Technical Memorandum No. 33-199

SFPRO—Single Precision Cowell Trajectory Processor

Alan D. Rosenberg
Robert J. White
Peter S. Fisher
Raymond A. Harris
Nicholas S. Newhall

N 66 24601

(JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA)

January 15, 1966

GPO PRICE $  
CFSTI PRICE(S) $
Hard copy (HC) $6.00 
Microfiche (MF) $1.25

653 July 65
Technical Memorandum No. 33-199

SFPRO—Single Precision Cowell Trajectory Processor

Alan D. Rosenberg
Robert J. White
Peter S. Fisher
Raymond A. Harris
Nicholas S. Newhall

James F. Scott, Group Supervisor
Trajectory Systems Programming

H. Fred Lesh, Manager
Computer Applications

JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

January 15, 1965
CONTENTS

I. Introduction .......................................................... 1
II. Basic Program Logic .................................................. 5
   A. Phasing ........................................................... 6
   B. End-of-Step Calculations ........................................ 7
   C. Derivative Box ................................................... 7
III. Machine and System Configuration ................................. 8
IV. Input ................................................................. 9
   A. Input Capability .................................................. 9
   B. Input Definition ................................................ 10
   C. JPTRAJ Restrictions ............................................. 13
      1. Program Control Block ....................................... 14
      2. Symbol Table ................................................ 15
   D. Common Map and Load Map ..................................... 16
   E. Input Forms ..................................................... 25
   F. Spacecraft Ephemeris Tape Format ............................. 33
V. Output ............................................................... 35
   A. SAVE Tape Format ............................................... 35
   B. Printed Output Format and Definitions ....................... 37
   C. Job-Shop Output Capability ................................... 45
   D. SFOF Output Capability ....................................... 46
VI. Subroutines ......................................................... 47
   1 - ABORT/ERPRT/JEXIT/PRSET/....../TIME ...................... 48
   2 - ADD ............................................................ 50
   3 - ARCOS/ARSIN ............................................... 51
   4 - ARTAN ........................................................ 52
   5 - BCDNO/NEWBCD .............................................. 53
   6 - CHANGE ....................................................... 54
   7.1 - CLASS ....................................................... 55
   7.2 - JEKYL ....................................................... 59
   7.3 - SPECL ....................................................... 63
   8 - CLUCK ........................................................ 65
   9 - COS/SIN/QCOS/QSIN ......................................... 66
  10 - CROSS/PROD/UNIT ............................................. 67
CONTENTS (Cont'd)

11 - DAYS ........................................ 69
12 - DUMMY/EOS/CANCLK/DATCEL/RGGSAV/RGGSTR/
    EXPORT ...................................... 70
13 - EARTH/SPACE .............................. 71
14 - ECLIP ...................................... 74
15 - EFFECT ..................................... 76
16 - EPHEM ...................................... 77
17 - EPHSET/E. T./INTR1 .......................... 83
18 - FIX/FLOAT ................................. 85
19 - FIXT/FLOT ................................... 86
20 - GEDLAT ..................................... 88
21 - GETTER ..................................... 90
22 - GHA ........................................ 91
23 - GRUPPE .................................... 93
24. 1 - INTRAN .................................. 94
24. 2 - NUTATE .................................. 95
24. 3 - RESET .................................... 96
24. 4 - ROT ....................................... 97
25 - LN/LOG10 .................................... 98
26 - LOOP ......................................... 99
27 - MARSMM/MARSPC/MARFIX/MHA/PMAT/PPMAT ....... 111
28. 1 MATRIX .................................... 115
28. 2 - MNA/MNA1/MNAMD/MNAMD1/NUTEPH/NUTLON/
    NUTOBL ....................................... 116
29 - PATH/DIST ................................... 125
30 - PLLLT/PLTSET/PLTQ/FILENO/RECNUM/CANCLK ...... 126
31 - PRINTD/PRNTD1/CONIC ........................... 128
32 - PROUT/FLUSH ................................ 130
33 - READN/READ1/READC/SPAM .................... 138
34 - ROTEQ/DELTJD ............................... 139
35 - RVIN/RVOUT ................................ 142
36 - SAVEIT ..................................... 145
37 - SEITE/CASE/EJECT/EJECT1/LINES/PAGBCD ....... 149
## CONTENTS (Cont'd)

