = E\,\bar{x}_{n1}$

$L1RHA2 = \tan^{-1}(y_{n2}/x_{n2})$ $\qquad 0^\circ \leq L1RHA2 < 360^\circ$

$L1DEC2 = \sin^{-1}(z_{n2})$ $\qquad -90^\circ \leq L1DEC2 \leq 90^\circ$

3. $\bar{x}_{n10} = CWT\,\bar{x}_{n1}$

$L1AZ = \tan^{-1}(y_{n10}/z_{n10})$ $\qquad 0^\circ \leq L1AZ < 360^\circ$

$L1EL = \sin^{-1}(x_{n10})$ $\qquad -90^\circ \leq L1EL \leq 90^\circ$

Vehicle velocity orientation angles

The computation of the vehicle velocity orientation angles for the following coordinate systems are described below.

1. Mean of 1950.0

$VRHA1 = \tan^{-1}(\dot{y}_{v1}/\dot{x}_{v1})$ $\qquad 0^\circ \leq VRHA1 \leq 360^\circ$

$VDEC1 = \sin^{-1}(\dot{z}_{v1}/|\bar{v}_{v1}|)$ $\qquad -90^\circ \leq VDEC1 \leq 90^\circ$

2. Ecliptic mean of 1950.0

$\bar{v}_{v2} = E\,\bar{v}_{v1}$

$VRHA2 = \tan^{-1}(\dot{y}_{v2}/\dot{x}_{v2})$ $\qquad 0^\circ \leq VRHA2 < 360^\circ$

$VDEC2 = \sin^{-1}(\dot{z}_{v2}/|\bar{v}_{v2}|)$ $\qquad -90^\circ \leq VDEC2 \leq 90^\circ$

LONS2

The computation of the longitude of the Sun in the ecliptic mean of 1950.0 coordinate system is as follows.

$$\bar{r}_{s2} = E\ \bar{r}_{s1}$$

$$LONS2 = \tan^{-1}(y_{s2}/x_{s2}) \ ; \ 0^{o} \leq LONS2 < 360^{o}$$

VLOS

The angle between the vehicle velocity vector and the instrument line-of-sight is computed as follows.

$$VLOS = \cos^{-1}\left[\frac{\left(\bar{v}_{v1}\right)\cdot\left(\bar{x}_{n1}\right)}{|\bar{v}_{v1}|\ |\bar{x}_{n1}|}\right] \ ; \ 0 \leq VLOS \leq 180^{o}$$

ESLOS AND ESLOSS

The angle between the Earth-Sun line and the instrument line-of-sight is computed in the following manner.

$$ESLOS = \cos^{-1}\left[\frac{\left(\bar{r}_{s1}\right)\cdot\left(\bar{x}_{n1}\right)}{|\bar{r}_{s1}|\ |\bar{x}_{n1}|}\right] \ ; \ 0^{o} \leq ESLOS \leq 180^{o}$$

$$ESLOSS = 180^{o} - ESLOS$$

4.4.2.5 Support parameters for the helium glow experiment (MA-088): The support parameters for the helium glow experiment are identical to those for the UV survey experiment (MA-083). A detailed definition of the support parameters is presented in the preceding section.

4.4.2.6 Support parameters for the light flash experiment (MA-106): The additional parameters that are required to support the light flash experiment are presented below.

ALPH10, BETA10, and PHI10

The orientation angles for the vehicle body axes with respect to the UEN coordinate system are computed as follows.

$$\bar{x}_7 = GDR\ T^T W^T C^T\ \bar{x}_{10}$$

$$\bar{x}_7 = Y\bar{x}_{10} = (y_{ij})\bar{x}_{10}$$

$$ALPH10 = \tan^{-1}(y_{12}/y_{13});\ 0° \leq ALPH10 < 360°$$

$$BETA10 = \cos^{-1}(y_{11});\ 0° \leq BETA10 \leq 180°$$

$$PHI10 = \tan^{-1}(-y_{21}/-y_{31});\ 0° \leq PHI10 < 360°$$

where ALPH10, BETA10, and PHI10 are illustrated in figure 4-5.

BMAG and LMAG

The magnitudes of the intensity of the Earth's magnetic field and the "L-shell" radius are computed as a function of vehicle position with the use of the NASA/GSFC subroutines described in reference 9. The actual spherical harmonic coefficients that will be used to compute the geomagnetic field are designated as GSFC/65 in the above-referenced document. This model has been used in past programs to support experiments such as S-230 (Skylab).

4.4.2.7 Support parameters for the biostack experiment (MA-107): The additional parameters that are required to support the biostack experiment are the magnitude of the geomagnetic field intensity and the "L-shell" radius. The compuatations of these two parameters are discussed in the preceding section.

4.4.2.8 Support parameters for the Earth observations experiment (MA-136): The additional parameters required to support the Earth observations experiment are similar to those provided for Apollo except that the reference body is the Earth instead of the Moon. Also, the parameter list will be expanded to provide some parameters that were not computed for Apollo support. The required formulations for all parameters are presented below.

The transformation F' for MA-136 is defined as

$$F' = VAF$$

$$F = \begin{bmatrix} \hat{x}^T \\ \hat{y}^T \\ \hat{z}^T \end{bmatrix}$$

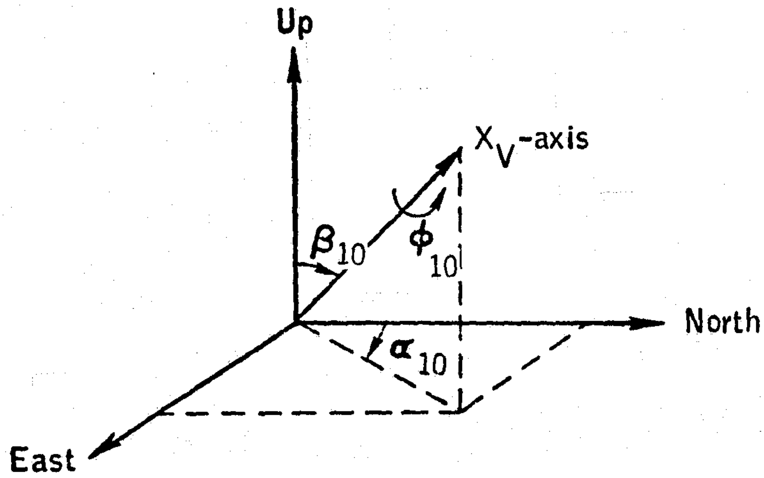


Figure 4-5.- MA-106 support parameters.

where

$$\hat{z} = (-\cos\theta, -\sin\theta\sin\phi, \sin\theta\cos\phi)^T$$

$$\bar{v} = \hat{z} \times (1, 0, 0)^T$$

$$\hat{y} = \bar{y}/|\bar{y}|$$

$$\hat{x} = \hat{y} \times \hat{z}$$

and where $\theta = 57.5°$ and $\phi = 58.9°$.

The transformation V orients the camera $\dot{x}$-axis to within $\pm 45°$ of the vehicle velocity vector; V is specified below.

$$V = \begin{bmatrix} \cos(-n\pi/2) & \sin(-n\pi/2) & 0 \\ -\sin(-n\pi/2) & \cos(-n\pi/2) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

where

$$n = k \text{ if } -\pi/4 + k\pi/2 < \beta \leq \pi/4 + k\pi/2 \text{ for } k = 0, 1, 2, \text{ and } 3$$

and where

$$\beta = \tan^{-1}(v_{yo}/v_{xo})$$

$$\bar{v}_{v9} = AFGDR\bar{v}_{v1}$$

See figure 4-6 for an illustration of the nominal instrument base coordinate system.

Principal point and FOV footprint

The computation of the principal point and the field-of-view intersection points is presented below.

$$\bar{x}_{i4} = WT\,R^T D^T G^T F'^T \bar{x}_{i9};\ i = A, B, C, D, n$$

where A, B, C, and D designate the FOV and n designates the principal point. Compute $\bar{r}_{n4}$, $\bar{r}_{A4}$, $\bar{r}_{B4}$, $\bar{r}_{C4}$, and $\bar{r}_{D4}$ by algorithm 1.

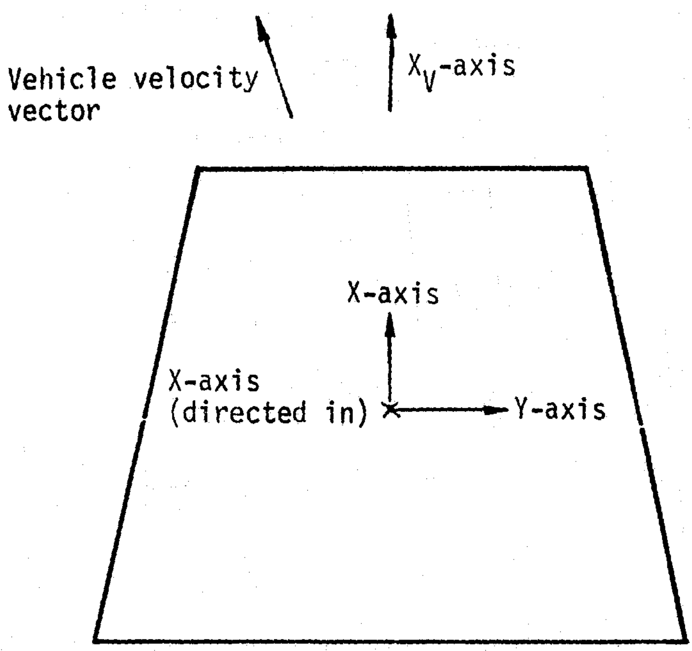


Figure 4-6.- MA-136 camera coordinate system (CM right side window).

$$LAT_i = \tan^{-1}\left\{ z_{i4}/\left[(x_{i4}{}^2 + y_{i4}{}^2)^{1/2}\ (1 - f)^2\right]\right\} \quad ; -90^\circ \leq LAT_i \leq 90^\circ$$

$$LON_i = \tan^{-1}(y_{i4}/x_{i4});\ 0^\circ \leq LON_i < 360^\circ$$

Algorithm 1

Let

$\bar{r}$ = principal point or FOV intersection vector with respect to origin

$\bar{r}_v$ = position of the vehicle

$\bar{x}_i$ = instrument pointing vector (unit vector)

d = magnitude of instrument pointing vector

where all vectors are with respect to the geographic inertial coordinate system. Now

$$\bar{r} = \bar{r}_v + d\bar{x}_i$$

$$f(\bar{r}) = \frac{x^2}{a^2} + \frac{y^2}{a^2} + \frac{z^2}{b^2} = 1$$

Given an initial estimate d, denoted by $d_o = r_v \cos\ \alpha - \sqrt{r^2 - r_v^2 \sin^2\alpha}$,

where

r = geodetic radius of the Earth at the subvehicle point

r_v = magnitude of $\bar{r}_v$

α = angle between $\bar{x}_i$ and $-\bar{r}_v$

compute

$$\bar{r}_o = \bar{r}_v + d_o\bar{x}_i$$

$$f(\bar{r}_o) = k_o$$

To estimate d,

$$f(\bar{r}) - f(\bar{r}_o) = 1 - k_o = \frac{\partial f}{\partial \bar{r}_o} \frac{\partial \bar{r}_o}{\partial d} \delta d = m\delta d$$

$$d = d_o + \delta d$$

where

$$\frac{\partial f}{\partial \bar{r}_o} = \left(\frac{2x_o}{a^2}, \frac{2y_o}{a^2}, \frac{2z_o}{b^2} \right)$$

$$\frac{\partial \bar{r}_o}{\partial d} = \bar{x}_i$$

$$\delta d = (1 - k_o)/m$$

Repeat the process until $\left| 1 - k_i \right| < \varepsilon$. Set $\bar{r} = \bar{r}_i$.

Slant range (SR)

The slant range SR is a by-product of algorithm 1; that is,

$$SR = d$$

Scale factor (SF)

The scale factor is computed as follows.

$$SF = f/h$$

where h is the geodetic altitude of the vehicle and f is the focal length of the camera lens.

Focal length (FL)

The camera focal length is available by card input as a function of time.

Altitude rate (ALTR) and horizontal velocity (HV)

The altitude rate and the horizontal velocity with respect to the UEN coordinate system associated with the principal point are defined as follows.

$$\bar{v}_{v10} = C_p WT\, \bar{v}_{v1}$$

$$HV = \left(v_{y10}^{\;2} + v_{z10}^{\;2}\right)^{1/2}$$

$$ALTR = v_{x10}$$

where C_p designates the UEN system associated with the principal point. Figure 4-7 illustrates these parameters.

TILT and TILTAZ

These parameters are computed as follows.

$$\bar{x}_{n10} = C_v WTR^T D^T G^T F'^T \begin{bmatrix} 0 \\ 0 \\ -1 \end{bmatrix}$$

$$TILT = \cos^{-1}(-x_{n10});\ 0° \leq TILT \leq 180°$$

$$TILTAZ = \tan^{-1}(y_{n10}/z_{n10});\ 0° \leq TILTAZ < 360°$$

where C_v designates the UEN system associated with the vehicle. Figure 4-8 illustrates these parameters.

SELP and SAZP

The Sun azimuth and Sun elevation with respect to the principal point are specified as follows.

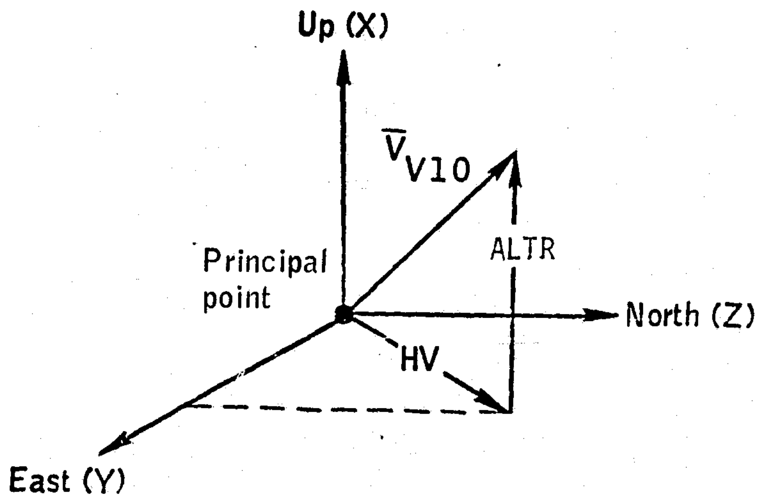
$$r_{s10} = c_p WT\, \bar{r}_{s1}$$

$$\bar{r}_{ps10} = \bar{r}_{s10} - \bar{r}_{p10}$$

$$SELP = \sin^{-1}\left(x_{ps10}/\left|r_{ps10}\right|\right);\ -90° \leq SELP \leq 90°$$

$$SAZP = \tan^{-1}(y_{ps10}/z_{ps10});\ 0° \leq SAZP < 360°$$

where C_p designates the UEN system associated with the principal point. See figure 4-9, which illustrates the output parameters.



$\bar{V}$ - inertial velocity of the vehicle

Figure 4-7.- ALTR and HV parameters.

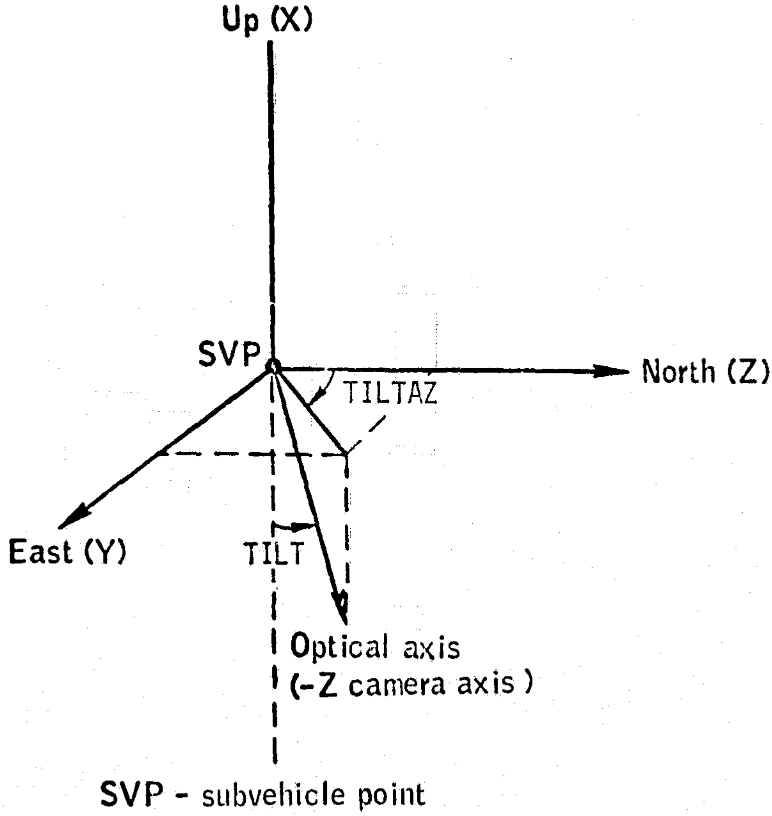


Figure 4-8 .- Tilt and tilt azimuth.

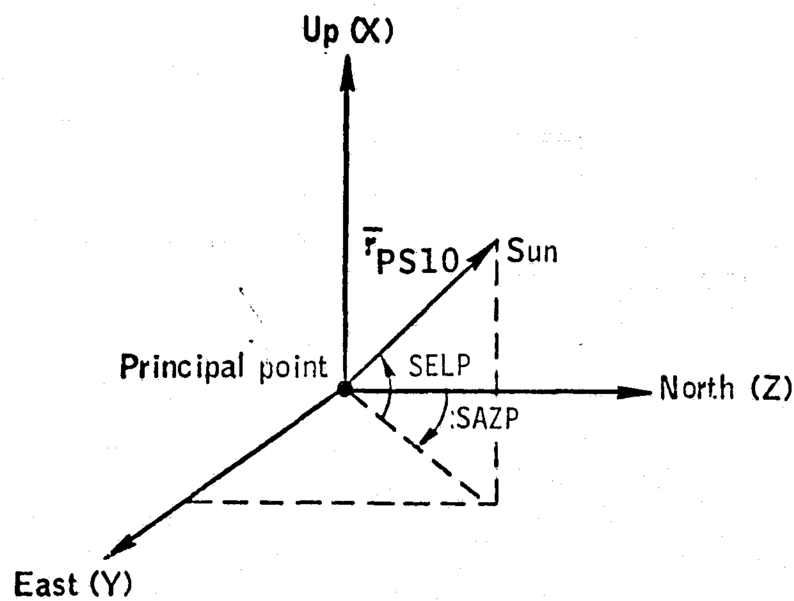


Figure 4-9.- Sun elevation and Sun azimuth.

LATS and LONS

The geodetic latitude and longitude of the subsolar point are computed as follows.

$$\bar{r}_{s4} = WT\ \bar{r}_{s1}$$

$$LATS = \tan^{-1}\left\{ z_{s4}/[(x_{s4}^{\ 2} + y_{s4}^{\ 2})^{1/2}\ (1 - f)^2] \right\};\ -90^\circ \leq LATS \leq 90^\circ$$

$$LONS = \tan^{-1}(y_{s4}/x_{s4})\ ;\ 0^\circ \leq LONS < 360^\circ$$

These parameters are illustrated in figure 4-10.

EMISS, NDA, and SWING angles

These parameters are specified as follows.

$$\bar{r}_{u9} = F'GDPT^T W^T C_P^{\ T} \begin{bmatrix} -1 \\ 0 \\ 0 \end{bmatrix}$$

$$EMISS = \cos^{-1}(-z_{u9}/|r_{u9}|);\ 0^\circ \leq EMISS \leq 180^\circ$$

$$\bar{r}_{n9} = F'GDPT^T W^T C_P^{\ T} \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$NDA = \tan^{-1}(y_{n9}/x_{n9});\ 0^\circ \leq NDA < 360^\circ$$

$$\bar{r}_{u9} = F'GDPT^T W^T C_V^{\ T} \begin{bmatrix} -1 \\ 0 \\ 0 \end{bmatrix}$$

$$SWING = \tan^{-1}(x_{u9}/y_{u9});\ 0^\circ \leq SWING < 360^\circ$$

where C_p and C_v designate the UEN systems associated with the principal point and the vehicle, respectively. Figures 4-11 through 4-13 depict these parameters.

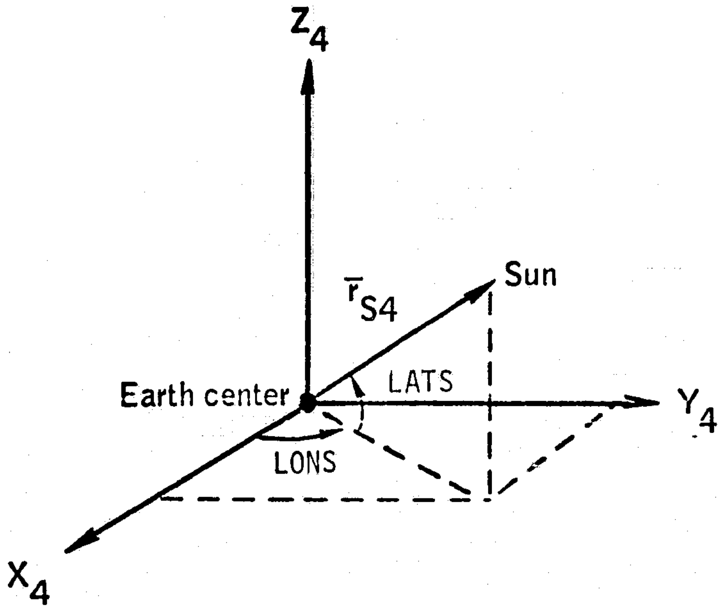
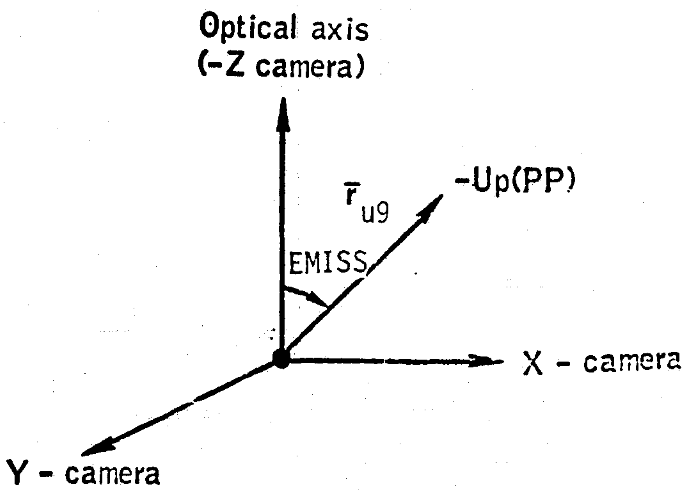


Figure 4-10.- Subsolar point.



PP - principal point

Figure 4-11.- Emission angle.