<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>SPASM</td>
<td>150</td>
</tr>
<tr>
<td>39</td>
<td>SPRAY</td>
<td>152</td>
</tr>
<tr>
<td>40</td>
<td>SQRT</td>
<td>153</td>
</tr>
<tr>
<td>41</td>
<td>TIME1/TIME2/TIME3/LAUNCH</td>
<td>154</td>
</tr>
<tr>
<td>42.1</td>
<td>TRAJ</td>
<td>156</td>
</tr>
<tr>
<td>42.2</td>
<td>FLOTT</td>
<td>157</td>
</tr>
<tr>
<td>43</td>
<td>WOLF/TIM/MACH</td>
<td>158</td>
</tr>
<tr>
<td>VII.</td>
<td>Check Cases</td>
<td>159</td>
</tr>
<tr>
<td>A.</td>
<td>Case 1</td>
<td>161</td>
</tr>
<tr>
<td>B.</td>
<td>Case 2</td>
<td>173</td>
</tr>
<tr>
<td>C.</td>
<td>Case 3</td>
<td>183</td>
</tr>
<tr>
<td>D.</td>
<td>Case 4</td>
<td>203</td>
</tr>
<tr>
<td>References</td>
<td></td>
<td>207</td>
</tr>
</tbody>
</table>
SFPRO, a Single Precision Cowell Trajectory Processor, is a link under the JPL IBSYS-SFOF-JPTRAJ monitor. SFPRO is a digital computer program written in the FAP language for the IBM 7094 computer. Created because of core limitations imposed by the SFOF system, SFPRO, in combination with SPACE, a Single Precision Cowell Trajectory Program, preserves the full output capability of the older JPL Space Trajectories Program. Given a spacecraft ephemeris tape generated by SPACE, SFPRO can perform tracking station view period calculations, and at specified intervals of time it can generate tracking station printouts, and printouts of spacecraft position and velocity and other quantities relative to the Earth, the Sun, and the target body, referenced to any of several planes. SFPRO can generate a binary SAVE tape, containing a time history of the position and velocity of the spacecraft with reference to the bodies of the integration scheme of SPACE, the orientation of the spacecraft with reference to as many as five tracking stations, and various auxiliary quantities. The spacecraft ephemeris contains all physical constants and other data which define the trajectory of a spacecraft. Therefore the trajectory cannot be modified by SFPRO. The program has all the output capabilities of SPACE, and in addition, the tracking station and SAVE tape options.

Herein presented are the general logic flow of SFPRO, definitions of input and output, hardware and software configurations, and interfaces of the program with the systems.

I. INTRODUCTION

SFPRO, Single Precision Cowell Trajectory Processor, originated from a need to maintain capabilities previously available in the JPL Space Trajectories Program, described in Ref. 1 and 2 Section VIII, while producing a program which would operate under the IBSYS-SFOF-FPTRAJ monitor. The core storage requirements of such a program dictated that two separate links be written.

One link, SPACE, Single Precision Cowell Trajectory Program, would provide the trajectory integration and normal printing capability, and would
generate a chronologically ordered collection of data on magnetic tape, consisting of the results of integrating the equations of motion in SPACE, and other quantities generated by the integrator in performing its task. This collection of data is known as a spacecraft (or probe) ephemeris.

The spacecraft ephemeris becomes input data to SFPRO, which then produces printing as requested, computes epochs of tracking station view periods, and generates a trajectory SAVE tape on input request. A SAVE tape consists of records of fixed format containing position and velocity information for the spacecraft and the bodies of the integration scheme, as well as tracking station-related data and other quantities of engineering interest.

The JPL Double Precision Ephemeris System is used by SFPRO to determine planetary and lunar position and velocity when these quantities are required for output purposes.

SFPRO produces printed output with respect to the centers of the Earth, the Sun and the target body specified when the spacecraft ephemeris was generated by SPACE. The coordinate frames in which positions, velocities and angular quantities may be expressed are mean Earth equator and equinox of 1950.0, mean ecliptic and equinox of 1950.0, mean Earth equator and equinox of date, mean ecliptic and equinox of date, or true ecliptic and equinox of date. When Mars is the target selected and aerocentric output is requested, position and velocity of the spacecraft and the angular orientation of the Earth and Sun will be computed based on a Mars equator and equinox system assumed not to precess or nutate from its 1950.0 orientation. This coordinate system and its generation are described in subroutine 27 (Section VI). With the Moon as target, spacecraft position, velocity, and certain angular quantities are computed and printed with respect to a true lunar equator (selenographic-spherical) coordinate system whose formation is indicated in Section VI in subroutine 28.2.