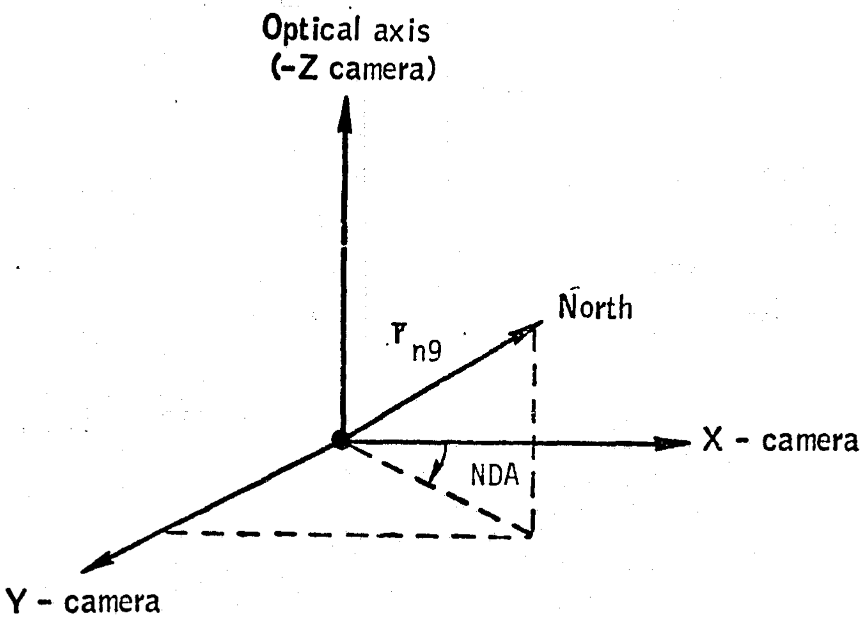
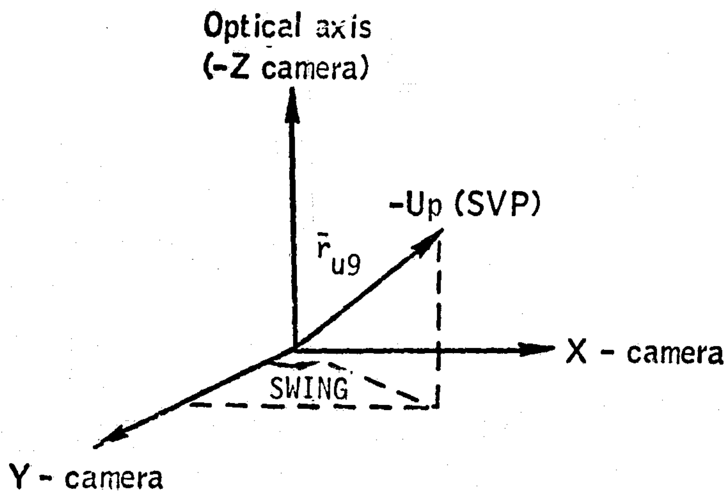


Figure 4-12.- North deviation angle.



SVP - subvehicle point

Figure 4-13.- Swing angle.

PHASE

The Sun phase angle is defined below.

$$\bar{r}_{s4} = WT\ \bar{r}_{s1}$$

$$\bar{r}_{ps4} = \bar{r}_{s4} - \bar{r}_{p4}$$

$$PHASE = \cos^{-1}\left(\frac{-\bar{r}_{ps4} \cdot \bar{x}_{n4}}{\left|\bar{r}_{ps4}\right| \left|\bar{x}_{n4}\right|}\right);\ 0° \leq PHASE \leq 180°$$

Figure 4-14 illustrates this parameter.

XTILT, YTILT, and HEAD angles

The specification of the XTILT, YTILT, and HEAD angles is presented below. Refer to figure 4-15, which depicts these parameters.

$$\bar{x}_{x10} = C_v WTR^T D^T G^T F'^T \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$YTILT = \sin^{-1}(x_{x10});\ -90° \leq YTILT \leq 90°$$

$$HEAD = \tan^{-1}(y_{x10}/z_{x10});\ 0° \leq HEAD < 360°$$

$$\bar{x}_{y10} = C_v WTR^T D^T G^T F'^T \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

$$XTILT = \sin^{-1}(x_{y10});\ -90° \leq TILT \leq 90°$$

where C_v designates the UEN system associated with the vehicle.

Camera orientation angles

The camera orientation (PHI, KAPPA, and OMEGA) angles with respect to the UEN coordinate system are computed as follows.

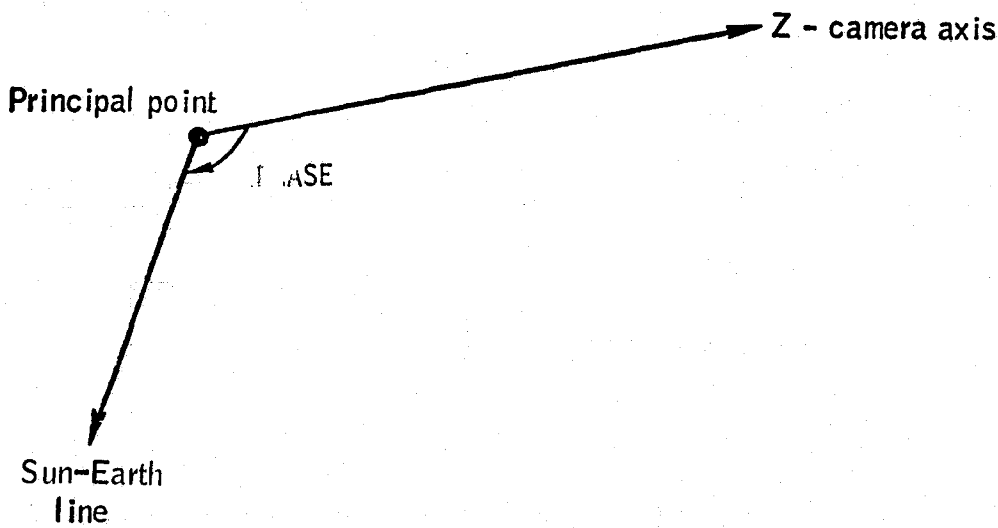
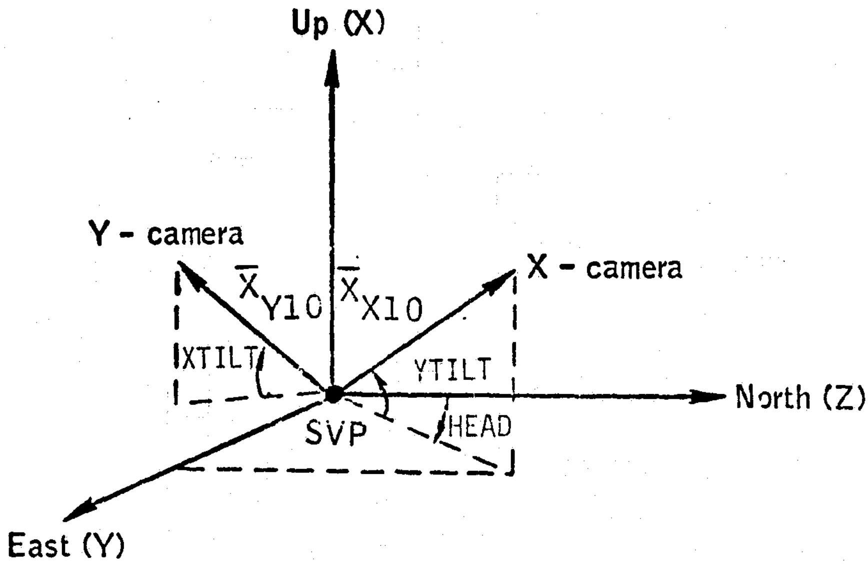


Figure 4-14.- PHASE angle.



SVP - subvehicle point

Figure 4-15.- XTILT, YTILT, and HEAD angles.

$$M = F'GDRT^T W^T C_v^{\,T} \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} = (m_{ij})$$

$$PHI = \tan^{-1}(m_{13}/m_{33}) \; ; \; 0^\circ \leq PHI < 360^\circ$$

$$KAPPA = \sin^{-1}(-m_{23}) \; ; \; -90^\circ \leq KAPPA \leq 90^\circ$$

$$OMEGA = \tan^{-1}(m_{21}/m_{22}) \; ; \; 0^\circ \leq OMEGA < 360^\circ$$

where C_v designates the UEN system associated with the vehicle.

LOSX, LOSY, and LOSZ

The direction cosines for the vector from the spacecraft to the principal intersection point in the geographic system are computed in the following manner.

$$LOSX = \hat{x}_{n4} \cdot \hat{x}$$

$$LOSY = \hat{x}_{n4} \cdot \hat{y}$$

$$LOSZ = \hat{x}_{n4} \cdot \hat{z}$$

where $\hat{x}$, $\hat{y}$, and $\hat{z}$ are unit vectors in the geographic coordinate system.

GEOCAM and GEOUEN

The geographic to camera system transformation and the UEN (vehicle) to camera axis transformation are specified as follows.

$$GC = F'GDRT^T W^T$$

$$LH = F'GDRT^T W^T C_v^{\,T}$$

ALPHA angle

The ALPHA angle, depicted by figure 4-16, is computed in the following manner.

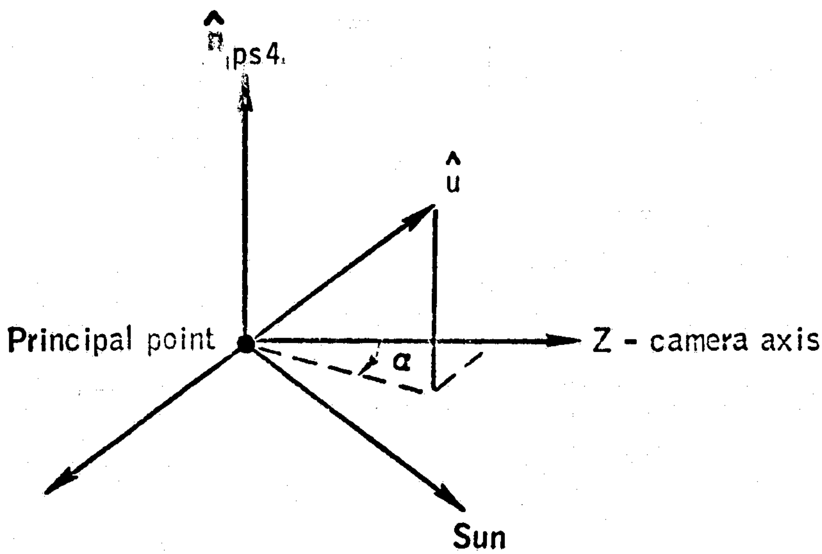


Figure 4-16.- ALPHA angle.

$$\bar{r}_{ps4} = WT\,\bar{r}_{s1} - \bar{r}_{p4}$$

$$\hat{x}_{n4} = \bar{x}_{n4}/|\bar{x}_{n4}|$$

$$\hat{r}_{ps4} = \bar{r}_{ps4}/|\bar{r}_{ps4}|$$

$$\bar{n}_{ps4} = \left(\hat{r}_{ps4} \times \hat{x}_{n4}\right)$$

$$\hat{n}_{ps4} = \bar{n}_{ps4}/|\bar{n}_{ps4}|$$

$$\hat{s}_4 = C_p^{\,T} \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}$$

$$\bar{t} = \hat{s}_4 - \left(\hat{n}_{ps4} \cdot \hat{s}_4\right) \hat{n}_{ps4}$$

$$\text{ALPHA} = \cos^{-1}\left[\left(-\hat{x}_{n4} \cdot \bar{t}\right)/|\bar{t}|\right] \;;\; 0^\circ \le \text{ALPHA} \le 180^\circ$$

Surface arc length (AL)

The surface distance between nadir and the principal point is computed in the following manner.

$$\hat{r}_{v4} = \bar{r}_{v4}/|\bar{r}_{v4}|$$

$$\hat{r}_{p4} = \bar{r}_{p4}/|\bar{r}_{p4}|$$

$$\theta = \cos^{-1}(\hat{r}_{v4} \cdot \hat{r}_{p4})$$

$$AL = r(\lambda, \phi)\theta$$

where $r(\lambda, \phi)$ is the geodetic radius at the nadir point. The surface arc length computation is illustrated in figure 4-17.

Forward overlap ratio (OVR)

The forward overlap ratio is computed as follows.

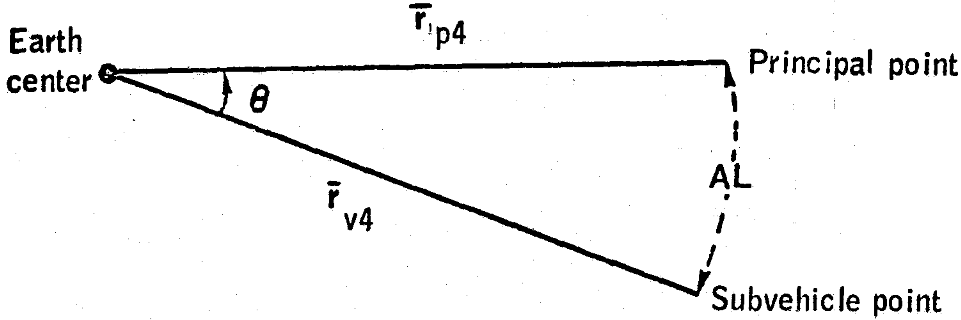


Figure 4-17.- Surface arc length.

$$\hat{r}_{c4}(t_i) = \bar{r}_{c4}(t_i)/|\bar{r}_{c4}(t_i)|$$

$$\hat{r}_{d4}(t_i) = \bar{r}_{d4}(t_i)/|\bar{r}_{d4}(t_i)|$$

$$\bar{n}(t_i) = \hat{r}_{c4}(t_i) \times \hat{r}_{d4}(t_i)$$

$$\hat{n}(t_i) = \bar{n}(t_i)/|\bar{n}(t_i)|$$

$$\bar{s} = \bar{r}_{c4}(t_{i+1}) - \left[\bar{r}_{c4}(t_{i+1})\cdot\hat{n}(t_i)\right]\hat{n}(t_i)$$

Compute the arc length between $\bar{s}$ and $\bar{r}_{d4}(t_i)$, AL_s, and the arc length between $\bar{r}_{c4}(t_i)$ and $\bar{r}_{d4}(t_i)$, AL_{cd}. Compute the overlap ratio as follows.

$$OVR = AL_s/AL_{cd}$$

See figure 4-18.

DELTAT

The time interval between adjacent photographs is

$$\Delta t = t_i - t_{i-1}$$

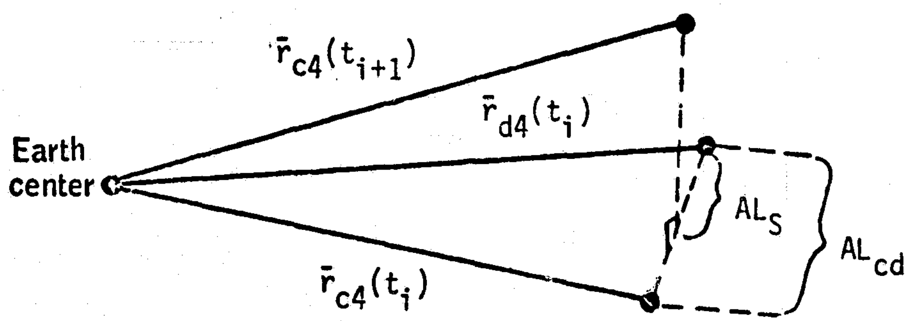


Figure 4-18.- Forward overlap ratio.

5.0 EXPERIMENT SUPPORT PROGRAMS

5.1 Design Philosophy

There are several major programs and a large number of utility programs that will be involved in the preprocessing and processing of ASTP mission data in order to produce requested experiment support products. This section lists each of the major programs and provides a brief description of the functions and capabilities of each. Further information concerning any of these programs can be obtained through the referenced documents or by contacting the Mathematical Physics Branch.

In formulating the ASTP experiment support system, the major design philosophy was to maximize the use of existing software. As a result, only one truly new program, the Apollo-Soyuz Experiment Parameter (ASEP) program, was designed; and even that program made extensive use of formulation from its lunar orbit predecessor, the Apollo Photo Evaluation (APE) program. All other programs used in the processing represent existing software. Only minor modifications to existing programs were required in order to accommodate ASTP data formats. In adhering to this philosophy, several elements of the ASTP system were designed so as to minimize the programing impact rather than maximize the efficiency and utility of the resulting design. Figure 5-1 shows the experiment support system design from a program standpoint and, as such, is a simplification of figure 3-1. In designing future systems, it is hoped that we may be able to more closely follow the design suggested in figure 5-2. The basic functions of this proposed system are identical to those of the ASTP system, but many of the functions have been combined and/or modified to facilitate the handling of large volumes of data. The differences between the proposed system and the ASTP system are enumerated below.

1. The T/M preprocessing functions, performed in two steps by the GPREP and GEDIT programs for ASTP, would be combined into a single processor. The use of an online processor similar to the RTCC system, with DTV and user interface capabilities, could reduce the T/M data preprocessing operation (refers only to that portion of the T/M data reduction directly related to ephemeris, pointing, and field-of-view data) for a mission such as ASTP from an effort requiring several months of offline processing to one that could be completed in a day or less once all raw data become available at JSC.

2. The trajectory generation function would provide only state vectors and the associated physical constants required for their propagation by other integrators. In the ASTP system, the trajectory tape output by the trajectory generation program (HOPE) eventually becomes the driver for the program that generates the experiment support data (ASEP). Thus, all desired output times must be known prior to generating the trajectory tape. As a result, the raw T/M preprocessing and trajectory generation must proceed serially. In the proposed system, the trajectory integration package would be contained within the experiment support program and the trajectory generation would be accomplished in the final step on the basis of the state vectors and constants provided. Thus, the raw T/M preprocessing and trajectory determination functions could proceed independently and in parallel.

3. The experiment support programs, as mentioned above, would be modified to include a trajectory integration package.

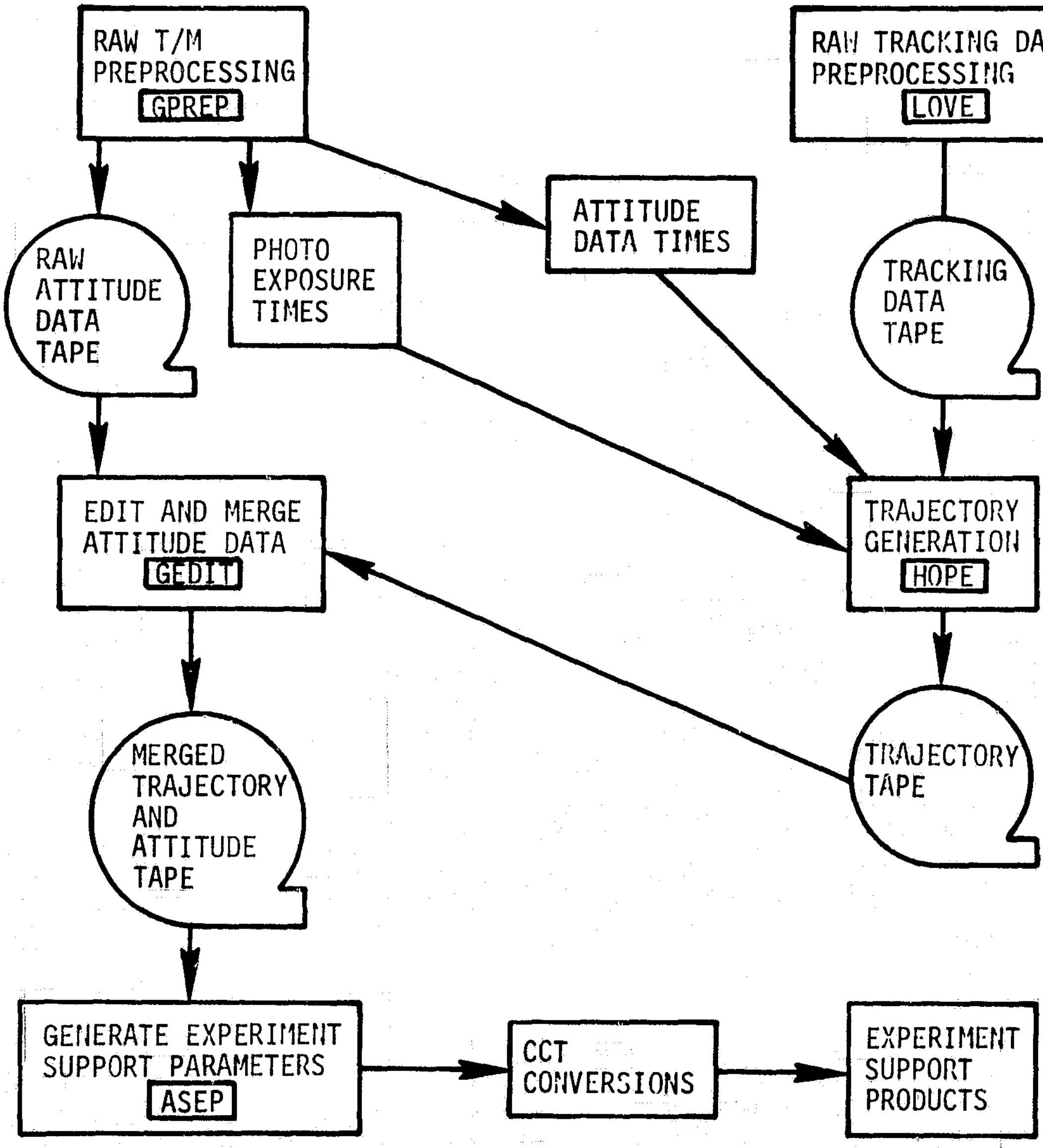


Figure 5-1.- ASTP experiment support system software.

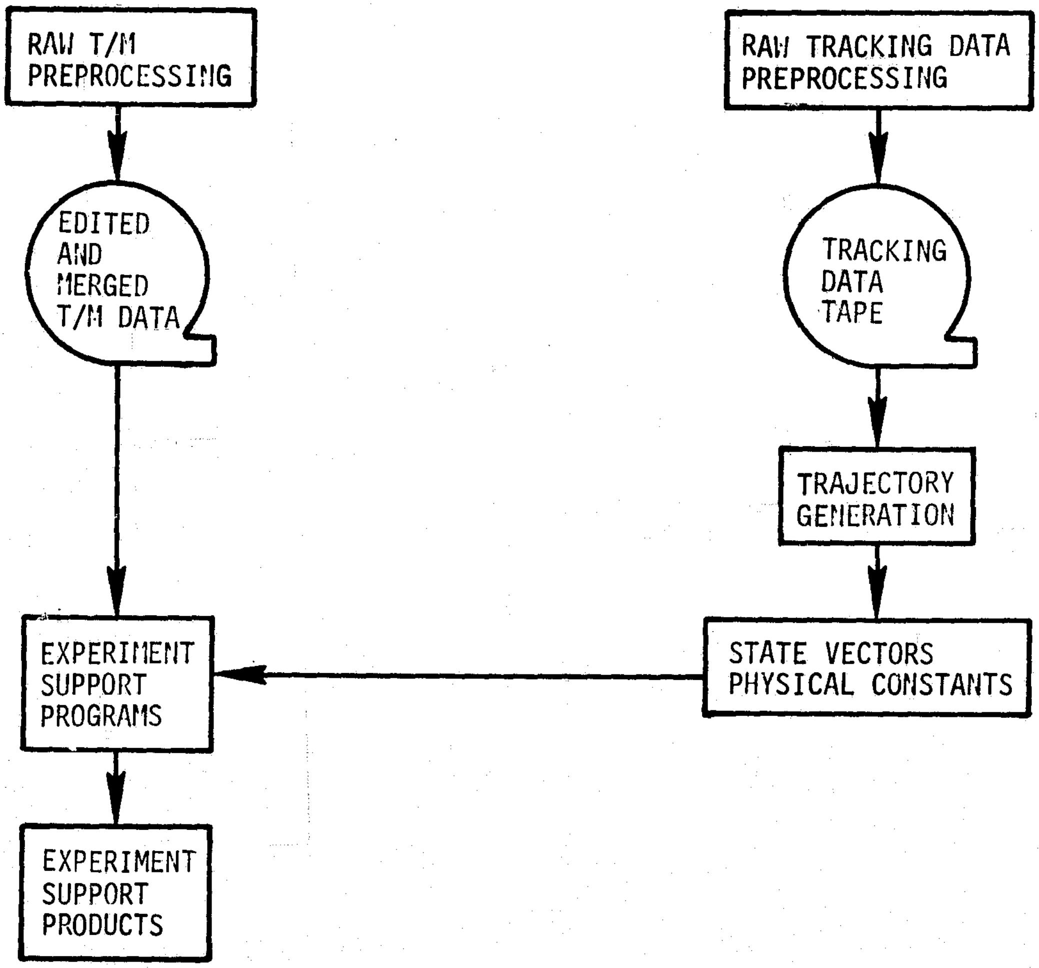


Figure 5-2.- Optimized experiment support system design.

It is believed that utilization of a system with these design characteristics could reduce production time for a mission such as ASTP from the current estimate of 4 to 5 months to a maximum of 1 month. Manpower requirements could be correspondingly reduced by 60 to 80 percent.

5.2 Preprocessing Programs

5.2.1 GPREP.- GPREP is an attitude data preprocessing program that strips time and CSM gimbal angles from a tape containing data from the CMC telemetry downlist and reformats these data in a form compatible with the experiment support processing.

5.2.2 GEDIT.- The GEDIT program operates on tapes output by GPREP. The purpose of the program is to provide a clean attitude data tape to be used in the experiment support data production. The raw attitude data are edited by eliminating duplicate points, discarding all bad data, and, where possible, filling data gaps with the use of a linear interpolation routine. (The use of a higher order routine was investigated, but the linear routine proved to be best suited for the job because of the linear nature of the orientation angles.) The program is also used to merge various segments of edited data to form master attitude data tapes and finally to merge these with HOPE-generated ephemeris tapes to form the merged trajectory and gimbal tapes that are used as direct input to the experiment support (ASEP) program.

5.2.3 LOVE.- The LOVE program is used to preprocess spacecraft tracking data. It has the capability of generating master tracking data tapes from raw data in any of the formats currently provided by the STDN network, GSFC, and JPL.

5.3 Processing Programs

5.3.1 HOPE.- The Houston Operations Predictor/Estimator (HOPE) - references 3, 4, and 5 - is a two-vehicle double-precision orbit determination/prediction program. It has the capability of solving for the inertial and/or relative orbits of one or two orbiting vehicles with the use of a variety of observation types, including ground-based, vehicle-vehicle, and vehicle-ground observations. The orbit determination is accomplished by means of a weighted-least-squares differential correction technique. The program also has stand-alone integration capability for use as a trajectory prediction tool, as well as dummy data generation capability. The user has ready access to all program constants by means of simplified card and/or tape input.

5.3.2 ASEP.- The Apollo-Soyuz Experiment Parameter (ASEP) program acts as an executive routine for the generation of spacecraft ephemeris and orientation data from the merged trajectory and gimbal tapes (see sec. 5.2.2 and fig. 3-1), in addition to calculating all special experiment-related parameters requested by various PI's. The program outputs all PI experiment support data (microfilm, tabulator listings, and experiment support data tapes). Details of the ASEP design can be found in section 6.

6.0 EXPERIMENT SUPPORT PROGRAM DESIGN

The purpose of this section is to specify the design of the Apollo-Soyuz Experiment Parameter (ASEP) program that will provide ephemeris, attitude, pointing, and field-of-view parameters as defined in section 4.0. An overview of the program is presented in section 6.1. The details of the program design are discussed in section 6.2, whereas the required subroutines are described in section 6.3.

6.1 Program Structure

To provide a better understanding of the ASEP program, a brief discussion of the major program functions is presented in this section. The major functions of the program can be divided into three categories: input processing, support parameter computations, and output processing. Figure 6-1 provides an overview of these functions.

The first step is to read and process the input control cards and the mission data cards. Next, the input data tape is searched until the processing start time (input by card) is found. Now the computation of the support parameters begins.

On the basis of the trajectory and attitude data that are read from tape, the nominal support parameters are computed as specified in section 4.4.1. Next, the experiment on-off times for MA-007 are tested to determine if the parameters peculiar to that experiment are required. If they are, the parameters are computed as specified in section 4.4.2.1. If not, then the on-off times for the next experiment are tested. This process continues until all required experiment specific parameters are computed.

At this point, all the output parameters are formatted and output on tape, microfilm, and listing as required. When this is completed, the next data record is read from the input data tape and the process is repeated until all the data records are processed or the processing stop time (input by card) is reached. The final operation is to write an end-of-file on the output tape.

6.2 Detailed Design

This section specifies in detail the various processing elements of the ASEP program: input - tape and card, computations (nominal and experiment specific) - and output - tape, microfilm, and listing.

6.2.1 <u>Input</u>.-

6.2.1.1 Tape: The input tape that is produced by the GEDIT program (see sec. 3.2.1) provides time-ordered ephemeris, attitude, and transformation data from which all the experiment support parameters can be computed. Table 6-I specifies the format of this tape.

6.2.4.2 Card: Card inputs are required for the specification of ASEP program options and for loading ASTP mission and experiment specific data. Table 6-II specifies the name, type, dimension, and a description of the function of each of the input variables. The Univac 1108 Exec II NAMELIST option will be used to load the data.

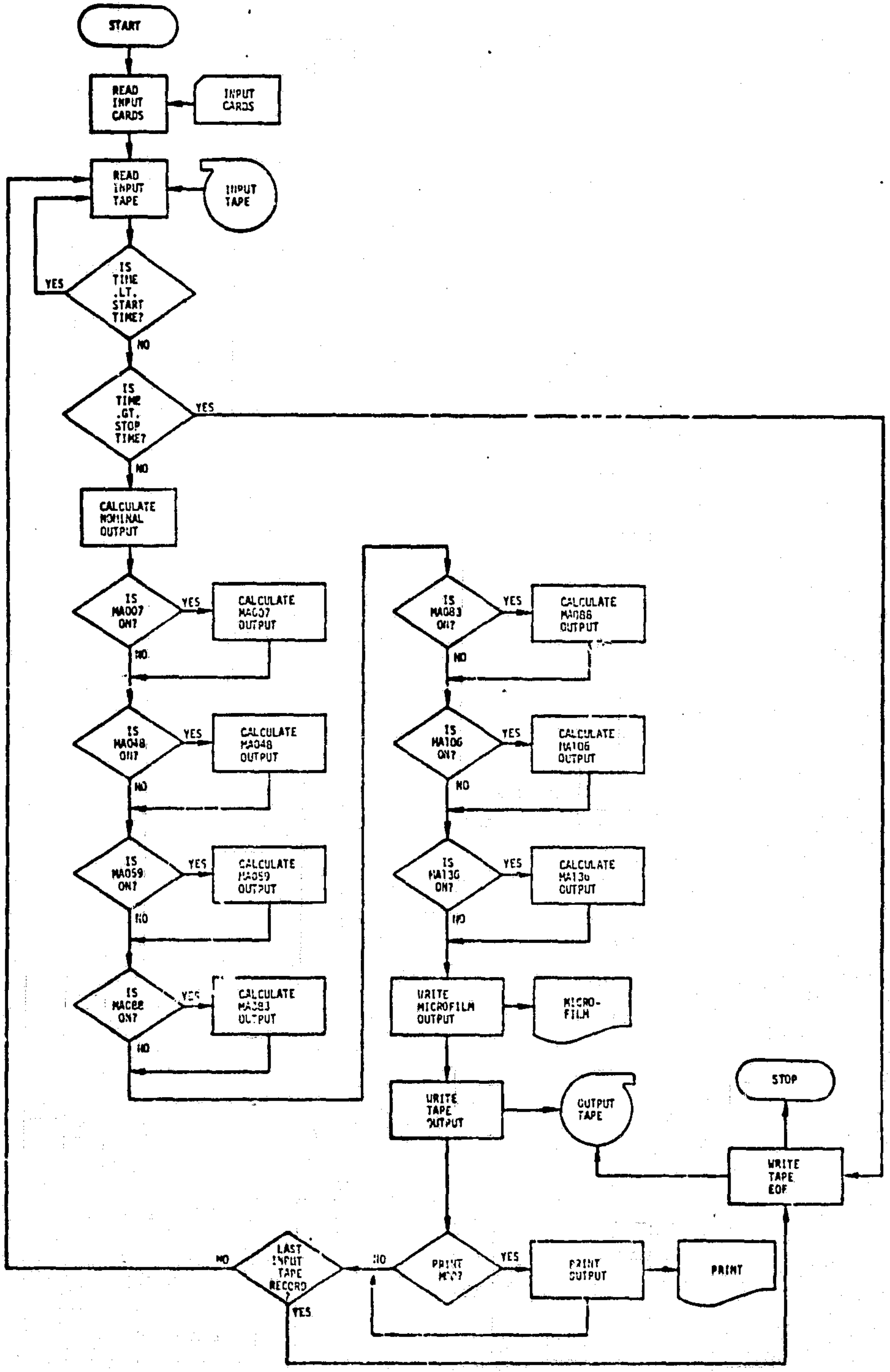


Figure 6-1.- ASEP processing overview.

TABLE 6-I.- ASEP INPUT DATA TAPE FORMAT

(a) Initial record

Word	ID	Type	Description	
1	BTIME	DP	Year (mod. 1900)	Base date
2	BTIME	DP	Month	
3	BTIME	DP	Day	
4	BTIME	DP	Hour	
5	BTIME	DP	Minute	
6	BTIME	DP	Second	
7	GET	DP	Minutes from launch of base time	
8	GHAE	DP	Right ascension of Greenwich midnight day of epoch	
9	GHAL	DP	Right ascension of Greenwich midnight day of launch	
10-20	TITLE	HOL	66 alphanumeric characters from HOPE title card	
21-23	N/A	SP	Not used	

(b) Data record (units: km, sec, and deg)

Word	ID	Type	Description
1	TAET	DP	Time (min) from BTIME
2-4	PECL	DP	Vehicle position - ecliptic mean of 1950.0
5-7	VECL	DP	Vehicle velocity - ecliptic mean of 1950.0
8-10	AECL	DP	Vehicle acceleration - ecliptic mean of 1950.0
11-13	PTOD	DP	Vehicle position - true of date
14-16	VTOD	DP	Vehicle velocity - true of date
17-19	ATOD	DP	Vehicle acceleration - true of date
20-22	PGEO	DP	Vehicle position - geographic inertial
23-25	VGEO	DP	Vehicle velocity - geographic inertial
26-28	AGEO	DP	Vehicle acceleration - geographic inertial

TABLE 6-I.- ASEP INPUT DATA TAPE FORMAT - Concluded

(b) Data record (units: km, sec, and deg) - Concluded

Word	ID	Type	Description
29-31	PM50	DP	Vehicle position - mean of 1950.0
32-34	VM50	DP	Vehicle velocity - mean of 1950.0
35-37	AM50	DP	Vehicle acceleration - mean of 1950.0
38-40	PROT	DP	Vehicle position - geographic rotating
41-43	VROT	DP	Vehicle velocity - geographic rotating
44-46	AROT	DP	Vehicle acceleration - geographic rotating
47-55	EMAT	DP	Mean of 1950.0 to ecliptic mean of 1950.0 matrix
56-64	TMAT	DP	Mean of 1950.0 to true of date matrix
65-73	WTMAT	DP	Mean of 1950.0 to geographic inertial matrix
74-76	SUNP	DP	Sun position - mean of 1950.0
77-79	SUNV	DP	Sun velocity - mean of 1950.0
80-82	CDUX, CDUY, CDUZ	DP	Gimbal angles
83-85	MUNP	DP	Moon position - mean of 1950.0
86-88	MUNV	DP	Moon velocity - mean of 1950.0
89	GIMF	DP	Gimbal status flag
90-91	N/A	DP	Not used

(c) Terminating record

Word	Type	Value
1-91	DP	0.00
92	SP	EOFΔΔΔ (where Δ = blank)

TABLE 6-II.- INPUT CARDS FOR ASEP

Variable name	Type	Dimension	Function
DRIFTX	DP	(4,4)	IMU X-drift (deg/hr) as a function of time (hr, min, sec)
DRIFTY	DP	(4,4)	IMU Y-drift (deg/hr) as a function of time (hr, min, sec)
DRIFTZ	DP	(4,4)	IMU Z-drift (deg/hr) as a function of time (hr, min, sec)
EXP007	DP	(3,2,10)	Operation periods for MA-007; start time (hr, min, sec) and stop time (hr, min, sec)
EXP048	DP	(3,2,10)	Operation periods for MA-048; start time (hr, min, sec) and stop time (hr, min, sec)
EXP059	DP	(3,2,10)	Operation periods for MA-059; start time (hr, min, sec) and stop time (hr, min, sec)
EXP083	DP	(3,2,10)	Operation periods for MA-083; start time (hr, min, sec) and stop time (hr, min, sec)
EXP088	DP	(3,2,10)	Operation periods for MA-088; start time (hr, min, sec) and stop time (hr, min, sec)
EXP106	DP	(3,2,10)	Operation periods for MA-106; start time (hr, min, sec) and stop time (hr, min, sec)
EXP136	DP	(3,2,10)	Operation periods for MA-136; start time (hr, min, sec) and stop time (hr, min, sec)
FL	DP	(4,11)	Lens focal length (mm) as a function of time (hr, min, sec)
GTBIAS	DP	(3,2,6)	g.e.t. time bias (hr, min, sec) as a function of time (hr, min, sec)
LAUNCH	DP	(6)	Launch time (yr (1900), month, day, hr, min, sec)
L1ADC1	DP	(4,6)	Alinement correction (deg) for declination for MA-083 as a function of time (hr, min, sec)
L1ARA1	DP	(4,6)	Alinement correction (deg) for right ascension for MA-083 as a function of time (hr, min, sec)
MODPRT	DP	(1)	Control flag for output print frequency
PET	DP	(3,2,5)	PET time bias (hr, min, sec) as a function of time (hr, min, sec)
REV	DP	(1)	Rev. number referenced to TSTART

TABLE 6-II.- INPUT CARDS FOR ASEP - Concluded

Variable name	Type	Dimension	Function
RF	DP	(3,4,11)	REFSMMAT matrix by row as a function of time (hr, min, sec)
TSTART	DP	(3)	Start time of run (hr, min, sec)
TSTOP	DP	(3)	Stop time of run (hr, min, sec)

Card input (NAMELIST) will also be used to override nominal program and experiment constants. Tables 6-III and 6-IV define all required program constants, the variable names, and the nominal values of the constants.

6.2.2 Nominal support parameters.- For each time point within the interval specified by TSTART and TSTOP, the nominal support parameters will be computed. Figure 6-2 illustrates the straightforward procedure by which all the required parameters are computed. Note that besides the nominal computations, matrices C, G, D, and R are precomputed for later use in the computation of the experiment-specific parameters.

6.2.3 Experiment-specific support parameters.- After the nominal parameters are computed, the experiment on-off times are tested to determine if the experiment-specific parameters need to be calculated. The sequential testing procedure and associated computations are illustrated in figure 6-3. Note that if any one of the three experiments MA-048, MA-083, and MA-088 are operating, then the parameter set, common to all three experiments, is computed. Parameter statistics are also computed at this point.

6.2.4 Output.- The forms of the output data include tape, microfilm, and listing. These outputs are discussed in detail in section 7 and in appendix B.

6.3 Subroutine Descriptions

This section describes the function of the various subroutines used by the ASEP program. These routines are described in tables 6-V and 6-VI.

TABLE 6-III.- ASEP PROGRAM CONSTANTS

Parameter	Nominal Value	Description
AE	6.378166000D3	Semimajor axis of the Earth's reference ellipsoid (km)
BE	6.356784287D3	Semiminor axis of the Earth's reference ellipsoid (km)
CRAD	5.7295779513082320 9D1	Radians to degrees
EMU	3.986032D5	Mu of the Earth (km^3/sec^2)
ER2KM	6.378165D3	Earth radii to kilometers
OMEGE	4.3752690880008D-3	Angular velocity of the Earth (rad/min)
RADS	6.96495618D5	Radius of the Sun (km)
REM	6.367475142D3	Mean Earth radius (km)
RS	1.49597900D8	AU (km)
TWOPI	6.28318530717958648D0	2π

TABLE 6-IV.- ASEP EXPERIMENT CONSTANTS

Parameter	Nominal value	Description
CLTMAG	11.5	Colatitude of the Earth's magnetic North Pole (deg)
FOV083	1.0	Field-of-view for MA-083 (deg)
FOV088	7.5	Field-of-view for MA-088 (deg)
FOV136	53.0	Field-of-view for MA-136 (mm)
LONMAG	-69.5	Longitude of the Earth's magnetic North Pole (deg)
MA007	I_{3x3}	MA-007 misalinement matrix
MA083	I_{3x3}	MA-083 misalinement matrix
MA136	I_{3x3}	MA-136 misalinement matrix
PHI007	58.9	ϕ, body orientation angle for MA-007 (deg)
PHI083	37.75	ϕ, body orientation angle for MA-083 (deg)
PHI136	58.9	ϕ, body orientation angle for MA-136 (deg)
THT007	57.5	θ, body orientation angle for MA-007 (deg)
THT083	90.0	θ, body orientation angle for MA-083 (deg)
THT136	57.5	θ, body orientation angle for MA-136 (deg)

TABLE 6-V.- UTILITY SUBROUTINES

Subroutine name	Function
DPMM	Multiplies matrices
MATRN	Transposes matrices
ROTX	Computes single-axis rotation matrix
UNIT	Vector operations - unitization, magnitude, dot product, and cross product

TABLE 6-VI.- COMPUTATIONAL SUBROUTINES

Subroutine name	Function
ADBARV	Computes spherical polar elements (see sec. 4.4.1.2)
CARMEL	One of six NASA/GSFC subroutines used to compute B&L coordinates
DRIFT	Computes the D matrix (see sec. 4.3.2)
FOV	Computes the MA-136 LOS and FOV intersection points
GI2GEO	Computes the B matrix (see sec. 4.3.10)
GI2UEN	Computes the C matrix (see sec. 4.3.9)
IM2NAV	Computes the G matrix (see sec. 4.3.3)
INTEG	One of six NASA/GSFC subroutines used to compute B&L coordinates
INVAR	One of six NASA/GSFC subroutines used to compute B&L coordinates
KEPLER	Computes Keplerian elements (see sec. 4.4.1.2)

TABLE 6-VI.- COMPUTATIONAL SUBROUTINES - Concluded

Subroutine name	Function
LINES	One of six NASA/GSFC subroutines used to compute B&L coordinates
MA007	Computes the support parameters for the MA-007 experiment (see sec. 4.4.2.1)
MA048	Computes the support parameters for the MA-048/MA-083/MA-088 experiments (see sec. 4.4.2.4)
MA059	Computes the support parameter for the MA-059 experiment (see sec. 4.4.2.3)
MA106	Computes the support parameters for the MA-106 experiment (see sec. 4.4.2.6)
MA136	Computes the support parameters for the MA-136 experiment (see sec. 4.4.2.8)
NEWMAG	One of six NASA/GSFC subroutines used to compute B&L coordinates
START	One of six NASA/GSFC subroutines used to compute B&L coordinates
SUBVEH	Computes the geodetic altitude, latitude, and longitude of the vehicle (see sec. 4.4.1.4)
SUNANG	Computes the Sun azimuth and elevation angles (see sec. 4.4.1.4)

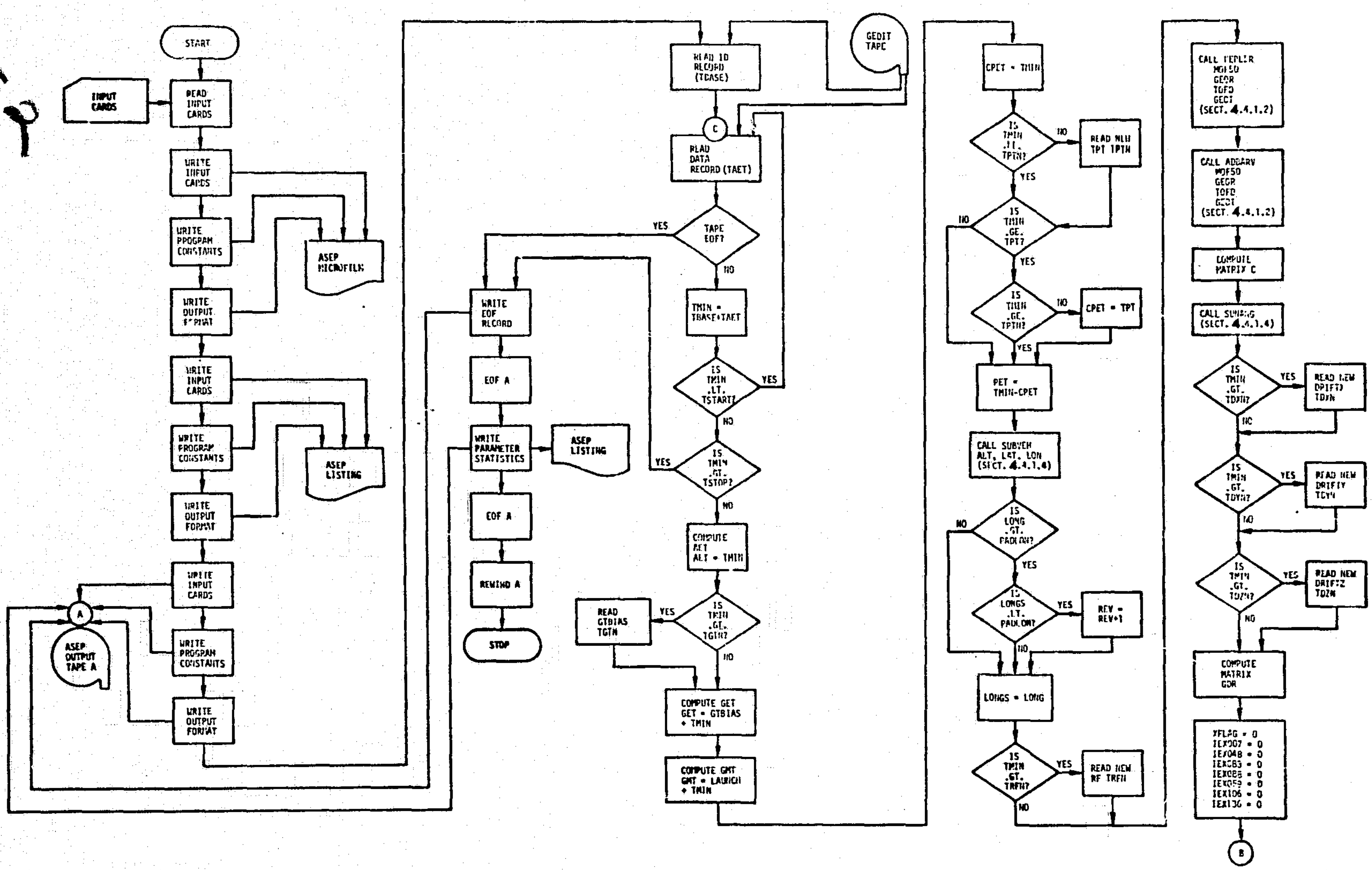


Figure 6-2.- Computations for the nominal support parameters.