Conic output may be called for; this expresses the osculating two-body orbit of the spacecraft with respect to the Earth, Sun or target in many sets of orbital elements referred to any of the above mentioned standard frames of reference, and in addition, to the plane of the orbit of the target body about its "parent" body, i.e. Earth-Moon or Sun-planet.

Tracking stations of the Deep Space Instrumentation Facility (DSIF) may be simulated using a topocentric spherical coordinate system, the positions of 15 DSIF stations being defined in SFPRO. The times of spacecraft rise,
extreme elevation and set with respect to the stations and the orientation of the spacecraft relative to the stations at these times can be computed and printed. This is the view period capability.

Simultaneously, these same quantities can be printed with the other blocks of output at the times specified for that output, during the duration of the spacecraft's visibility to a specific tracking station. This type of output is known as station prints.

Certain quantities computed relative to the stations are oriented toward the hardware configurations of the DSIF stations. In particular, equations for doppler frequency calculations are based on certain types of receiving and transmitting equipment. The antenna of a station may be mounted in the local horizontal plane, and is referred to as an azimuth-elevation (AZ-EL) station, or parallel to the Earth's equator, with the designation of hour angle-declination (HADEC). The DSIF stations are of both types, but the choice of computations may be made by input. The equations for tracking station quantities appear in subroutine Z6 in Section VI.

Requests for type and density of printing are made to SFPRO by use of "phasing". In each phase, three printing intervals and two odd-time prints are available, and any of the standard output blocks described in Section VB may be printed at these times. View periods and station prints are also requested in the phasing portion of the input.

Phasing may also be utilized to print when the spacecraft reaches a given distance from a specified body or at the point of closest approach to an input body. A phase is terminated when the print end time of the last print interval of the phase is reached, or at the attainment of closest approach or the desired radius.

As many as eight phases may be used in processing a spacecraft ephemeris, the only constraint being that any SFPRO phase must request by input the same integration central body as used by SPACE in the generation of that portion of the spacecraft ephemeris.

Of significant importance is the generation of trajectory SAVE tapes. When requested by input, a binary tape is produced by SFPRO with records of fixed size, each containing position and velocity of the spacecraft relative to the seven bodies of SPACE, angles relating the spacecraft to the principle
bodies, and to any of the DSIF tracking stations, up to five in number. Section \( \text{VA} \) contains a complete description of the format of a SAVE tape. A record is produced after passage of time equal to an input multiple of the integration step size used by SPACE, a quantity found on the spacecraft ephemeris tape.

The SAVE tapes generated by SFPRO are used as input to several programs at the Jet Propulsion Laboratory. These include a Plotting Program, a Spacecraft Attitude Reference Program, a Star Identification Program, and a Communications Prediction Program, all of which were used in connection with the Mariner 1964 mission.

The spacecraft ephemeris tape provided by SPACE has one basic format, with two options available. In either option, the first record contains identification information sufficient to specify a unique trajectory. The second through the last record each contains the integrated position and velocity of the spacecraft at the end of a series of integration steps, usually six, and the finite differences computed in the integration process. Section VI, subroutine 31, Ref. 10 describes the integration process and defines the above-mentioned finite differences. One option produces a spacecraft ephemeris which contains the integration of the variational equations, and the associated finite differences, as well as the position and velocity data. Section VI, subroutine 43 of Ref. 10 indicates the formulation of the variational equations used in SPACE. The other option is as above, but without the variational equations and the corresponding finite differences. The variational equations are mentioned here because they effect the contents of the spacecraft ephemeris, but they are not utilized by SFPRO.

Because the leading record of a spacecraft ephemeris contains the values of all physical constants, initial conditions and other related data used in the integration of a trajectory by SPACE, there is no way in which the trajectory may be altered by SFPRO.

A spacecraft ephemeris need not be processed by SFPRO immediately after its generation by SPACE. In addition, the spacecraft ephemerides for several trajectories may be placed on one physical tape due to a serialization feature which identifies spacecraft ephemerides. The value of the serialization assembled in SFPRO and the method of modification is described in Section VI, subroutine 33, and a detailed description of spacecraft ephemeris record format appears in Section IVF.
II. BASIC PROGRAM LOGIC

The operation of SFPRO can be separated into four logical segments. These are herein enumerated as initialization, phasing, end-of-step, and derivative box. Details of the latter three follow in Sections IIA, IIB, and IIC respectively.