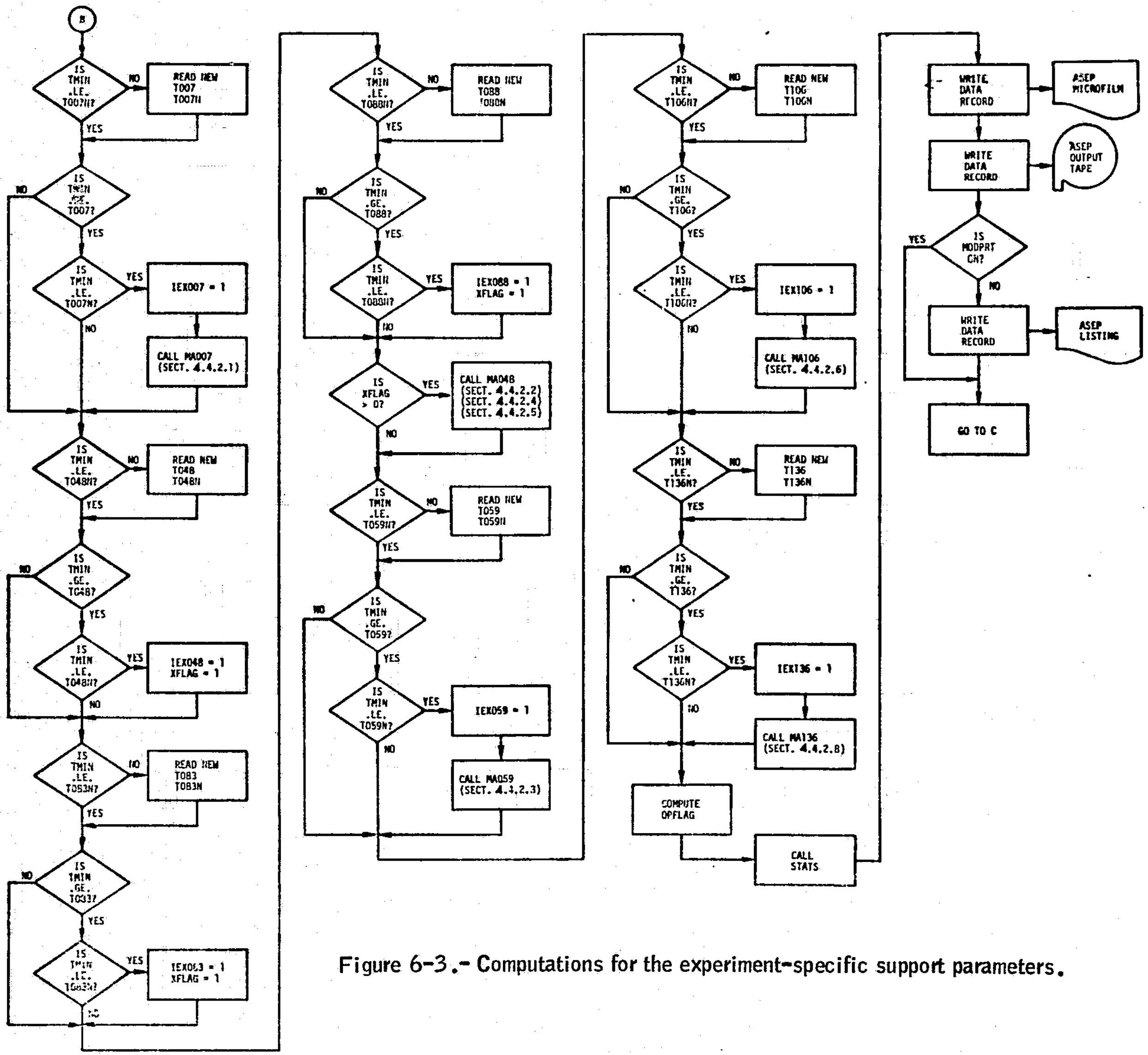


Figure 6-3.- Computations for the experiment-specific support parameters.

7.0 EXPERIMENT SUPPORT OUTPUT DATA FORMATS

7.1 Output Tape

The master support data tape consists of 7 records of input, constants, and format information, followed by the 241-word logical data records. Each data tape will be terminated with an end-of-file (EOF).

7.1.1 Header records.- The seven information records that precede the data records include the following items.

1. Input data - four records. These records include all namelist input data.

2. Program constants - one record. This record includes all the physical constants and experiment-specific data that will be used to compute the support data.

3. Data format - two records. These records specify the name and location on tape of all the support parameters.

It should be noted that the seven header records appea· ·nly on the master data tapes retained at JSC. They are not a part of PI CCT.

7.1.2 Data records.- 241 single-precision words. The format for the data records is specified in table 7-I. The table lists the parameter name, the type of parameter, the parameter location, and the parameter definition. For cross-reference purposes, table 7-II lists the output parameters in alphabetical order, with the associated word location. Note that the parameter units are kilometers, seconds, and degrees unless otherwise specified.

7.2 Listing and Microfilm

Figure 7-1 illustrates the output format for both listing and microfilm. All the parameter names correspond to those in table 7-I. The frequency of the microfilm output will be the same as the tape output frequency, whereas the listing frequency will be some integer multiple of the tape output frequency as specified by card input (MODPRT).

7.3 Output Parameter Statistics

As a quality assurance procedure, output parameter statistics will be computed for each support parameter. The statistics to be computed are as follows.

Mean

Second moment about the mean

Third moment about the mean

Fourth moment about the mean

TABLE 7-I.- EXPERIMENT SUPPORT DATA TAPE FORMAT

Parameter name(s)	Type of parameter	Parameter location	Parameter definition
GMT	Nominal	1-6	Greenwich mean time (yr (mod. 1900), month, day, hr, min, sec)
OPFLAG	Nominal	7	Code word to designate which experiments are operating
AETH, AETM, AETS	Nominal	8-10	Ground elapsed time (hr, min, sec)
GETH, GETM, GETS	Nominal	11-13	ASTP mission elapsed time (hr, min, sec)
CTEH, CTEM, CTES	Nominal	14-16	Onboard clock elapsed time (hr, min, sec)
PETH, PETM, PETS	Nominal	17-19	Phase elapsed time (hr, min, sec)
X1, Y1, Z1, XD1, YD1, ZD1	Nominal	20-25	State vector - Cartesian elements in the mean of 1950.0 coordinate system
ALF1, DLT1, BTA1, AZ1, R1, V1	Nominal	26-31	State vector - ADBARV elements in the mean of 1950.0 coordinate system
SMA1, ECC1, INC1, NOD1, OMG1, TA1	Nominal	32-37	State vector - the Keplerian elements in the mean of 1950.0 coordinate system
X12, Y12, Z12, XD12, YD12, ZD12	Nominal	38-43	State vector - Cartesian elements in the geographic rotating coordinate system
ALF12, DLT12, BTA12, AZ12, R12, V12	Nominal	44-49	State vector - ADBARV elements in the geographic rotating coordinate system
SMA12, ECC12, INC12, NOD12, OMG12, TA12	Nominal	50-55	State vector - Keplerian elements in the geographic rotating coordinate system
X3, Y3, Z3, XD3, YD3, ZD3	Nominal	56-61	State vector - Cartesian elements in the true of date coordinate system

Parameter name(s)	Type of parameter	Parameter location	Parameter definition
ALF3, DLT3, BTA3, AZ3, R3, V3	Nominal	62-67	State vector - ADBARV elements in the true of date coordinate system
SMA3, ECC3, INC3, NOD3, OMG3, TA3	Nominal	68-73	State vector - Keplerian elements in the true of date coordinate system
X4, Y4, Z4, XD4, YD4, ZD4	Nominal	74-79	State vector - Cartesian elements in the geographic inertial coordinate system
ALF4, DLT4, BTA4, AZ4, R4, V4	Nominal	80-85	State vector - ADBARV elements in the geographic inertial coordinate system
SMA4, ECC4, INC4, NOD4, OMG4, TA4	Nominal	86-91	State vector - Keplerian elements in the geographc coordinate system
XS1, YS1, ZS1, XDS1, YDS1, ZDS1	Nominal	92-97	Solar Cartesian elements in the mean of 1950.0 coordinate system
RF11, RF12, RF13	Nominal	98-100	Row 1 of REFSMMAT
CDUX, CDUY, CDUZ	Nominal	101-103	Gimbal angles
RF21, RF22, RF23	Nominal	104-106	Row 2 of REFSMMAT
LAT4, LON4, ALT4	Nominal	107-109	Geodetic altitude, latitude, and longitude
RF31, RF32, RF33	Nominal	110-112	Row 3 of REFSMMAT
SEL10, SAZ10	Nominal	113-114	Solar azimuth and elevation wrt the subvehicle point
GHA	Nominal	115	Greenwich hour angle
T11, T12, T13	Nominal	116-118	Row 1 of the T matrix (mean of 1950.0 to true of date)
E11, E12, E13	Nominal	119-121	Row 1 of the E matrix (mean of 1950.0 to ecliptic mean of 1950.0)

TABLE 7-I.- EXPERIMENT SUPPORT DATA TAPE FORMAT - Continued

Parameter name(s)	Type of parameter	Parameter location	Parameter definition
T21, T22, T23	Nominal	122-124	Row 2 of the T matrix
E21, E22, E23	Nominal	125-127	Row 2 of the E matrix
T31, T32, T33	Nominal	128-130	Row 3 of the T matrix
E31, E32, E33	Nominal	131-133	Row 3 of the E matrix
GIMB	Nominal	134	Gimbal status flag
REV	Nominal	135	Rev. number
SUNF	MA-007	136	Sunrise/sunset flag
SUNH, SUNM, SUNS	MA-007	137-139	Sunrise/sunset time (hr, min, sec)
XANG, YANG	MA-007	140-141	x-angle and y-angle deviations
X11, Y11, Z11	MA-048, MA-083, MA-088	142-144	Geomagnetic position of the vehicle
SCSA	MA-048, MA-083, MA-088	145	Vehicle - Sun angle
ALF2, DLT2	MA-048, MA-083, MA-088	146-147	Right ascension and declination of the vehicle in the ecliptic mean of 1950.0 coordinate system
L1RHA1, L1DEC1	MA-048, MA-083, MA-088	148-149	Right ascension and declination of the LOS in the mean of 1950.0 coordinate system
L1RH2, L1DEC2	MA-048, MA-083, MA-088	150-151	Right ascension and declination of the LOS in the ecliptic mean of 1950.0 coordinate system

TABLE 7-I.- EXPERIMENT SUPPORT DATA TAPE FORMAT - Continued

Parameter name(s)	Type of parameter	Parameter location	Parameter definition
L1AZ, L1EL	MA-048, MA-083, MA-088	152-153	Azimuth and elevation of the LOS
F3RHA1, F3DCA1	MA-048, MA-083, MA-088	154-155	Right ascension and declination of FOV A in the mean of 1950.0 coordinate system for MA-083
F3RHB1, F3DCB1	MA-048, MA-083, MA-088	156-157	Right ascension and declination of FOV B in the mean of 1950.0 coordinate system for MA-083
F3RHC1, F3DCC1	MA-048, MA-083, MA-088	158-159	Right ascension and declination of FOV C in the mean of 1950.0 coordinate system for MA-083
F3RHD1, F3DCD1	MA-048, MA-083, MA-088	160-161	Right ascension and declination of FOV D in the mean of 1950.0 coordinate system for MA-083
F8RHA1, F8DCA1	MA-048, MA-083, MA-088	162-163	Right ascension and declination of FOV A in the mean 1950.0 coordinate system for MA-088
F8RHB1, F8DCB1	MA-048, MA-083, MA-088	164-165	Right ascension and declination of FOV B in the mean 1950.0 coordinate system for MA-088
F8RHC1, F8DCC1	MA-048, MA-083, MA-088	166-167	Right ascension and declination of FOV C in the mean 1950.0 coordinate system for MA-088
F8RHD1, F8DCD1	MA-048, MA-083, MA-088	168-169	Right ascension and declination of FOV D in the mean 1950.0 coordinate system for MA-088

TABLE 7-I.- EXPERIMENT SUPPORT DATA TAPE FORMAT - Continued

Parameter name(s)	Type of parameter	Parameter location	Parameter definition
L1ARA1, L1ADC1	MA-048, MA-083, MA-088	170-171	Corrected right ascension and declination of the LOS in the mean of 1950.0 coordinate system
VRHA1, VDEC1	MA-048, MA-083, MA-088	172-173	Right ascension and declination of velocity in the mean of 1950.0 coordinate system
VRHA2, VDEC2	MA-048, MA-083, MA-088	174-175	Right ascension and declination of velocity in ecliptic mean of 1950.0 coordinate system
VLOS	MA-048, MA-083, MA-088	176	Velocity - LOS angle
LONS2	MA-048, MA-083, MA-088	177	Longitude of the vehicle in the ecliptic mean of 1950.0 coordinate system
ESLOS	MA-048, MA-083, MA-088	178	Angle between Earth-Sun vector and the LOS
ESLOSS	MA-048, MA-083, MA-088	179	Supplement of ESLOS
THETA	MA-106	180	Angle between x_v-axis and the perpendicular to the CSM velocity vector
BMAG	MA-106	181	Magnetic field intensity (gauss)
LMAG	MA-106	182	L-shell radius (e.r.)
ALPH10, BETA10, PHI10	MA-106	183-185	Orientation angles of the vehicle body axes wrt the UEN

TABLE 7-I.- EXPERIMENT SUPPORT DATA TAPE FORMAT - Continued

Parameter name(s)	Type of parameter	Parameter location	Parameter definition
LATA, LONA	MA-136	186-187	Geodetic latitude and longitude of the FOV A corner
LATB, LONB	MA-136	188-189	Geodetic latitude and longitude of the FOV B corner
LATP, LONP	MA-136	190-191	Geodetic latitude and longitude of the principal point
LATC, LONC	MA-136	192-193	Geodetic latitude and longitude of the FOV C corner
LATD, LOND	MA-136	194-195	Geodetic latitude and longitude of the FOV D corner
SF	MA-136	196	Scale factor
DT	MA-136	197	Time interval between adjacent photographs
ALTR	MA-136	198	Attitude rate wrt the principal point
HV	MA-136	199	Horizontal velocity wrt the principal point
TILTAZ	MA-136	200	Tilt azimuth angle
TILT	MA-136	201	Tilt angle
SELP, SAZP	MA-136	202-203	Sun elevation and azimuth wrt the principal point
LATS, LONS	MA-136	204-205	Subsolar point - geodetic latitude and longitude
ALPHA	MA-136	206	Alpha angle

TABLE 7-I.- EXPERIMENT SUPPORT DATA TAPE FORMAT - Continued

Parameter name(s)	Type of parameter	Parameter location	Parameter definition
SWING	MA-136	207	Swing angle
EMISS	MA-136	208	Emission angle
PHASE	MA-136	209	Phase angle
NDA	MA-136	210	North deviation angle
XTILT	MA-136	211	x-tilt angle
YTILT	MA-136	212	y-tilt angle
HEAD	MA-136	213	Heading angle
SR	MA-136	214	Slant range to the principal point
OVR	MA-136	215	Forward overlap ratio
PHI, KAPPA, OMEGA	MA-136	216-218	Angles that rotate the camera axes system into the local-horizontal system
AL	MA-136	219	Surface arc length between nadir and the principal point
FL	MA-136	220	Focal length of camera lens
LOSX, LOSY, LOSZ	MA-136	221-223	Direction cosines of the camera LOS vector in the geographic coordinate system
GC11, GC12, GC13	MA-136	224-226	Row 1 of the geographic to camera transformation
LH11, LH12, LH13	MA-136	227-229	Row 1 of the local horizontal to camera transformation

TABLE 7-I.- EXPERIMENT SUPPORT DATA TAPE FORMAT - Concluded

Parameter name(s)	Type of parameter	Parameter location	Parameter definition
GC21, GC22, GC23	MA-136	230-232	Row 2 of the geographic to camera transformation
LH21, LH22, LH23	MA-136	233-235	Row 2 of the local horizontal to camera transformation
GC31, GC32, GC33	MA-136	236-238	Row 3 of the geographic to camera transformation
LH31, LH32, LH33	MA-136	239-241	Row 3 of the local horizontal to camera transformation

TABLE 7-II.- ALPHABETICAL CROSS-REFERENCE FOR ASTP EXPERIMENT SUPPORT PARAMETERS

		126	E22	115	GHA	187	LONA	112	RF33	174	VRHA2
8	AETH	127	E23	134	GIMB	189	LONB	114	SAZ10	20	X1
9	AETM	131	E31	3	GMTD	193	LONC	203	SAZP	142	X11
10	AETS	132	E32	4	GMTH	195	LOND	145	SCSA	38	X12
219	AL	133	E33	5	GMTM	191	LONP	113	SEL10	56	X3
26	ALF1	33	ECC1	2	GMTMO	205	LONS	202	SELP	74	X4
44	ALF12	51	ECC12	6	GMTS	177	LONS2	196	SF	140	XANG
146	ALF2	69	ECC3	1	GMTY	221	LOSX	32	SMA1	23	XD1
62	ALF3	87	ECC4	213	HEAD	222	LOSY	50	SMA12	41	XD12
80	ALF4	208	EMISS	199	HV	223	LOSZ	68	SMA3	59	XD3
206	ALPHA	178	ESLOS	34	INC1	210	NDA	86	SMA4	77	XD4
183	ALPH10	179	ESLOSS	52	INC12	35	NOD1	214	SR	95	XDS1
109	ALT4	155	F3DCA1	70	INC3	53	NOD12	136	SUNF	92	XS1
198	ALTR	157	F3DCB1	88	INC4	71	NOD3	137	SUNH	211	XTILT
29	AZ1	159	F3DCC1	217	KAPPA	89	NOD4	138	SUNM	21	Y1
47	AZ12	161	F3DCD1	171	L1ADC1	218	OMEGA	139	SUNS	143	Y11
65	AZ3	154	F3RHA1	170	L1ARA1	36	OMG1	207	SWING	39	Y12
		156	F3RHB1	152	L1AZ	54	OMG12	116	T11	57	Y3
83	AZ4	158	F3RHC1	149	L1DEC1	72	OMG3	117	T12	75	Y4
184	BETA10	160	F3RHD1	151	L1DEC2	90	OMG4	118	T13	141	YANG
181	BMAG	163	F8DCA1	153	L1FL	7	OPFLAG	122	T21	24	YD1
23	BTA1	165	F8DCB1	148	L1RHA1	215	OVR	123	T22	42	YD12
46	BTA12	167	F8DCC1	150	L1RHA2	17	PETH	124	T23	60	YD3
64	BTA3	169	F8DCD1	107	LAT4	18	PETM	128	T31	78	YD4
82	BTA4	162	F8RHA1	186	LATA	19	PETS	129	T32	96	YDS1
101	CDUX	164	F8RHB1	188	LATB	209	PHASE	130	T33	93	YS1
102	CDUY	166	F8RHC1	192	LATC	216	PHI	37	TA1	212	YTILT
103	CDUZ	168	F8RHD1	194	LATD	185	PHI10	55	TA12	22	Z1
14	CTEH	220	FL	190	LATP	30	R1	73	TA3	144	Z11
15	CTEM	224	GC11	204	LATS	48	R12	91	TA4	40	Z12
16	CTES	225	GC12	227	LH11	66	R3	180	THETA	58	Z3
27	DLT1	226	GC13	228	LH12	84	R4	201	TILT	76	Z4
45	DLT12	230	GC21	229	LH13	135	REV	200	TILTAZ	25	ZD1
147	DLT2	231	GC22	233	LH21	98	RF11	31	V1	43	ZD12
63	DLT3	232	GC23	234	LH22	99	RF12	49	V12	61	ZD3
81	DLT4	236	GC31	235	LH23	100	RF13	67	V3	79	ZD4
197	DT	237	GC32	239	LH31	104	RF21	85	V4	97	ZDS1
119	E11	238	GC33	240	LH32	105	RF22	173	VDEC1	94	ZS1
120	E12	11	GETH	241	LH33	106	RF23	175	VDEC2		
121	E13	12	GETM	182	LMAG	110	RF31	176	VLOS		
125	E21	13	GETS	108	LON4	111	RF32	172	VRHA1		

```
DECEMBER  7  1973 8150. HR  56. MIN  40.000 SEC                              OPFLAG      0.
             AET 8171. HR  25. MIN  10.000 SEC
             GET 8124. HR  26. MIN  11.000 SEC                    TSTART   0. HR    0. MIN   .000 SEC
             CTE    0. HR   0. MIN    .000 SEC                AET
             PET    0. HR   0. MIN    .000 SEC                    TSTOP  999. HR    0. MIN   .000 SEC

A1     .36898324+04 Y1    -.19831772+04 Z1    -.52332533+04 XD1    .36304691+01 YD1    .67163717+01 ZD1    .17283156+00
ALF1   .33303040+03 DLT1  -.50112257+02 BTA1   .90078566+02 AZ1    .88071617+02 H1     .68203275+04 V1     .70367489+01
SMA1   .68059462+04 ECC1   .25167320-02 INC1   .50139371+02 NOD1   .60523603+02 OMG1   .58704833+02 TA1    .21290611+03

A12    .22785210+03 Y12    .43768590+04 Z12   -.52490353+04 XD12  -.72919800+01 YD12   .57945202+00 ZD12   .18132842+00
ALF12  .87021323+02 DLT12 -.49991654+02 BTA12  .90061997+02 AZ12   .87688699+02 H12    .68203275+04 V12    .73172137+01
SMA12  .62925553+04 ECC12  .83884600-01 INC12  .50024293+02 NOD12  .17426576+03 OMG12  .90075604+02 TA12   .18069555+03

A3     .39213395+04 Y3    -.19619930+04 Z3    -.52490353+04 XD3    .35936042+01 YD3    .67359530+01 ZD3    .18132842+00
ALF3   .33341940+03 DLT3  -.49991654+02 BTA3   .90078566+02 AZ3    .87977077+02 H3     .68203275+04 V3     .70367489+01
SMA3   .68059462+04 ECC3   .25187320-02 INC3   .50021618+02 NOD3   .60779187+02 OMG3   .58790972+02 TA3    .21290611+03

A4     .22785210+03 Y4     .43780590+04 Z4    -.52490353+04 XD4   -.76112915+01 YD4    .59606727+00 ZD4    .18132842+00
ALF4   .87021323+02 DLT4  -.49991654+02 BTA4   .90078566+02 AZ4    .87977077+02 H4     .68203275+04 V4     .70367489+01
SMA4   .68059462+04 ECC4   .25187320-02 INC4   .50021618+02 NOD4   .17438163+03 OMG4   .58790972+02 TA4    .21290611+03

A53   -.46736750+00 Y53   -.12989780+09 Z53   -.56326440+00 XD53   .29097371+02 YD53  -.77495319+01 ZD53  -.32462685+01

R11   -.23181920-01 R12   -.76289660+00 R13    .61699336+00 COOX   .00000000    COOY   .00000000    COOZ   .00000000
R21   -.64741665+00 R22   -.43986600+00 R23   -.62238812+00 LAT4  -.50181024+02 LON4   .67021323+02 ALT4   .45473184+03
R31    .75951770+00 R32   -.43999830+00 R33   -.47910554+00 SEC5   .25360160+02 SA25   .26188160+03 GHA    .49517497+02

T11    .99998253+00 T12   -.54229560-02 T13   -.23565126-02 E11    .99998299+00 E12   -.53407670-02 E13   -.23252085-02
T21    .54220491-02 T22    .99998531+00 T23   -.41552484-05 E21    .58323130-02 E22    .91749298+00 E23    .39762454+00
T31    .23565005-02 T32   -.86193962-05 T33    .99999722+00 E31    .53754795-05 E32   -.39783133+00 E33    .91745657+00

WIND   .00000000    REV    .00000000

SUNF   .00000000    SUNH   .00000000    SUNM   .00000000    SUNS   .00000000    XANG   .00000000    YANG   .00000000

X11    .00000000    Y11    .00000000    Z11    .00000000    SCSA   .00000000    ALF2   .00000000    DLT2   .00000000
LIRMA1 .00000000    LIDEC1 .00000000    LIRMA2 .00000000    LIDEC2 .00000000    LIA2   .00000000    LIEL   .00000000
F3RMA1 .00000000    F3DCA1 .00000000    F3RMB1 .00000000    F3DCB1 .00000000    F3RMC1 .00000000    F3DCC1 .00000000
F3RMD1 .00000000    F3DCD1 .00000000    F4RMA1 .00000000    F4DCA1 .00000000    F4RMB1 .00000000    F4DCB1 .00000000
FCRMC1 .00000000    FCDCC1 .00000000    F4RMD1 .00000000    F4DCD1 .00000000    LIAR1  .00000000    LIAD1  .00000000
VRMA1  .00000000    VDEC1  .00000000    VRMA2  .00000000    VDEC2  .00000000    VLOS   .00000000    LONS2  .00000000
ESLOS  .00000000    ESLOSS .00000000                                                                THETA  .00000000

EMAG   .00000000    LMAG   .00000000    ALPHIO .00000000    BETAIO .00000000    PHIIO  .00000000

LATA   .00000000    LONA   .00000000    LATB   .00000000    LONB   .00000000    LATP   .00000000    LONP   .00000000
LATC   .00000000    LONC   .00000000    LATD   .00000000    LOND   .00000000    SF     .00000000    DT     .00000000
ALTR   .00000000    RV     .00000000    TILTAZ .00000000    TILT   .00000000    SELP   .00000000    SAZP   .00000000
LATS   .00000000    LONS   .00000000    ALPHA  .00000000    SWING  .00000000    EMISS  .00000000    PHASE  .00000000
RDA    .00000000    ATILT  .00000000    YTILT  .00000000    HEAD   .00000000    SR     .00000000    OVR    .00000000
PHI    .00000000    KAPPA  .00000000    OMEGA  .00000000    AL     .00000000    FL     .00000000
ECSA   .00000000    LOST   .00000000    LOS2   .00000000
GC11   .00000000    GC12   .00000000    GC13   .00000000    LM11   .00000000    LM12   .00000000    LM13   .00000000
GC21   .00000000    GC22   .00000000    GC23   .00000000    LM21   .00000000    LM22   .00000000    LM23   .00000000
GC31   .00000000    GC32   .00000000    GC33   .00000000    LM31   .00000000    LM32   .00000000    LM33   .00000000
```

Figure 7-1.- Listing/microfilm format.

At the end of each run, these data will be written out on the second file or the ASEP tape. The data will also be listed in the following tabular format.

Parameter	Number	Mean	Second Moment	Third Moment	Fourth Moment

As with the header record data, these data will appear only on the JSC master tapes. They will not be included on PI CCT's.

7.4 Details of Tape Formats

A detailed discussion of experiment support tape formats can be found in Appendix B.

8.0 TEST PLAN

The purpose of this test plan is to outline the procedures associated with a "closed loop" test that was conducted by JSC/TRW Task 308 in conjunction with the ASTP principal investigators who require ephemeris, attitude, pointing, or field-of-view support data, and in accordance with the Postflight Requirement Forms. The purpose of the test was twofold: (1) Verify that each principal investigator can read his computer compatible tape, and (2) verify that the experiment support parameters are computed correctly and displayed properly. Section 8.1 describes the procedures by which the test data were generated, and section 8.2 defines the test data formats.

8.1 Test Data Generation Procedures

Test data - computer compatible tapes, microfilm, and hard copies - were generated for each principal investigator who required ephemeris, attitude, pointing, or field-of-view data. The test data were based on the ASTP premission reference attitude and trajectory (ref. 2). The attitude data were supplied by JSC/TRW Task 302, whereas the trajectory data were supplied by the Mission Planning and Analysis Division of JSC.

Two segments of test data were generated.

- Segment 1: This 5 hour and 17 minute segment (104^h14^m to 109^h31^m) contains approximately 90 points at intervals of 0.1 to 15 minutes.
- Segment 2: This 10 hour and 35 minute segment (148^h10^m to 158^h45^m) contains approximately 185 points at intervals of 0.1 to 15 minutes.

Each experiment has at least one scheduled operation period in one of these two intervals (see table 8-I). Thus, any data during a scheduled operation period should provide realistic values of the experiment-specific parameters for that experiment. For a detailed description of the attitude time line, see reference 2. Note that MA-089 is not listed in table 8-I since it only requires ephemeris support data.

The data generation procedure is illustrated by figure 8-1. First, the required attitude data were stripped from the reference attitude tape in order to produce a gimbal data tape compatible with the GEDIT program. (See sec. 3.1 for a description of the various processing functions and the associated software.) A parallel operation produced the trajectory tape based on the reference trajectory. The trajectory and attitude data were merged by the GEDIT program to produce the input tape for the Apollo-Soyuz Experiment Parameter (ASEP) program, which generates the required experiment support data. The final step was to convert the Univac 1108 binary tapes (ASEP output tapes) into the various computer compatible formats used by the principal investigators.

8.2 Test Data Formats

The purpose of this section is to specify the test data formats. The tape record format, the microfilm format, and the hard copy format are defined in

TABLE 8-I.- EXPERIMENT OPERATION PERIODS IN THE TWO SEGMENTS OF TEST DATA

Experiment	Operation period(s) in segment 1	Operation period(s) in segment 2
MA-007	No	Yes
MA-048	No	Yes
MA-059	Yes	No
MA-083	Yes	No
MA-088	No	Yes
[a]MA-106	No	Yes
MA-136	Yes	Yes

[a] The MA-107 experiment-specific parameter set is the same as the MA-106 set.

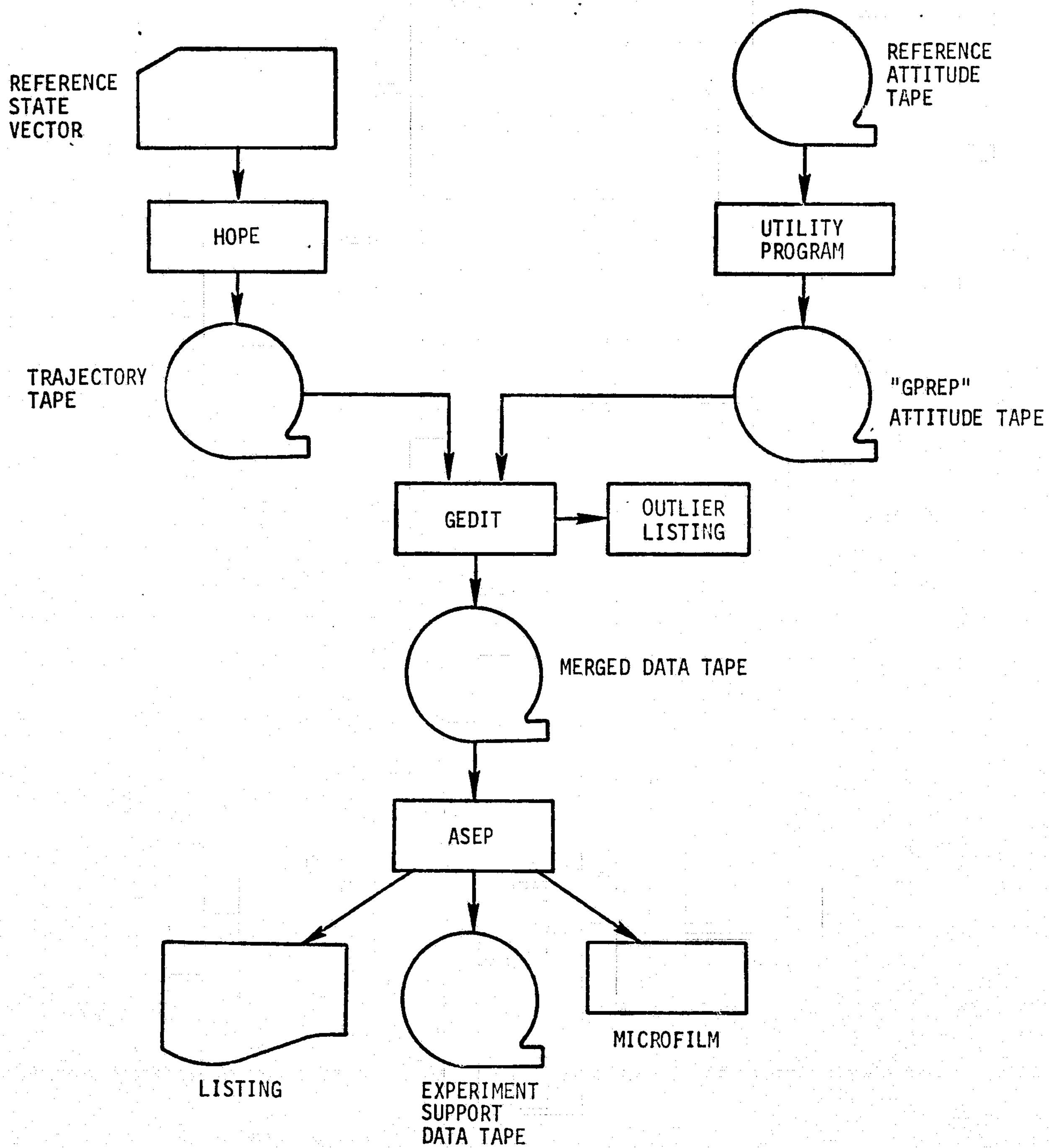


Figure 8-1.- Test data generation procedure.

detail in section 7.0, whereas the computer compatible tape format is specified in table 8-II as a function of experiment. All experiments except MA-107 will be provided a computer compatible tape, microfilm, and a hard copy. MA-107 will receive only microfilm and a hard copy.

In reading the data tapes, the investigator should design his software so that he can edit data by time or record number. In addition, he should be able to test on two important code words. These are described below.

- OPFLAG (parameter 7) - This seven-digit positional code word specifies whether an experiment is operating or not. It is defined as follows.

1	2	3	4	5	6	7
↑	↑	↑	↑	↑	↑	↑
MA-007	MA-048	MA-059	MA-083	MA-088	MA-106	MA-136

  where a zero indicates the experiment is not operating and all leading zeros are dropped. For example, the number 1030067. specifies that MA-007, MA-059, MA-106, and MA-136 are operating whereas the other experiments are not. Likewise, the number 204500. indicates that MA-048, MA-083, and MA-088 are operating whereas the other experiments are not. If an experiment is not operating, the value of the experiment-specific parameters will be zero. For the test data, all experiments will be assumed to be operating.

- GIMB (parameter 134) - The gimbal data quality flag denotes the status of the gimbal data.

$$\text{GIMB} = \begin{cases} 0 & \text{Good data} \\ 1 & \text{Interpolated data - "user beware"} \\ 2 & \text{No data} \\ 3 & \text{Bad data} \\ 4 & \text{Premission attitude reference data (MA-048 only)} \end{cases}$$

  When no gimbal data are available or the data are bad, the value of all attitude, pointing, and FOV parameters is 0.77777770+7.

For the MA-136 experiment, a value of 0.88888888+8 for the geodetic location of an FOV corner point(s) or the principal point indicates that the associated line-of-sight is "above the horizon." If this is the case, then any other parameter that depends on the principal point or the FOV corner point(s) will be set equal to 0.88888888+8.

TABLE 8-II.- COMPUTER COMPATIBLE TAPE DESCRIPTION

Experiment	Computer compatible tape	Tape density	Tape parity	Number of tracks	Word length	Type of format	Comments
MA-007 (LARC)	CDC 6600	800	Odd	7	60	Floating point	None
MA-007 (U. of Wyoming)	CDC 3000	800	Odd	7	48	Floating point	JSC does not have Univac 1108 to Sigma 7 conversion software. However, University of Wyoming does have CDC 3000 to Sigma 7 conversion package.
MA-048	CDC 3800	556	Odd	7	48	Floating point	None
MA-059 (JSC)	Univac 1110	800	Odd	7	36	Floating point	None
MA-059 (U. of Michigan)	IBM 360	800	Odd	7	32	Floating point	IBM 360 tape is compatible with IBM 371-68 computer.
MA-083	IBM 360	556	Odd	7	32	Floating point	IBM 360 tape is compatible with INTERDATA 70 computer.
MA-088	IBM 360	556	Odd	7	32	Floating point	IBM 360 tape is compatible with INTERDATA 70 computer.
MA-089	CDC 6400	800	Odd	7	60	Floating point	None
MA-106	CDC 6600	800	Odd	7	60	Floating point	CDC 6600 tape is compatible with CDC 7600 computer.
MA-136	Univac 1108	800	Odd	7	36	Floating point	Two tapes are required.

9.0 TEST RESULTS

The test data were delivered to PI's in two phases. First, a dummy tape was shipped to each PI to verify its compatibility with his computer. This tape was shipped March 13, 1975. These tapes were followed by the final test tapes, as described in section 8, on April 25, 1975. This was 1 week earlier than the PRF schedule. Table 9-I summarizes results as of June 1, 1975, the test cutoff date as established in the PRF schedule for each experiment. Note that several PI's have not responded on one or both phases of the test.

As of June 1, 1975, no further requests for changes in ASTP experiment support output can be accepted other than through the normal channel of a PRF change request, with review by the DSAD CCB.

TABLE 9-I.- VALIDATION TEST RESULTS

Experimenter	Compatibility test	Final test
MA-007		
LRC	OK	OK
University of Wyoming	OK	OK
MA-048	OK	No response
MA-059		
JSC	OK	No response
University of Michigan	No response	No response
MA-083	OK	OK
MA-088	OK	OK
MA-089	Question - 5/18/75 No further response	No response
MA-106	OK	No response
MA-107	Did not participate	Did not participate
MA-136	OK	OK

10.0 QUALITY ASSURANCE FOR ASTP EXPERIMENT SUPPORT PRODUCTS

A key element in the generation of large amounts of experiment support products is the quality of such data. Inaccurate and incorrect data products or untimely delays in the delivery of support data due to reruns can seriously jeopardize schedules or invalidate the scientific results. For the ASTP mission, it is estimated that approximately 1/2 million records of support data will be generated by JSC/TRW task 308 in support of principal investigators.

The purpose of this section is to identify the controls that will be instituted both prior to the mission and after the mission to help guarantee high-quality data support products that will be generated in accordance with the production plan (see sec. 3.0). A summary of these controls is presented below.

- Independent verification will be performed for all new or modified software prior to the mission.
- End-to-end testing of all data processing functions will be performed prior to the flight with simulated data and after the mission with real data.
- Independent verification will be performed for all intermediate data products.
- Quality control will be maintained on final support products.

Naturally, there are some areas that are beyond the control of the task. These areas include the quality and amount of input telemetry data, the inherent limitation in the accuracy of trajectory, the attitude and pointing input data, and the transmittal of the required data products. The following subsections detail the controls in the four areas described above.

10.1 Independent Software Verification

The modified preprocessing software - GREP, GEDIT, and MA-059 utility programs - will be independently verified prior to the mission. The Apollo-Soyuz Experiment Parameter (ASEP) program, a new program, will be hand checked to eight places. After this is successfully completed, an independent, engineering verification will be performed to ensure that the computation of the output parameters satisfies the principal investigator (PI) requirements.

10.2 End-to-End-Testing

Two types of end-to-end testing will be performed; one using simulated data prior to the mission and one using real data after the mission. These two tests are described in more detail below.

Prior to the mission, in accordance with the DSAD PRF's, a computer compatible support data tape will be delivered to each PI. This tape will be generated by the ASEP program with the use of ASTP reference trajectory and attitude data. Both nominal and experiment-specific parameters will be computed for each of the eight experiments supported by the task. The closed-loop test will be completed when each PI successfully reads the test tape and validates the test data.

As soon as possible after the mission, support data for a series of data takes over well-known U.S. sites will be generated for the MA-136 PI. This closed-loop test will provide the PI with a measure of the misalinement of the camera and allow for a final end-to-end test of the data processing system prior to the generation of the mission support data tapes.

10.3 Independent Test of Intermediate Data Products

The general operational philosophy will be to use standard data input decks, maintain accurate processing records, maintain a file of all intermediate data products, and double check data at all intermediate steps. Specifically, the following steps will be taken.

Refined state vectors

- Tracking data residual statistics from the HOPE program will be checked for "goodness of fit."
- The time base will be checked for consistency with other types of data.
- Trajectory "match point" comparisons will be made for adjacent fit segments as a measure of the consistency of the state vectors.

Gimbal data

- Gaps where gimbal data should exist will be identified. A determination of the status of the data will be made.
- Segments where gimbal data exist but are not supposed to exist will be identified, and a determination of the validity of the data will be made.
- Segments where the gimbal data are bad will be identified.
- Low-bit-rate intervals will be identified.
- Segments where the gimbal data are interpolated will be identified.
- Plots of the first differences of the gimbal data will be made in order to edit "wild points."

Master input data

Before the generation of the support data by the ASEP program, the following tests will be made on the merged input data (trajectory and attitude).

- Spot checks of the quality of the merged data will be made.
- Data record counts will be tabulated for later comparison with the output record counts. This is a check on an inadvertent deletion of data.

10.4 Quality Control on Final Support Products

The operational philosophy will be to use standard input decks and standard production operations and to double check all card inputs. In addition, other specific measures will be taken to maintain the quality of the output products.

- Quick-look support data for MA-136 will be generated.
- Spot checks of the quality of the support data will be made.
- Parameter statistics - mean and 2nd, 3rd, and 4th moments about the mean - will be generated to help isolate problem segments.
- Output data record count will be recorded and compared with the merged input record count.

Note that verification tests will also be made on the reformatted tapes that will be delivered to the PI's.

11.0 MISSION DESCRIPTION

(TO BE PUBLISHED)

12.0 ASTP MISSION DELIVERABLES

(TO BE PUBLISHED)

13.0 ARCHIVED PRODUCTS

(TO BE PUBLISHED)

APPENDIX A - ASTRONOMICAL COORDINATE SYSTEMS

[1]APPENDIX A

ASTRONOMICAL COORDINATE SYSTEMS

A1.0 INTRODUCTION

The purpose of this appendix is to provide an engineering description of the astronomical coordinate transformations used in the HOPE program.

All transformations are performed within the framework of the celestial sphere. The mean-of-date coordinate system is used as a pivot system; all rotations pass through this frame even if they do not start or end there. Rotations are set up to go from the mean-of-date coordinate system to the input (sec. 2) and output (sec. 7) coordinate systems.

Each of the various astronomical coordinate systems used in the HOPE program can be classified as one of the following types.

Planetographic

Selenographic

Planetocentric

Selenocentric

Heliocentric

Planetographic or selenographic coordinates are coordinates that are rigidly attached to the planet or Moon, defined by the planet's or Moon's equator and prime meridian.

Planetocentric means referred to the center of a planet as dynamical center or origin of coordinates. The possible base planes for a planetocentric coordinate system are as follows.

Celestial equator

Ecliptic plane

Planetary equator

The possible X-axes are as follows.

Mean equinox of date

True equinox of date

Mean equinox of epoch[2]

Planetary vernal equinox

---

[1]The data contained in appendix A were obtained from reference 4.

[2]Epoch may be any fixed date; for example, the beginning of the nearest Besselian year.

Selenocentric means referred to the center of the Moon. Heliocentric means that the center of the Sun is the origin of the coordinate system. For both these systems, a planetary equator is not a possible base plane.

Section A2 of this appendix discusses the basic concepts underlying the theory of astronomical coordinate transformations.

The transformation logic is discussed in section A3.

A discussion of the computation of mean angles, precession, and physical libration terms and angles that define the orientation of a planetographic or planetocentric coordinate system is in section A4.

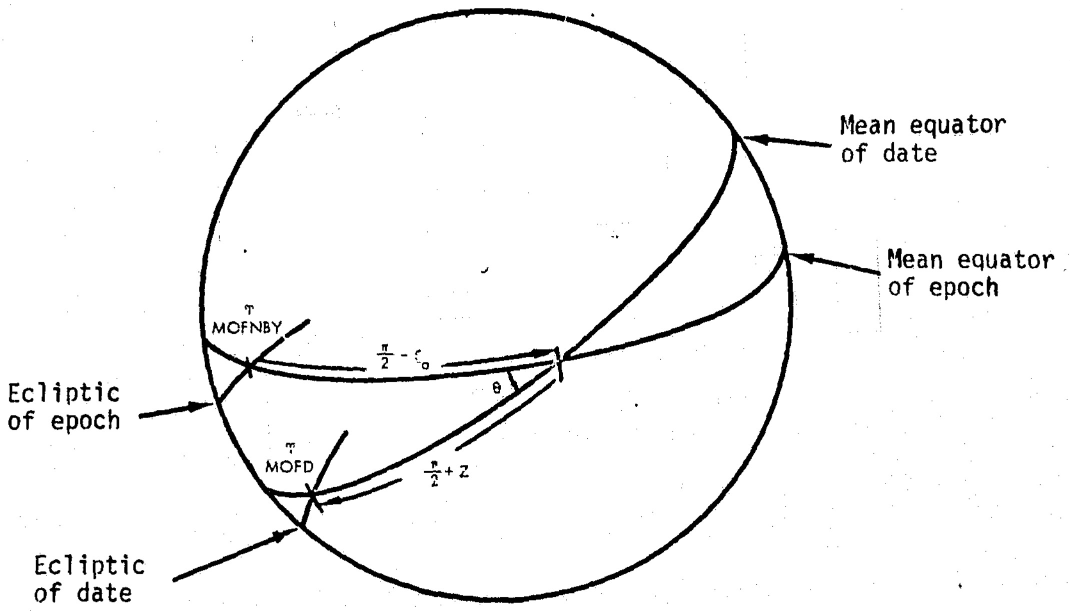
A2.0 DISCUSSION OF BASIC CONCEPTS

A2.1 Motion of the Earth

The equinox ♈ is defined by the intersection of the planes of the Earth's equator and the ecliptic. In turn, the equator is defined as being normal to the Earth's pole. The primary motion of the equinox is called precession and is due mainly to the precession of the Earth's pole. The precessional motion of the mean equinox is due to the combined motions of the two planes (equator and ecliptic) that define it.

The motion of the celestial pole, or of the equator, is due to the gravitational action of the Sun and Moon on the equatorial bulge of the Earth. It consists of two components, lunisolar precession and nutation. Lunisolar precession is the smooth long-period motion of the mean pole of the equator (the word mean indicates that nutation is being neglected) around the pole of the ecliptic, with an amplitude of approximately 23.5 degrees and a period of about 26 000 years. Nutation is a relatively short period motion that carries the actual (or true) pole around the mean pole in a somewhat irregular curve, with an amplitude of about 9 seconds of arc and a period of about 18.6 years. The motion of the ecliptic - that is, the mean plane of the Earth's orbit - is due to the gravitational action of the planets on the Earth and consists of a slow rotation of the ecliptic. This motion is known as planetary precession and gives a precession of the equinox of about 12 seconds of arc per century and a decrease of the obliquity of the ecliptic (the angle between the ecliptic and the Earth's equator) of about 47 seconds of arc per century. The motions of the mean pole, together with the motion of the ecliptic, are known as general precession. General precession is discussed further in section A2.1.1, and nutation is discussed in section A2.1.2.

A2.1.1 <u>General precession of the pole of the Earth</u>.- As mentioned in section A2.1, the precession of the Earth consists of two components, lunisolar precession and planetary precession. It is customary to consider the two components together as a single quantity called general precession, which is described by the angles ζ_0, θ, Z. These precession angles are illustrated in figure A-1. The transformation from the mean-of-nearest-Besselian-year (mean-of-epoch) coordinate system to the mean-of-date coordinate system is accomplished by the [P] matrix, which is made up of three rotation matrices as follows.



$\frac{\pi}{2} - \zeta_o$	:	angle from mean equinox of epoch to the intersection of the mean equator of date and the mean equator of epoch
θ	:	angle between the mean equator of date and the mean equator of epoch
$\frac{\pi}{2} + z$	:	angle from intersection of the mean equator of date with the mean equator of epoch to the mean equinox of date, measured clockwise in the mean equatorial plane
MOFD	:	mean-of-date coordinate system
MOFNBY	:	mean-of-nearest-Besselian-year coordinate system

Figure A-1.- Geometry for general precession terms.

- A counterclockwise rotation about the Z-axis through the angle $\frac{\pi}{2} - \zeta_o$

$$[R_1] = \begin{bmatrix} \cos(\frac{\pi}{2} - \zeta_o) & \sin(\frac{\pi}{2} - \zeta_o) & 0 \\ -\sin(\frac{\pi}{2} - \zeta_o) & \cos(\frac{\pi}{2} - \zeta_o) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

- A counterclockwise rotation about the new X-axis through the angle θ

$$[R_2] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & -\sin\theta & \cos\theta \end{bmatrix}$$

- A clockwise rotation about the new Z-axis through the angle $\frac{\pi}{2} + Z$

$$[R_3] = \begin{bmatrix} \cos(\frac{\pi}{2} + Z) & -\sin(\frac{\pi}{2} + Z) & 0 \\ \sin(\frac{\pi}{2} + Z) & \cos(\frac{\pi}{2} + Z) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Then the [P] matrix is given by

$$[P] = [R_3][R_2][R_1] \tag{A1}$$

where

$$P_{11} = \cos\zeta_o \cos\theta \cos Z - \sin\zeta_o \sin Z$$

$$P_{12} = -\sin\zeta_o \cos\theta \cos Z - \cos\zeta_o \sin Z$$

$$P_{13} = -\sin\theta \cos Z$$

$$P_{21} = \cos\zeta_o \cos\theta \sin Z + \sin\zeta_o \cos Z$$

$$p_{22} = -\sin \zeta_o \cos \theta \sin Z + \cos \zeta_o \cos Z$$

$$p_{23} = -\sin \theta \sin Z$$

$$p_{31} = \cos \zeta_o \sin \theta$$

$$p_{32} = -\sin \zeta_o \sin \theta$$

$$p_{33} = \cos \theta$$

Thus, if $\vec{r}$ is a vector in the mean-of-nearest-Besselian-year coordinate system, the same vector measured in the mean-of-date coordinate system is given by $\vec{R}$.

$$\vec{R} = [P]\vec{r}$$

The transpose of [P] performs the transformation from the mean-of-date coordinate system to the mean-of-nearest-Besselian-year coordinate system. The [P] matrix is orthogonal, and therefore the inverse of [P] is equal to the transpose of [P]; that is, $[P]^{-1} = [P]^T$. The computation of the angles ζ_o, θ, and Z is described in section A4.2.

A2.1.2 Nutation of the pole of the Earth.- Nutation is that part of the precessional motion of the pole of the Earth's equator that depends on the periodic motions of the Sun and Moon in their orbits around the Earth. The long-period motion of the mean pole is called lunisolar precession (sec. A2.1). Nutation is the circular motion of the true pole about the mean pole in a period of about 19 years, with an amplitude of about 9 seconds of arc. The principal term depends on the longitude of the node of the Moon's orbit and has a period of 6798 days or 18.6 years; the amplitude of this term, 9.210 seconds of arc, is known as the constant of nutation. In the complicated theory of the gravitational action of the Sun and Moon on the rotating nonspherical Earth, other terms arise that depend on the mean longitudes and mean anomalies of the Sun and Moon and on their combinations with the longitude of the Moon's node. The resulting shift of the true pole with respect to the mean pole can be resolved into corrections to the longitude ($\delta\Psi$, nutation in longitude) and to the mean obliquity ($\delta\varepsilon$, nutation in obliquity). Expressions for $\delta\Psi$ and $\delta\varepsilon$ are generally developed in series form. The terms divide naturally into those not depending on the Moon's longitude, which can be interpolated at intervals of 10 days, and those depending on the Moon's longitude, with periods of less than about 60 days, which cannot be so interpolated. Nutation is therefore divided into long-period and short-period terms. The short-period terms, which have periods less than 35 days, are traditionally summed separately as $d\Psi$ and $d\varepsilon$ and are called the short-period terms of nutation in longitude and obliquity, respectively. The long-period terms of nutation in longitude and obliquity are denoted by $\Delta\Psi$ and $\Delta\varepsilon$, respectively. Thus, the total nutations in longitude and obliquity (fig. A-2) are given by

$$\delta\Psi = \Delta\Psi + d\Psi$$

$$\delta\varepsilon = \Delta\varepsilon + \dot{d}\varepsilon$$

The angle ε in figure A-2 is the mean obliquity of the ecliptic, defined as the angle between the ecliptic of date and the mean celestial equator of date. The angle ε is computed in section A4.1. The nutations and their derivatives are read from the JPL double-precision ephemeris tape.

The transformation from the mean-of-date coordinate system to the true-of-date coordinate system is accomplished by the [N] matrix, which is made up of three rotation matrices as follows.

- A counterclockwise rotation about the X-axis through an angle ε

$$[R_4] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\varepsilon & \sin\varepsilon \\ 0 & -\sin\varepsilon & \cos\varepsilon \end{bmatrix} \qquad (A2)$$

Note: $[R_4]$ is the transformation from the mean-of-date coordinate system to the ecliptic-mean-of-date coordinate system.

- A clockwise rotation about the new Z-axis through an angle $\delta\Psi$

$$[R_5] = \begin{bmatrix} \cos\delta\psi & -\sin\delta\psi & 0 \\ \sin\delta\psi & \cos\delta\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

- A clockwise rotation about the new X-axis through an angle $\varepsilon + \delta\varepsilon$

$$[R_6] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\varepsilon+\delta\varepsilon) & -\sin(\varepsilon+\delta\varepsilon) \\ 0 & \sin(\varepsilon+\delta\varepsilon) & \cos(\varepsilon+\delta\varepsilon) \end{bmatrix} \qquad (A3)$$

Note: $[R_6]$ is the transformation from the ecliptic-true-equinox coordinate system to the true-of-date coordinate system.

Then the [N] matrix is given by

$$[N] = [R_6][R_5][R_4] \qquad (A4)$$

where

$$n_{11} = \cos \delta\psi$$
$$n_{12} = -\sin \delta\psi \cos \varepsilon$$
$$n_{13} = -\sin \delta\psi \sin \varepsilon$$
$$n_{21} = \cos (\varepsilon + \delta\varepsilon) \sin \delta\psi$$
$$n_{22} = \cos (\varepsilon + \delta\varepsilon) \cos \delta\psi \cos \varepsilon + \sin (\varepsilon + \delta\varepsilon) \sin \varepsilon$$
$$n_{23} = \cos (\varepsilon + \delta\varepsilon) \cos \delta\psi \sin \varepsilon - \sin (\varepsilon + \delta\varepsilon) \cos \varepsilon$$
$$n_{31} = \sin (\varepsilon + \delta\varepsilon) \sin \delta\psi$$
$$n_{32} = \sin (\varepsilon + \delta\varepsilon) \cos \delta\psi \cos \varepsilon - \cos (\varepsilon + \delta\varepsilon) \sin \varepsilon$$
$$n_{33} = \sin (\varepsilon + \delta\varepsilon) \cos \delta\psi \sin \varepsilon + \cos (\varepsilon + \delta\varepsilon) \cos \varepsilon$$

The transpose of [N] performs the transformation from the true-of-date coordinate system to the mean-of-date coordinate system.

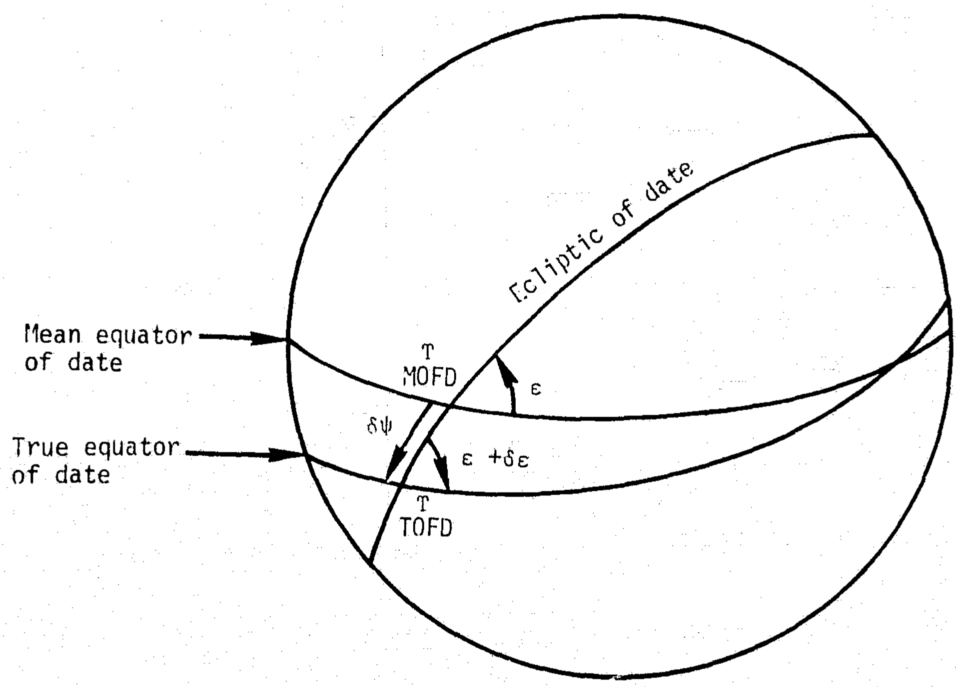


Figure A-2.- Geometry for nutation terms.

A2.2 Current Precession Calculations

Consider an inertial mean-of-nearest-Besselian-year coordinate system that is coincident with the mean-of-date coordinate system; that is, the epoch date.

$$T_t = 0.0$$

$$T_{ot} = \frac{JED - JED_{1900.0}}{36524.219879} \tag{A5}$$

where

JED = Julian ephemeris date.

$JED_{1900.0}$ = 2415020.313, Julian ephemeris date at the beginning of the Besselian year 1900.0.

Under these conditions, the precession angles ζ_o, θ, and Z are zero at the current date, but their time rates of change are finite.

$$\dot{\zeta}_{o_E} = 2304.2530'' + 1.3973''\, T_{ot} + 0.00006''\, T_{ot}^2 \tag{A6}$$

$$\dot{\theta}_E = 2004.6850'' - 0.8533''\, T_{ot} - 0.00037''\, T_{ot}^2 \tag{A7}$$

$$\dot{Z}_E = 2304.2530'' + 1.3972''\, T_{ot} + 0.00006''\, T_{ot}^2 \tag{A8}$$

The expression for the rate of change of general precession in right ascension m_E, obtained by adding equations (A6) and (A8), is

$$m_E = \dot{\zeta}_{o_E} + \dot{Z}_E$$

$$= 4608.5060'' + 2.7945''\, T_{ot} + 0.00012''\, T_{ot}^2 \text{ (seconds of arc/ tropical century)} \tag{A9}$$

The rate of change of general precession in longitude (measured in the ecliptic) is

$$p = \dot{\theta}_E \sin \varepsilon + m_E \cos \varepsilon \tag{A10}$$

A2.3 Greenwich Hour Angle Computation

The angle α_g between the true-of-date equinox and the Greenwich meridian, measured in the true celestial equator (fig. A-3), is given by

$$\alpha_g = \alpha_{gm} + \delta\Psi \cos(\varepsilon + \delta\varepsilon) \tag{A11}$$

where

α_{gm} = angle between the mean equinox and the Greenwich meridian, measured in the mean celestial equator.

The mean rotational rate of the Earth relative to the mean-of-date system ω_g is found by considering the following two components of the rotational motion.

- The daily sidereal rate or rate of Greenwich sidereal time.
- The average daily rotation rate of seconds of arc per mean solar day.

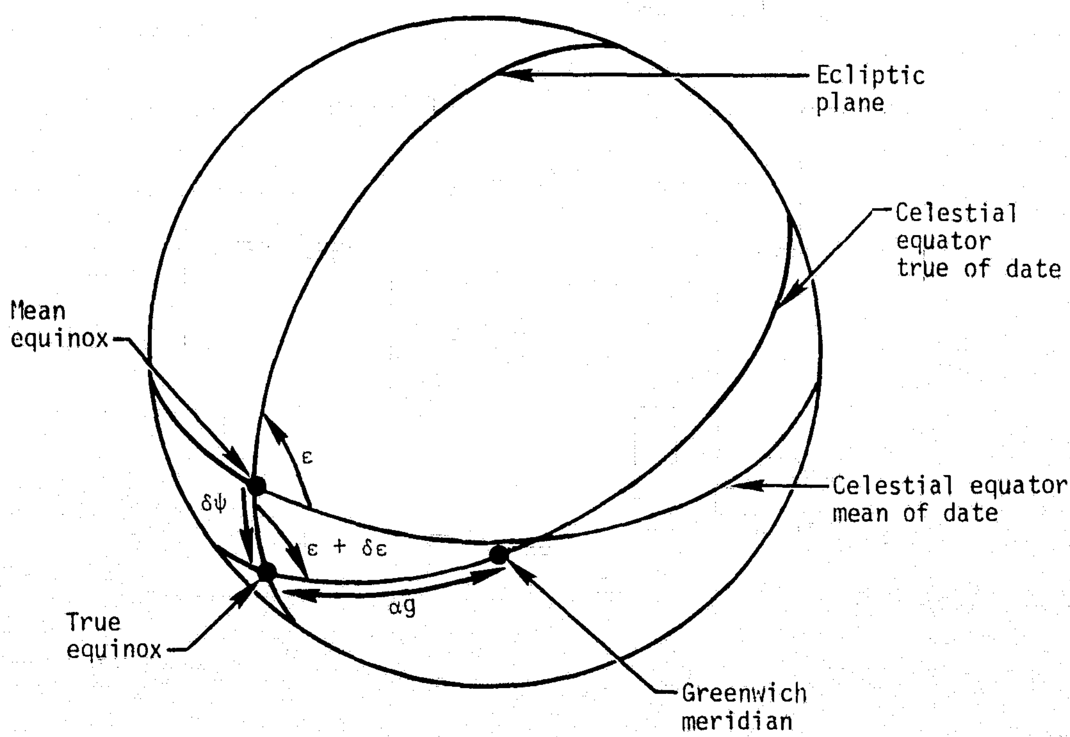


Figure A-3.- Nutation transformation geometry.

The first component is found by differentiation of the Greenwich mean sidereal time at 12 hours universal time, which is given by

$$R_u = 18^h 38^m 45.836^s + 8640184.542^s \, T_u + 0.0929^s \, T_u^2 \qquad \text{(A12)}$$

where

T_u = number of Julian centuries of 36 525 days of universal time elapsed since 12 hours universal time on 1900 January 0.

The equation for T_{um}, the number of Julian centuries of 36 525 days of universal time elapsed from 12 hours universal time on 1900 January 0 to midnight prior to the current date, is

$$T_{um} = \frac{JUD_m - 2415020}{36525} \qquad \text{(A13)}$$

where

$JUD_m = \left[JED - \frac{\Delta T}{86400} + 0.5 \right] - 0.5$, Julian universal date at midnight prior to the current date

and where

$[\ \ ]$ = greatest integer function.

ΔT = difference between ephemeris and universal time.

The second computation is simply time seconds of arc/mean solar day. The sum of the two components is given by

$$\omega_g = 86400 + \frac{\dot{R}_u}{36525} \qquad \text{(A14)}$$

where

$$\dot{R}_u = (8640184.542^s) + 0.1858^s\ T_{um}$$

Now, the angle α_{gm} is given by

$$\alpha_{gm} = \frac{2\pi(\alpha_{go} + \omega_g \Delta T)}{86400} \tag{A15}$$

where

$$\alpha_{go} = \left(18^h 38^m 45.836^s + 8640184.542^s\ T_{um} + 0.0929^s\ T_{um}^{\ 2} - 12^h\right) + \frac{\dot{R}_u}{36525},\ \text{hours of right ascension}$$

A2.4 Ephemeris Time and Universal Time

This section is a brief discussion of the systems of time measurement that pertain to the determination of coordinate system transformations.

There are three basic systems of time measurement currently in use.

- Sidereal time - based on the diurnal motion of the stars, or the period of rotation of the Earth.
- Universal time - based on the diurnal motion of the Sun, or the day and night cycle.
- Ephemeris time - based on the orbital motion of the Earth, Moon, and Sun in the solar system.

Sidereal time is directly related to the rotation of the Earth and is determined by observations of star transits. Equal intervals of angular motion correspond to equal intervals of sidereal time. Sidereal time is important because universal time is not determined by observation but is related to sidereal time by a numerical formula. Universal time, or Greenwich mean solar time, is the measure of time used as a basis for all civil timekeeping; it is a close approximation to the mean diurnal motion of the Sun.

Universal time is defined as 12 hours plus the Greenwich hour angle of a point on the equator whose right ascension, measured from the mean equinox of date, is given by equation (A12). Note that HOPE assumes universal time.

Equation (A12) is used to relate rigorously sidereal and universal time. Thus, the sidereal and universal time systems are not independent, and the use of one instead of the other is purely a matter of convenience.

APPENDIX A

Ephemeris time is a theoretically uniform time scale that came into being when it was discovered that the Earth's rotation rate is subject to slight variations. The length of the ephemeris second is fixed by definition. Ephemeris time is considered to be the independent time argument of the ephemerides of the Sun, Moon, and planets. There is a fundamental difference between ephemeris time and the two systems of time measurement discussed previously. Ephemeris time is defined to be uniform and is determined, in practice, through the motion of the Moon in its orbit around the Earth. Sidereal time (or universal time) is determined from the actual rotation of the Earth. Thus, it is not possible to express one system in terms of the other; the relation between them must be determined empirically.

In the determination of coordinate transformations, ephemeris time is the independent time argument in the precession, nutation, and libration terms. Universal time is used in the computation of R_u (eq. A12). Sidereal time is not used as a time argument in any of the expressions used to determine coordinate transformations.

A3.0 TRANSFORMATION DESCRIPTION

This section describes the logic and philosophy for the astronomical coordinate transformations (rotations, not translations). The underlying philosophy is that the mean-of-date coordinate system is used as the pivot coordinate system; all rotations pass through this frame even if they do not start or end there. Rotations are set up to go from the mean-of-date coordinate system to the input and output coordinate systems. The astronomical coordinate systems are listed below and described in table A-I.

The HOPE program is capable of generating the matrix for rotation between any two of the following sets of astronomical coordinate systems.

(1) Mean of date

(2) True of date

(3) Ecliptic, true equinox

(4) True selenographic

(5) Mean of epoch (where "epoch" may be any fixed date; for example, the beginning of the nearest Besselian year)

(6) Mean selenographic

(7) Ecliptic, mean equinox

(8) Planetographic

(9) Planetocentric, planetary equator

In the coordinate systems listed above, the vector is represented in Cartesian form (table A-I).

APPENDIX A

TABLE A-I.- CARTESIAN COORDINATE SYSTEMS

Number	Name	Base plane	X-axis
(1)	Mean of date	Mean celestial equator of date	Mean equinox of date
(2)	True of date	True celestial equator of date	True equinox of date
(3)	Ecliptic, true equinox	Ecliptic plane of date	True equinox of date
(4)	True selenographic	True lunar equator	Prime lunar meridian
(5)	Mean of epoch	Mean celestial equator of epoch	Mean equinox of epoch
(6)	Mean selenographic	Mean lunar equator of date	Prime lunar meridian
(7)	Ecliptic, mean equinox	Ecliptic plane of date	Mean equinox of date
(8)	Planetographic	Planet's equator of date	Planet's prime meridian
(9)	Planetocentric, planetary equator	Planet's equator of date	Planetary vernal equinox of date[a]

[a]Defined at this time to be the mean planetary vernal equinox of date.

By noting the following definitions -

ε = mean obliquity.

$\delta\Psi$ = total nutation in longitude.

$\delta\varepsilon$ = total nutation in obliquity.

Ω = longitude of the mean ascending node of the lunar orbit.

σ = physical libration in node.

I = mean inclination of the Moon's equatorial plane with respect to the ecliptic plane.

ρ = physical libration in inclination.

☾ = geocentric mean longitude of the Moon.

τ = physical libration in longitude.

$Z + \frac{\pi}{2}$ = angle from intersection of the mean equator of date with the mean equator of epoch to the mean equinox of date, measured clockwise in the mean equatorial plane.

θ = angle between the mean equator of date and the mean equator of epoch.

$\frac{\pi}{2} - \zeta_o$ = angle from mean equinox of epoch to the intersection of the mean equator of date and the mean equator of epoch.

APPENDIX A

α_p = right ascension of the planet's north pole on the celestial sphere, referred to the mean pole and equinox of date.

δ_p = declination of the planet's north pole on the celestial sphere, referred to the mean pole and equinox of date.

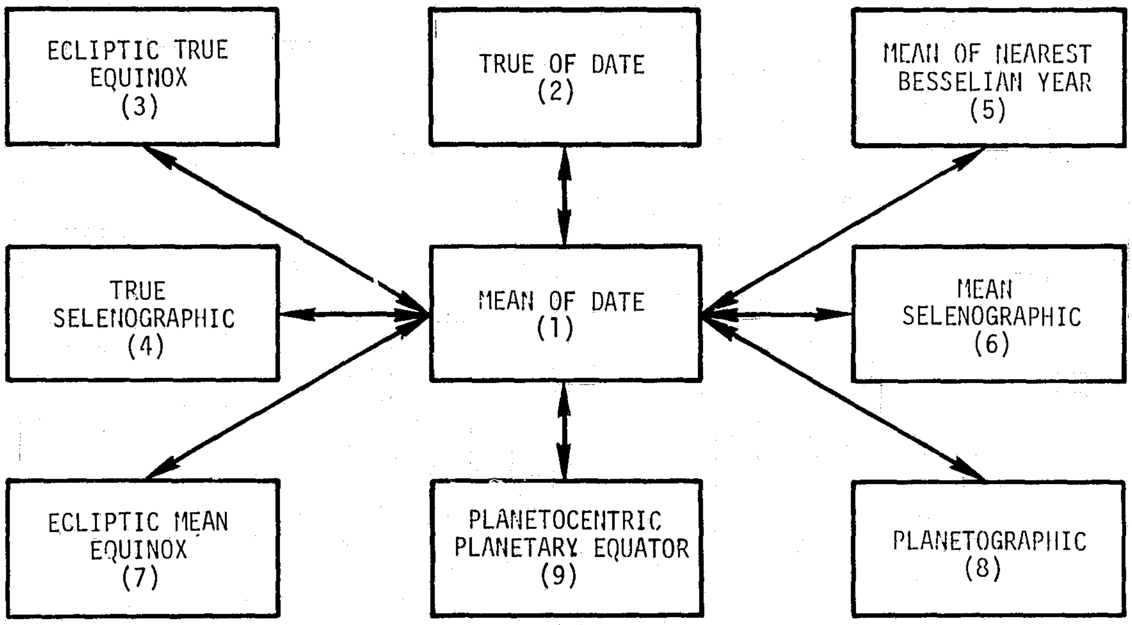
V_p = hour angle of the planetary vernal equinox, measured from the planetary prime meridian.

Φ = angle between the planetary vernal equinox and the ascending node of the planetary orbit, measured counterclockwise along the planetary equator.

and using coordinate system (1) as the pivot frame, the various transformations are summarized as follows.

Option	Rotation 1 about X	Rotation 2 about Z	Rotation 3 about X	Rotation 4 about Z
(1) → (2)	ε	$-\delta\Psi$	$-(\varepsilon+\delta\varepsilon)$	0
(1) → (3)	ε	$-\delta\Psi$	0	0
(1) → (4)	ε	$\Omega + \sigma + \pi$	$I + \rho$	(☾ $-\Omega$) + $(\tau-\sigma)$
(1) → (5)	0	$Z + \frac{\pi}{2}$	$-\theta$	$\zeta_o - \frac{\pi}{2}$
(1) → (6)	ε	$\Omega + \pi$	I	☾ $- \Omega$
(1) → (7)	ε	0	0	0
(1) → (8)	0	$\alpha_p + \frac{\pi}{2}$	$\frac{\pi}{2} - \delta_p$	$V_p - \Phi$
(1) → (9)	0	$\alpha_p + \frac{\pi}{2}$	$\frac{\pi}{2} - \delta_p$	$-\Phi$

The logic for the transformations between coordinate systems is shown in figure A-4.



The arrows between coordinate systems indicate the procedure by which vectors are transformed. For example, a transformation between coordinate systems (5) and (6) is not made directly; the procedure is (5) → (1) → (6) or vice versa.

Figure A-4.- Logic diagram for astronomical coordinate system transformations.

A4.0 BASIC COMPUTATIONS

A4.1 Computation of Mean Angles

There are eight mean angles to be determined: six mean longitudes, the mean obliquity, and the angle of inclination of planetary orbit to ecliptic. The mean longitudes, the mean obliquity, and the angle of inclination of planetary orbit plane to ecliptic are defined as follows.

Γ = mean longitude of the Sun's perigee measured in the ecliptic plane from the mean equinox of date.

Γ' = mean longitude of the Moon's perigee measured in the ecliptic plane from the mean equinox of date to the mean ascending node of the lunar orbit and then along the orbit.

L = mean longitude of the Sun measured in the ecliptic plane from the mean equinox of date.

Ω = longitude of the mean ascending node of the lunar orbit measured in the ecliptic plane from the mean equinox of date.

☾ = geocentric mean longitude of the Moon measured in the ecliptic plane from the mean equinox of date to the mean ascending node of the lunar orbit and then along the orbit.

Ω_p = angle, measured along the ecliptic, between the mean (Earth) vernal equinox and the ascending node of the planetary orbit on the plane of the ecliptic.

ε_p = inclination of the planetary orbit plane to the ecliptic.

ε = angle between the mean celestial equator and the ecliptic (mean obliquity).

The mean longitude of the Sun's perigee, Γ, and the mean obliquity, ε, are slowly varying functions of time as compared to Γ', L, Ω, and ☾. The nutations and librations are small periodic variations about the mean position.

The expressions for the mean angles and the mean obliquity are obtained through the use of the following algorithm.

$$T_E = \frac{\text{J.D.} - (\text{J.D.})_{1900.0 \text{ January } 0.5}}{36525} \tag{A16}$$

where

T_E = time in Julian centuries of 36 525.0 ephemeris days from the epoch date.

J.D. = Julian date, ephemeris time.

and where

epoch date = $(\text{J.D.})_{1900.0 \text{ January } 0.5} = 2415020.0$

The mean angles and the mean obliquity are then given by the following expressions.

$$\Gamma = 1012395.00'' + 6189.03''\ T_E + 1.63''\ T_E^2 + 0.012''\ T_E^3 \tag{A17}$$

$$\Gamma' = 1203586.40'' + 14648522.52''\ T_E - 37.17''\ T_E^2 - 0.045''\ T_E^3 \tag{A18}$$

$$L = 1006908.04'' + 129602768.13''\ T_E + 1.089''\ T_E^2 \tag{A19}$$

$$\Omega = 933059.79'' - 6962911.23''\ T_E + 7.48''\ T_E^2 + 0.008''\ T_E^3 \tag{A20}$$

$$☾ = 973562.99'' + 1732564379.31''\ T_E - 4.08''\ T_E^2 + 0.0068''\ T_E^3 \tag{A21}$$

$$\Omega_p = 175631.19'' + 2775.57''\ T_E - 0.005''\ T_E^2 - 0.0192''\ T_E^3 \qquad (A22)$$

$$\varepsilon = 84428.26'' - 46.845''\ T_E - 0.0059''\ T_E^2 + 0.00181''\ T_E^3 \qquad (A23)$$

$$\varepsilon_p = 6661.20'' - 2.430''\ T_E + 0.0454''\ T_E^2 \qquad (A24)$$

A4.2 Computation of Precession Terms

This section presents expressions for the determination of the three terms ζ_o, Z, and θ. These three terms determine the general precession of the equinox between two dates.

Each of the equations for the components of the total precession are expressed in terms of the following quantities.

T_{ot} = time from 1900.0 to the selected reference epoch in tropical centuries.

T_t = elapsed time since the reference epoch in tropical centuries.

The quantity T_{ot} is a constant determined by the particular reference epoch chosen. The quantity T_{ot} is computed according to equation (A5).

The quantity T_t is computed according to

$$T_t = \frac{\text{JED - epoch}}{36524.219879}$$

The three general precession terms are defined as follows.

$\zeta_o + Z$ = general precession in right ascension.

θ = precession in declination.

$\frac{\pi}{2} - \zeta_o$ = angle from mean equinox of epoch to ascending node of mean equator of date.

The values of the above variables are determined from the following equations.

$$\zeta_o = \left(2304.2530'' + 1.3973''\, T_{ot} + 0.00006''\, T_{ot}^{\ 2}\right) T_t + \left(0.3023'' - 0.00027''\, T_{ot}\right) T_t^{\ 2} + 0.0180''\, T_t^{\ 3} \quad \text{(A25)}$$

$$\theta = \left(2004.6850'' - 0.8533''\, T_{ot} - 0.00037''\, T_{ot}^{\ 2}\right) T_t - \left(0.4267'' + 0.00037''\, T_{ot}\right) T_t^{\ 2} - 0.0418''\, T_t^{\ 3} \quad \text{(A26)}$$

$$z = \left(2304.2530'' + 1.3972''\, T_{ot} + 0.00006''\, T_{ot}^{\ 2}\right) T_t + \left(1.0950'' + 0.00039''\, T_{ot}\right) T_t^{\ 2} + 0.01832''\, T_t^{\ 3} \quad \text{(A27)}$$

APPENDIX B - EXPERIMENT SUPPORT TAPE FORMATS

APPENDIX B

EXPERIMENT SUPPORT TAPE FORMATS

B1.0 INTRODUCTION

The objective of this appendix is to provide a summary of the formats of the tapes associated with ASTP experiment support data processing. The tape formats that are summarized in the following sections include:

- Computer word tape
- Camera shutter tape
- ASEP input tape
- ASEP output tape
- MA-059 observation tape
- MA-059/HOPE output tape
- MA-059 experiment support tape

All tapes are 7-track, 800 bpi Univac 1108 compatible.

B2.0 COMPUTER WORD TAPE FORMAT

The computer word tape contains the downlink telemetry parameters that are required for the generation of ASTP experiment support data. The computer word tape is an input to the GEDIT program (see sec. 2.2.1). The tape has no header records; the data records consist of 72 single-precision words in engineering units. Table B-I specifies the parameter name, the location on tape for each parameter, and the computer word number associated with the same parameter on the Skylab computer word tape.

B3.0 CAMERA SHUTTER TAPE FORMAT

The camera shutter tape contains the times of the "shutter open" event for the two MA-136 cameras. The tape contains two header records; each data record contains 60 integer words.

TABLE B-I.- PARAMETER LIST FOR THE IDSD COMPUTER WORD TAPE

Output parameter location	Computer word no.	Parameter		Output parameter location	Computer word no.	Parameter		Output parameter location	Computer word no.	Parameter
1	1	RANGE TIME		25	98	MARICDUZ		49	177	VHF CNT
2	26	DELV	X	26	99	MAROCDUT		50	178	VHF TIME
3	27	DELV	Y	27	100	MARICDUX		51	200	T PIP
4	28	DELV	Z	28	101	CDUT		52	207	MARK2TIME
5	32	RCSM	X	29	102	CDUS		53	208	MARK2ICDUY
6	33	RCSM	Y	30	104	REFMAT	0	54	209	MARK2PCDUS
7	34	RCSM	Z	31	105	REFMAT	1	55	210	MARK2ICDUZ
8	35	VCSM	X	32	106	REFMAT	2	56	211	MARK2OCDUT
9	36	VCSM	Y	33	107	REFMAT	3	57	212	MARK2ICDUX
10	37	VCSM	Z	34	108	REFMAT	4	58	213	CDUT
11	38	T STATE		35	109	REFMAT	5	59	215	ADOT X
12	41	CDU	X	36	110	REFMAT	6	60	216	ADOT Y
13	42	CDU	Y	37	111	REFMAT	7	61	217	ADOT Z
14	43	CDU	Z	38	112	REFMAT	8	62	224	RM
15	80	R OTHER	X	39	125	ADOT	X	63	238	OGC
16	81	R OTHER	Y	40	126	ADOT	Y	64	239	IGC
17	82	R OTHER	Z	41	127	ADOT	Z	65	240	MGC
18	83	V OTHER	X	42	156	TNOW		66	247	CODE
19	84	V OTHER	Y	43	170	PIPA	X	67	248	CODE
20	85	V OTHER	Z	44	171	PIPA	Y	68	259	TRKMKCNT
21	86	T OTHER		45	172	PIPA	Z	69	269	STARID1
22	95	MARKDOWN		46	174	CDU	X	70	270	STARID2
23	96	MARICDUY		47	175	CDU	Y	71	508	DVTOTAL
24	97	MAROCDUS		48	176	CDU	Z	72	509	MARKTIME

B3.1 Header Records

The two header records are identical and contain 48 BCD characters in the following format.

APOLLObSOYUZbTESTbPROJ.bEXPbMA136bbbMMDDYYbRUNbX

MM/DD/YY = date of run, where

MM = month (01-12)

DD = day (01-31)

YY = year (75)

X = run number

b = blank

B3.2 Data Records

Each physical record contains 30 data frames. Each data frame contains two words of data, as follows.

Word no.	Contents
1	Time (integer milliseconds)
2	Shutter open data
	a. Bits 1-24: Unused (bit 1 - leftmost or MSB)
	b. Bits 25-36: CK1043 (shutter open value)

Time that is used is the G.m.t. of the frame in which "shutter open" status occurred or that G.m.t. plus 10 milliseconds; which one depends on whether the "shutter open" status occurred with the first or second sample in the frame. The remaining words of an incomplete record are filled with 7's. If the final data frame completes a record, then the words in the last record are filled with 7's.

B4.0 ASEP INPUT TAPE FORMAT

The ASEP input tape that is produced by the GEDIT program (see sec. 2.2.1) provides time-ordered ephemeris, attitude, and transformation data from which all experiment support parameters can be computed. Table B-II specifies the format of this tape.

APPENDIX B

TABLE B-II.- ASEP INPUT DATA TAPE FORMAT

(a) Initial record

Word	ID	Type	Description	
1	BTIME	DP	Yr (mod. 1900)	Base date
2	BTIME	DP	Month	
3	BTIME	DP	Day	
4	BTIME	DP	Hr	
5	BTIME	DP	Min	
6	BTIME	DP	Sec	
7	GET	DP	Min from launch of base time	
8	GHAE	DP	Right ascension of Greenwich midnight day of epoch	
9	GHAL	DP	Right ascension of Greenwich midnight day of launch	
10-20	TITLE	HOL	66 alphanumeric characters from HOPE title card	
21-23	N/A	SP	Not used	

(b) Data record (units: km, sec, and deg)

Word	ID	Type	Description
1	TAET	DP	Time (min) from BTIME
2-4	PECL	DP	Vehicle position - ecliptic mean of 1950.0
5-7	VECL	DP	Vehicle velocity - ecliptic mean of 1950.0
8-10	AECL	DP	Vehicle acceleration - ecliptic mean of 1950.0
11-13	PTOD	DP	Vehicle position - true of date
14-16	VTOD	DP	Vehicle velocity - true of date
17-19	ATOD	DP	Vehicle acceleration - true of date
20-22	PGEO	DP	Vehicle position - geographic inertial
23-25	VGEO	DP	Vehicle velocity - geographic inertial
26-28	AGEO	DP	Vehicle acceleration - geographic inertial
29-31	PM50	DP	Vehicle position - mean of 1950.0
32-34	VM50	DP	Vehicle velocity - mean of 1950.0
35-37	AM50	DP	Vehicle acceleration - mean of 1950.0
38-40	PROT	DP	Vehicle position - geographic rotating
41-43	VROT	DP	Vehicle velocity - geographic rotating
44-46	AROT	DP	Vehicle acceleration - geographic rotating
47-55	EMAT	DP	Mean of 1950.0 to ecliptic mean of 1950.0 matrix
56-64	TMAT	DP	Mean of 1950.0 to true-of-date matrix
65-73	WTMAT	DP	Mean of 1950.0 to geographic inertial matrix
74-76	SUNP	DP	Sun position - mean of 1950.0
77-79	SUNV	DP	Sun velocity - mean of 1950.0
80-82	CDUX, CDUY, CDUZ	DP	Gimbal angles
83-85	MUNP	DP	Moon position - mean of 1950.0
86-88	MUNV	DP	Moon velocity - mean of 1950.0
89	GIMF	DP	Gimbal status flag
90-91	N/A	DP	Not used

(c) Terminating record

Word	Type	Value
1-91	DP	0.00
92	SP	EOFΔΔΔ (where Δ = blank)

APPENDIX B

B5.0 ASEP OUTPUT TAPE FORMAT

The ASEP output data tape consists of data records with 241 single-precision words per record. Each data tape is terminated with an end-of-file (EOF). The format for the data records is specified in table B-III. The table lists the parameter name, the type of parameter, the parameter location, and the parameter definition. Note that the parameter units are kilometers, seconds, and degrees unless otherwise specified.

B6.0 MA-059 OBSERVATION TAPE FORMAT

A special utility program is used to generate an angle-tracking data tape in the LOVE EDITED MASTER format based on the ASTP gimbal angle data. The format is described in table B-IV.

B7.0 MA-059/HOPE OUTPUT TAPE

This HOPE output tape contains special MA-059 parameters derived from the reconstruction of the Soyuz trajectory with respect to the CSM. The Fortran, binary, double-precision tape has three word records. There are no header records.

Word	Word description
1	Time (minutes from AET)
2	Range (kilometers)
3	γ (degrees)

A double EOF will be placed at the end of the data records.

B8.0 MA-059 EXPERIMENT SUPPORT TAPE

This tape is created by merging the nominal experiment support parameters from the ASEP output tape with the parameters from the MA-059/HOPE output tape. The Fortran, binary tape has records with 139 single-precision words. There are no header records.

Word	Word description
1-135	Nominal ASEP parameters
136	Range (word 2 of A)
137	θ (word 180 of ASEP)
138	γ (word 3 of A)
139	$\Delta = \theta - \gamma$ (computed)

A double EOF will be placed at the end of the data records.

TABLE B-III.- EXPERIMENT SUPPORT DATA TAPE FORMAT

Parameter name(s)	Type of parameter	Parameter location	Parameter definition
GMT	Nominal	1-6	Greenwich mean time (yr (mod. 1900), month, day, hr, min, sec)
OPFLAG	Nominal	7	Code word to designate which experiments are operating
AETH, AETM, AETS	Nominal	8-10	Ground elapsed time (hr, min, sec)
GETH, GETM, GETS	Nominal	11-13	ASTP mission elapsed time (hr, min, sec)
CTEH, CTEM, CTES	Nominal	14-16	Onboard clock elapsed time (hr, min, sec)
PETH, PETM, PETS	Nominal	17-19	Phase elapsed time (hr, min, sec)
X1, Y1, Z1, XD1, YD1, ZD1	Nominal	20-25	State vector - Cartesian elements in the mean of 1950.0 coordinate system
ALF1, DLT1, BTA1, AZ1, R1, V1	Nominal	26-31	State vector - ADBARV elements in the mean of 1950.0 coordinate system
SMA1, ECC1, INC1, NOD1, OMG1, TA1	Nominal	32-37	State vector - the Keplerian elements in the mean of 1950.0 coordinate system
X12, Y12, Z12, XD12, YD12, ZD12	Nominal	38-43	State vector - Cartesian elements in the geographic rotating coordinate system
ALF12, DLT12, BTA12, AZ12, R12, V12	Nominal	44-49	State vector - ADBARV elements in the geographic rotating coordinate system
SMA12, ECC12, INC12, NOD12, OMG12, TA12	Nominal	50-55	State vector - Keplerian elements in the geographic rotating coordinate system
X3, Y3, Z3, XD3, ZD3	Nominal	56-61	State vector - Cartesian elements in the true of date coordinate system
ALF3, DLT3, BTA3, AZ3, R3, V3	Nominal	62-67	State vector - ADBARV elements in the true of date coordinate system

TABLE B-III.- EXPERIMENT SUPPORT DATA TAPE FORMAT - Continued

Parameter name(s)	Type of parameter	Parameter location	Parameter definition
SMA3, ECC3, INC3, NOD3, OMG3, TA3	Nominal	68-73	State vector - Keplerian elements in the true of date coordinate system
X4, Y4, Z4, XD4, YD4, ZD4	Nominal	74-79	State vector - Cartesian elements in the geographic inertial coordinate system
ALF4, DLT4, BTA4, AZ4, R4, V4	Nominal	80-85	State vector - ADBARV elements in the geographic inertial coordinate system
SMA4, ECC4, INC4, NOD4, OMG4, TA4	Nominal	86-91	State vector - Keplerian elements in the geographic coordinate system
XS1, YS1, ZS1, XDS1, YDS1, ZDS1	Nominal	92-97	Solar Cartesian elements in the mean of 1950.0 coordinate system
RF11, RF12, RF13	Nominal	98-100	Row 1 of REFSMMAT
CDUX, CDUY, CDUZ	Nominal	101-103	Gimbal angles
RF21, RF22, RF23	Nominal	104-106	Row 2 of REFSMMAT
LAT4, LON4, ALT4	Nominal	107-109	Geodetic altitude, latitude, and longitude
RF31, RF32, RF33	Nominal	110-112	Row 3 REFSMMAT
SEL10, SAZ10	Nominal	113-114	Solar azimuth and elevation wrt the subvehicle point
GHA	Nominal	115	Greenwich hour angle
T11, T12, T13	Nominal	116-118	Row 1 of the T matrix (mean of 1950.0 to true of date)
E11, E12, E13	Nominal	119-121	Row 1 of the E matrix (mean of 1950.0 to ecliptic mean of 1950.0)
T21, T22, T23	Nominal	122-124	Row 2 of the T matrix

TABLE B-III.- EXPERIMENT SUPPORT DATA TAPE FORMAT - Continued

Pamameter name(s)	Type of parameter	Parameter location	Parameter definition
E21, E22, E23	Nominal	125-127	Row 2 of the E matrix
T31, T32, T33	Nominal	128-130	Row 3 of the T matrix
E31, E32, E33	Nominal	131-133	Row 3 of the E matrix
GIMB	Nominal	134	Gimbal status flag
REV	Nominal	135	Rev. number
SUNF	MA-007	136	Sunrise/sunset flag
SUNH, SUNM, SUNS	MA-007	137-139	Sunrise/sunset time (hr, min, sec)
XANG, YANG	MA-007	140-141	x-angle and y-angle deviations
X11, Y11, Z11	MA-048, MA-083, MA-088	142-144	Geomagnetic position of the vehicle
SCSA	MA-048, MA-083, MA-088	145	Vehicle - Sun angle
ALF2, DLT2	MA-048, MA-083, MA-088	146-147	Right ascension and declination of the vehicle in the ecliptic mean of 1950.0 coordinate system
L1RHA1, L1DEC1	MA-048, MA-083, MA-088	148-149	Right ascension and declination of the LOS in the mean of 1950.0 coordinate system
L1RHA2, L1DEC2	MA-048, MA-083, MA-088	150-151	Right ascension and declination of the LOS in the ecliptic mean of 1950.0 coordiante system

TABLE B-III.- EXPERIMENT SUPPORT DATA TAPE FORMAT - Continued

Parameter name(s)	Type of parameter	Parameter location	Parameter definition
L1AZ, L1EL	MA-048, MA-083, MA-088	152-153	Azimuth and elevation of the LOS
F3RHA1, F3DCA1	MA-048, MA-083, MA-088	154-155	Right ascension and declination of FOV A in the mean of 1950.0 coordinate system for MA-083
F3RHB1, F3DCB1	MA-048, MA-083, MA-088	156-157	Right ascension and declination of FOV B in the mean of 1950.0 coordinate system for MA-083
F3RHC1, F3DCC1	MA-048, MA-083, MA-088	158-159	Right ascension and declination of FOV C in the mean of 1950.0 coordinate system for MA-083
F3RHD1, F3DCD1	MA-048, MA-083, MA-088	160-161	Right ascension and declination of FOV D in the mean of 1950.0 coordinate system for MA-083
F8RHA1, F8DCA1	MA-048, MA-083, MA-088	162-163	Right ascension and declination of FOV A in the mean of 1950.0 coordinate system for MA-088
F8RHB1, F8DCB1	MA-048, MA-083, MA-088	164-165	Right ascension and declination of FOV B in the mean of 1950.0 coordinate system for MA-088
F8RHC1, F8DCC1	MA-048, MA-083, MA-088	166-167	Right ascension and declination of FOV C in the mean of 1950.0 coordinate system for MA-088
F8RHD1, F8DCD1	MA-048, MA-083, MA-088	168-169	Right ascension and declination of FOV D in the mean of 1950.0 coordinate system for MA-088

TABLE B-III.- EXPERIMENT SUPPORT DATA TAPE FORMAT - Continued

Parameter name(s)	Type of parameter	Parameter location	Parameter definition
L1ARA1, L1ADC1	MA-048 MA-083 MA-088	170-171	Corrected right ascension and declination of the LOS in the mean of 1950.0 coordinate system
VRHA1, VDEC1	MA-048 MA-083 MA-088	172-173	Right ascension and declination of velocity in the mean of 1950.0 coordinate system
VRHA2, VDEC2	MA-048 MA-083 MA-088	174-175	Right ascension and declination of velocity in ecliptic mean of 1950.0 coordinate system
VLOS	MA-048 MA-083 MA-088	176	Velocity - LOS angle
LONS2	MA-048 MA-083 MA-088	177	Longitude of the vehicle in the ecliptic mean of 1950.0 coordinate system
ESLOS	MA-048 MA-083 MA-088	178	Angle between Earth-Sun vector and the LOS
ESLOSS	MA-048 MA-083 MA-088	179	Supplement of ESLOS
THETA	MA-106	180	Angle between X_v-axis and the perpendicular to the CSM velocity vector
BMAG	MA-106	181	Magnetic field intensity (gauss)
LMAG	MA-106	182	L-shell radius (e.r.)

TABLE B-III.- EXPERIMENT SUPPORT DATA TAPE FORMAT - Continued

Parameter name(s)	Type of parameter	Parameter location	Parameter definition
ALPH10, BETA10, PHI10	MA-106	183-185	Orientation angles of the vehicle body axes wrt the UEN
LATA, LONA	MA-136	186-187	Geodetic latitude and longitude of the FOV A corner
LATB, LONB	MA-136	188-189	Geodetic latitude and longitude of the FOV B corner
LATP, LONP	MA-136	190-191	Geodetic latitude and longitude of the principal point
LATC, LONC	MA-136	192-193	Geodetic latitude and longitude of the FOV C corner
LATD, LOND	MA-136	194-195	Geodetic latitude and longitude of the FOV D corner
SF	MA-136	196	Scale factor
DT	MA-136	197	Time interval between adjacent photographs
ALTR	MA-136	198	Attitude rate wrt the principal point
HV	MA-136	199	Horizontal velocity wrt the principal point
TILTAZ	MA-136	200	Tilt azimuth angle
TILT	MA-136	201	Tilt angle
SELP, SAZP	MA-136	202-203	Sun elevation and azimuth wrt the principal point
LATS, LONS	MA-136	204-205	Subsolar point - geodetic latitude and longitude
ALPHA	MA-136	206	Alpha angle
SWING	MA-136	207	Swing angle
EMISS	MA-136	208	Emission angle

TABLE B-III.- EXPERIMENT SUPPORT DATA TAPE FORMAT - Concluded

Parameter name(s)	Type of parameter	Parameter location	Parameter definition
PHASE	MA-136	209	Phase angle
NDA	MA-136	210	North deviation angle
XTILT	MA-136	211	x-tilt angle
YTILT	MA-136	212	y-tilt angle
HEAD	MA-136	213	Heading angle
SR	MA-136	214	Slant range to the principal point
OVR	MA-136	215	Forward overlap ratio
PHI, KAPPA, OMEGA	MA-136	216-218	Angles that rotate the camera axes system into the local-horizontal system
AL	MA-136	219	Surface arc length between nadir and the principal point
FL	MA-136	220	Focal length of camera lens
LOSX, LOSY, LOSZ	MA-136	221-223	Direction cosines of the camera LOS vector in the geographic coordinate system
GC11, GC12, GC13	MA-136	224-226	Row 1 of the geographic to camera transformation
LH11, LH12, LH13	MA-136	227-229	Row 1 of the local horizontal to camera transformation
GC21, GC22, GC23	MA-136	230-232	Row 2 of the geographic to camera transformation
LH21, LH22, LH23	MA-136	233-235	Row 2 of the local horizontal to camera transformation
GC31, GC32, GC33	MA-136	236-238	Row 3 of the geographic to camera transformation
LH31, LH32, LH33	MA-136	239-241	Row 3 of the local horizontal to camera transformation

TABLE B-IV.- MA-059 OBSERVATION TAPE FORMAT

(a) Header record

The header record is defined as follows.

Word	Value
1-2	Double-precision Julian date (input)
3	Date of run: DAY-MONTH-YEAR (12 bits each)
4	Time of run: HRS-MIN-SEC (12 bits each)
5	1108_____M
6	ASTER_____
7-50	Comments

(b) Data record

Word	Bits	
1	0-17	Zero
1	18-35	Sequence number (1,3,5,...)
2	0-17	CSM (alphanumeric)
2	18-35	SOY (alphanumeric)
3	0-5	6 (right adjusted)
3	6-11	Zero
3	12-17	Zero
3	18-23	Zero
3	24-29	2 (right adjusted)
3	30-35	6 (right adjusted)
4	0-17	Same as word 3, bits (0-17)
4	18-35	Blank
5	0-35	Bit 32 = 1; 0 otherwise
6	0-35	Zero

TABLE B-IV.- MA-059 OBSERVATION TAPE FORMAT - Concluded

(b) Data record - Concluded

Word	Bits	
7-8	0-71	Time from base day (min)
9-10	0-71	Zero
11-12	0-71	Zero
13-14	0-71	$\pi/2$ rad
15-16	0-71	Zero
17-18	0-71	Zero
19-20	0-71	Inner GA (rad)
21-22	0-71	Middle GA (rad)
23-24	0-71	Outer GA (rad)
25-32	-	Zero

The total size of the data record is 640 words (twenty 32-word frames).

(c) Final record

The tape is terminated by an end-of-tape frame. This 32-word frame consists of 30 alphanumeric words of THE END in words 1-6 and 9-32 and 1 double-precision word (7-8) of 1.D30. This end-of-tape frame is placed in the remaining frames of an incomplete data record or in all 20 frames of the data record following a complete data record.

(d) EOF

An EOF mark is placed after the final record.

APPENDIX C - COMPUTER COMPATIBLE TAPE FORMATS

APPENDIX C

COMPUTER COMPATIBLE TAPE FORMATS

1.0 INTRODUCTION

The purpose of this appendix is to summarize the tape formats associated with the conversion of ASEP output tapes from the Univac 1180 computer to other computers. For completeness, the formats for all principal investigator experiment support tapes are included below.

C2.0 TAPE FORMAT FOR MA-007 (LRC)

Machine	- CDC 6600
Density	- 800 bpi
Parity	- odd (binary)
Number tracks	- 7
Word length	- 60 bits
Word type	- floating point
Number of words	- 241 data words per record. See appendix B5.0 for the definition of the data words.
Read	- Use Fortran binary read. The tape assign card should specify that the tape is an "L" tape written at 800 bpi. The word count should specify one more word than the largest record.

C3.0 TAPE FORMAT FOR MA-007 (UNIVERSITY OF WYOMING)

Machine	- Sigma 7. JSC does not have a Univac 1108 to Sigma 7 conversion package. However, the University of Wyoming does have a CDC 3000 to Sigma 7 conversion package. So a CDC 3000 compatible tape is supplied to the university.
Density	- 800 bpi
Parity	- odd (binary)
Number tracks	- 7
Word length	- 48 bits

Word type	- floating point
Number of words	- 243 words per record, of which the last two words are zeros. See appendix B5.0 for the definition of the first 241 words.
Read	- Use "BUFFER IN."

C4.0 TAPE FORMAT FOR MA-048

Machine	- CDC 3800
Density	- 556 bpi
Parity	- odd (binary)
Number tracks	- 7
Word length	- 48 bits
Word type	- floating point
Number of words	- 243 words per record, of which the last two words are zeros. See appendix B5.0 for the definition of the first 241 words.
Read	- Use "BUFFER IN."

C5.0 TAPE FORMAT FOR MA-059 (JSC)

Machine	- Univac 1108
Density	- 800 bpi
Parity	- odd (binary)
Number tracks	- 7
Word length	- 36 bits
Word type	- floating point
Number of words	- 241 data words per record. See appendix B5.0 for the definition of the data words.
Read	- Use Fortran binary read.

C6.0 TAPE FORMAT FOR MA-059 (UNIVERSITY OF MICHIGAN)

Machine	- IBM 371/68. An IBM 360 tape is compatible with the IBM 371/68 machine. So an IBM 360 tape is supplied to the university.
Density	- 800 bpi
Parity	- odd (binary)
Number tracks	- 9
Word length	- 32 bits
Word type	- floating point
Number of words	- 243 words per record, of which the last two words are zeros. See appendix B5.0 for the definition of the first 241 words.

C7.0 FORMAT FOR MA-083

Machine	- Interdata 70. An IBM 360 tape is compatible with the Interdata 70 machine. So an IBM 360 tape is supplied to the principal investigator.
Density	- 556 bpi
Parity	- odd (binary)
Number tracks	- 7
Word length	- 32 bits
Word type	- floating point
Number of words	- 243 words per record, of which the last two words are zeros. See appendix B5.0 for the definition of the first 241 words.

C8.0 FORMAT FOR MA-088

Machine	- Interdata 70. An IBM 360 tape is compatible with the Interdata 70 machine. So an IBM 360 tape is supplied to the principal investigator.
Density	- 556 bpi
Parity	- odd (binary)

Number tracks - 7

Word length - 32 bits

Word type - floating point

Number of words - 243 words per record, of which the last two words are zeros. See appendix B5.0 for the definition of the first 241 words.

C9.0 TAPE FORMAT FOR MA-089

Machine - CDC 6400

Density - 800 bpi

Parity - odd (binary)

Number tracks - 7

Word length - 60 bits

Word type - floating point

Number of words - 241 data words per record. See appendix B5.0 for the definition of the data words.

Read - Use Fortran binary read. The tape assign card should specify that the tape is an "L" tape written at 800 bpi. The word count should specify one more word than the largest record.

C10.0 TAPE FORMAT FOR MA-106

Machine - CDC 7600. A CDC 6600 tape is compatible with the CDC 7600 machine. So a CDC 6600 tape is supplied to the principal investigator.

Density - 800 bpi

Parity - odd (binary)

Number tracks - 7

Word length - 60 bits

Word type - floating point

Number of words - 241 data words per record. See appendix B5.0 for the definition of the data words.

Read - Use Fortran binary read. The tape assign card should specify that the tape is an "L" tape written at 800 bpi. The word count should specify one more word than the largest record.

C11.0 TAPE FORMAT FOR MA-136 (DMAAC)

Machine - Univac 1108

Density - 800 bpi

Parity - odd (binary)

Number tracks - 7

Word length - 36 bits

Word type - floating point

Number of words - 241 data words per record. See appendix B5.0 for the definition of the data words.

Read - Use Fortran binary read.

C12.0 TAPE FORMAT FOR MA-136 (SMITHSONIAN INSTITUTE)

Machine - Univac 1108

Density - 800 bpi

Parity - odd (binary)

Number tracks - 7

Word length - 36 bits

Word type - floating point

Number of words - 241 data words per record. See appendix B5.0 for the definition of the data words.

Read - Use Fortran binary read.

APPENDIX D - ASTP POSTFLIGHT EXPERIMENT SUPPORT DATA ACCURACIES

APPENDIX D

ASTP POSTFLIGHT EXPERIMENT SUPPORT DATA ACCURACIES

D1.0 INTRODUCTION

Many principal investigators (PI's) for the Apollo-Soyuz Test Project (ASTP) have expressed interest in the accuracy of ephemeris, pointing, and field-of-view information that they will receive from the Mission Planning and Analysis Division (MPAD) as a part of their postflight experiment support data requirements. Because of the nature of the many parameters that affect the uncertainties, there is no straightforward method of describing these accuracies for all cases. Parameters that directly affect these accuracies, such as the uncertainty in the vehicle ephemeris, can vary radically for different mission phases. The accuracy of the pointing data used by an investigator may improve as his knowledge of his instrument misalinement is refined through data processing and analysis. For these and many other reasons, it is desirable to devise a method through which each investigator may determine his own expected accuracies on the basis of his own particular set of conditions. This report describes the error sources that contribute ephemeris, pointing, and field-of-view uncertainties, in such a manner that each PI may use the postflight information provided by the MPAD to compute his own particular expected errors.

D2.0 SYMBOLS

ASTP	Apollo-Soyuz Test Project
d	distance
EOM	end of mission
g	acceleration of gravity at the Earth's surface
IMU	inertial measurement unit
MPAD	Mission Planning and Analysis Division
nav.	navigation
PI	principal investigator
rss	root-sum-square
Δt	elapsed time
δp	position error

D3.0 ANALYSIS

The MPAD will provide three basic classes of data to PI's requesting data - spacecraft ephemeris, spacecraft orientation, and instrument pointing. The first two classes are mutually exclusive (computed independently), and consequently their uncertainties are not related. Pointing errors, however, are a function of both ephemeris errors and orientation errors, as well as instrument misalinement. To understand this relationship, it is necessary to understand the transformations required to express the instrument line-of-sight definition in an Earth-fixed inertial system.

The nominal instrument line-of-sight is defined by a set of alinement angles that relate the line-of-sight to the rigid body of the Apollo spacecraft, or the navigation (nav.) base coordinate system. This transformation notation matrix is defined as $[F]^T$. The spacecraft body, in turn, can be related to the nominal inertial measurement unit (IMU) or reference platform coordinate system by the rotation defined by the matrices $[D]^T$ and $[G]^T$. The G matrix relates the actual IMU system to the nav. base system and is computed from the spacecraft orientation, or gimbal angles. The D matrix relates the nominal and actual IMU systems and accounts for platform misalinements and/or drift, if known. The nominal IMU system is related to the Earth-fixed system through a rotation matrix, $[R]^T$. The R matrix is known as REFSMMAT. By combining these rotations, the nominal instrument line-of-sight can be defined in the Earth-fixed coordinate system by utilizing the rotation matrix $[FGDR]^T$. This, then, defines the direction of the line-of-sight. The direction of the line-of-sight must be combined with the position of the instrument in Earth-fixed space to compute what the instrument is viewing. In practice, the spacecraft position is normally assumed as the instrument position, and spacecraft center of gravity/instrument location offsets are ignored. The effect of this assumption is an error of 3 meters or less for viewing distances of at least 225 kilometers, or an angular field-of-view error of less than 0.001 degree. Once the relationships discussed above are understood, it becomes reasonably simple to determine the prime sources of error in instrument line-of-sight and/or field-of-view computations.

The IMU is alined by the astronauts by observing known stars in their sextant. The 3σ uncertainty in a nominal alinement is 0.03 degree. The platform will drift from this initial alinement. The expected 3σ drift is 0.09 deg/hr. By computing the drift rates following each alinement and compensating for them, this uncertainty can be reduced to 0.02 deg/hr. All known drifts will be removed in the processing of instrument orientation data for ASTP experiment support. Thus, the expected 3σ uncertainty in the REFSMMAT, or R rotation, is 0.03 degree plus the uncertainty due to platform drift (0.02 deg/hr). The D rotation is an identity unless misalinement and/or IMU drift are known and accounted for. Since the experiment support data will be corrected for drift, the uncertainty in the R rotation due to drift will be 0.02 deg/hr. For each case, the actual uncertainty due to drift is determined by the time interval between the latest alinement and the observation being performed. Thus, if observations are performed 90 minutes following a platform alinement, the expected IMU orientation uncertainty would be 0.03 degree due to misalinement and 0.03 degree due to drift, or a total of 0.042 degree (root-sum-square (rss)).

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The relationship of the spacecraft or nav. base coordinate system to the platform system is described by the rotation matrix G. The expected 3σ error in boresighting the nav. base (the mounting error in the platform relative to the spacecraft body) is 0.05 degree. The expected error due to inaccuracies in the gimbal angles is 0.01 degree per axis, or a total rss error of 0.017 degree. Thus, the total expected error in the G transformation is 0.053 degree.

The transformation from the spacecraft body or nav. base system to the nominal instrument system described by the F transformation matrix is the largest error source in the line-of-sight computations. The error sources affecting this rotation and the corresponding error magnitudes are listed below.

1.	Instrument alinement	0.50°
2.	Mounting hole accuracy	0.25°
3.	1-to-zero-g structural deflections	1.00°
4.	Structural thermal variations	0.33°
	Total (rss)	1.19°

These error sources are collectively referred to as instrument misalinement.

The rotations discussed above determine the orientation of the instrument line-of-sight. To determine its position in space, and thus the point being viewed and/or the field-of-view, the vehicle position is also required. The 3σ uncertainties in the inertial vehicle position for the ASTP experiment support data will range from a minimum of 600 meters to as much as 10 kilometers. Nominally, these errors will be about 3 kilometers, 3σ. Only in cases such as the MA-059 data takes, where considerable command-and-service-module thrusting is taking place, should the uncertainties exceed 3 kilometers.

These position uncertainties will have varying effects on the accuracy of line-of-sight and field-of-view calculations, depending on the distance to the object being viewed. For the limiting case, star observations, the target, for all practical purposes, is at an infinite distance and the pointing computations are unaffected by vehicle position variations. For other cases - in particular, for Earth observations, where the target may be as close as 225 kilometers - the vehicle position errors can become significant. For the case of highest expected uncertainty, where the maximum expected error of 10 kilometers is combined with a minimum target distance of 225 kilometers, the angular error in the computed field-of-view could reach 2.55 degrees.

Obviously, the effects of spacecraft position errors cannot be simply generalized. Each case must be examined separately, with consideration given to both the magnitude of the expected position error and the distance of the target. The MPAD will provide PI's with trajectory uncertainties for each segment of the mission.

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On the basis of the discussions in the preceding paragraphs, the error sources that affect instrument line-of-sight and field-of-view calculations can be summarized as follows.

Source	Magnitude (degrees)
1. Platform misalinement	0.03°
2. Platform drift	$(0.02^\circ/\text{hr})(^{a}\Delta t)$
3. Nav. base misalinement	0.05°
4. Gimbal angle errors	0.02°
5. Instrument misalinement	[b]1.19°
6. Field-of-view uncertainty	Experiment dependent
7. Vehicle position error	Experiment dependent

[a] Δt is the time, in hours, from the latest platform alinement to the time of interest.

[b] If not corrected.

Sources 1, 3, and 4 are fixed and will be the same for all cases. Source 2 varies with Δt and must be determined separately for each case. Source 5 is fixed unless the PI is able to recover a misalinement estimate from his data. In its processing, the MPAD will include a rotation to account for instrument misalinement. This rotation will nominally be an identity unless the PI is able to specify the misalinements prior to the processing. These will be required by end of mission (EOM) + 3 months at the latest, and notification that a nonzero misalinement is expected will be required by EOM + 6 weeks. In the event that the misalinement error magnitude is to be corrected in the processing, the uncertainty estimate to replace the uncorrected uncertainty of 1.19 degrees will have to be determined by the PI. In no cases should this uncertainty be reduced significantly below the 0.33 degree due to thermal variations. Source 6 is the uncertainty in the geometric definition of the instrument field-of-view. It does not affect line-of-sight calculations. Again, determination of the magnitude of this uncertainty is the responsibility of the PI. Source 7, as previously discussed, must be evaluated separately for each case and may vary from zero degrees, for star observations, to several degrees for local-vertical Earth observations. The formula for approximating the uncertainty is

$$3\sigma = \sin^{-1} \delta p/d$$

where δp is the spacecraft position uncertainty (to be provided by the MPAD) and d is the distance to the target.

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The ASTP PI, by evaluating the magnitude of the uncertainty contributed by each of the seven sources noted previously and determining the root-sum-square of the results, can evaluate his expected pointing error for any segment of the mission.

APPENDIX E - MISSION-SPECIFIC DATA

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MISSION-SPECIFIC DATA

(TO BE PUBLISHED)

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REFERENCES

1. Apollo-Soyuz Test Project Reference Trajectory. JSC IN 74-FM-60, Sept. 1974.

2. Apollo-Soyuz Test Project Reference Attitude and Pointing Time Line. JSC IN 74-FM-87, Dec. 1974.

3. Houston Operations Predictor/Estimator (HOPE) User's Manual. TRW Note No. 70-FMT-931, Jan. 1974.

4. Houston Operations Predictor/Estimator (HOPE) Engineering Manual, Revision 01. TRW Note No. 70-FMT-792A, June 1970.

5. Houston Operations Predictor/Estimator (HOPE) Programing Manual. TRW Note No. 70-FMT-794, Feb. 1970.

6. Mission Requirements CSM-111/DM-2. JSC-08819, Change B, Apr. 1975.

7. ASTP Basic Flight Plan. Oct. 1974.

8. Wollenhaupt, W. R.: Experiments Support Data Archival Plans for ASTP. JSC Memo FM85 (75-84), Mar. 1975.

9. Computer Programs for the Computation of B and L (May 1966), NSSDC 67-27.

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