In the initialization process, the identification record of the spacecraft ephemeris is read to obtain the data which defines the trajectory to be processed (see Section IVF for the spacecraft ephemeris tape identification record format). This data consists in part of the initial time and coordinates of the spacecraft as they were originally input to SPACE, the body to which these are referenced, and the target body name. The values of the physical constants used in SPACE and other data either defining the trajectory or which are necessary for processing the spacecraft ephemeris tape are also part of this identification record. The initial conditions and physical constants are printed at the beginning of each processed trajectory in the format specified in Section VB. Should the generation of a trajectory SAVE tape be requested by input, this process is initialized by subroutine 30, PLTSET, in Section VI.

The phasing, described in detail in Section IIA, is now examined to determine the frequency of printing to be used in the first phase of the processing. On this basis, triggers are set up which inform the spacecraft ephemeris interpolation subroutine 38, SPASM, in Section VI, of the times at which it is to interrupt its processing to allow printing to occur. In similar fashion, triggers are set up for the station view period option, which like print times, is requested in each phase. Section IVB indicates the type of input required to request printing and view period computation. Subroutine 26, LOOP, Section VI, describes in detail the calculations used in determining view periods.

At this point the derivative box (Section IIC) is entered once to bring the first integrated data record from the spacecraft ephemeris into the portion of storage known as the HBANK, which is explained in subroutine 38, SPASM, Section VI. This is the final step of the initialization process and SPASM, the spacecraft ephemeris interpolator, is now prepared to begin processing.
A. PHASING

A method of segmenting a trajectory to provide a flexible output capability is utilized by SFPRO and is known as phasing. It is similar in many respects to that used by the program SPACE (Ref. 10), but not entirely the same. In SFPRO, phasing is used to control the times, frequencies, and types of printing desired. But unlike the phasing in SPACE, no means is available to control the integration of the trajectory in the phasing of SFPRO, as the integrated trajectory is indeed the primary input to SFPRO.

Internal to SFPRO, in subroutine 42.1, TRAJ (Section VI), are nominal sets of phasing for three prevalent cases, i.e., when the target is the Moon, Venus, or Mars. These "canned" phases are identical to their counterparts in SPACE, and provide a minimal amount of output suitable for the particular target body, and terminate processing at impact on or closest approach to the target. The canned phasing may be modified or completely overridden by input. In the event that a body other than those mentioned above is the target, phasing must be input which reflects this fact. Section IVB contains definitions of these and all other input parameters to SFPRO. Should a spacecraft ephemeris cover a shorter duration than the processing period requested in SFPRO, notice of this is given and processing is terminated. Conversely, a spacecraft ephemeris need not be processed to its full length, such processing to be terminated by the appropriate phasing input.

A phase ends when one of three possible conditions is satisfied, on the basis of whichever occurs first. If the final print time for a phase is reached, this causes termination of the phase. When the spacecraft reaches a distance from a body, both the distance and the body being inputs to the phasing, or when the spacecraft reaches closest approach with the target body, the phase is terminated. One must specify for each phase whether it is to be the last phase of the trajectory.

It is possible that the position of the spacecraft may not be known precisely enough beforehand for the user to ascertain in which phase to start processing, i.e., whether to start geocentric or selenocentric. If desired, for phasing which is identical or similar to that canned, the program will determine from the initial position of the spacecraft and the planetary ephemerides the phase in which to begin processing. This is referred to as "automatic phasing" and this mode is assumed by the program but may be overridden by input (again, see Section IVB).
B. END-OF-STEP CALCULATIONS

The "end-of-step box" is that coding to which subroutine SPASM, the spacecraft ephemeris interpolator, transfers at the end of each integration step it processes. Subroutine 38 (Section VI) spells out the details of the linkage between SPASM and the end-of-step box, which is located in subroutine TRAJ, 42.1.

Upon completion of processing each step, certain quantities must be recomputed to reflect the changes in the position and velocity of the spacecraft over that step, and the change in time itself. The quantities involved are the positions and velocities of the n-bodies with respect to the integration central body, referenced to the mean Earth equator and equinox of 1950.0, and the magnitudes of the n-body--central body, and n-body--spacecraft position vectors. Also updated at this time are the current values of quantities which are dependent variables for the trigger logic of SPASM. Included in this group are topocentric quantities for view period triggers (see LOOP, subroutine 26) and quantities for shadow and back-up target impact triggers. Subroutine 30, PLLLT, Section VI, is called and will generate a trajectory SAVE tape record if one has been requested by input. The arc distance travelled by the spacecraft is updated by subroutine 29, PATH, Section VI, for use with the public information output described in Section VB. Control is always returned to SPASM.

C. DERIVATIVE BOX

The "derivative box" logic in subroutine TRAJ is used by SPASM, and provides the latter with integrated data read from the spacecraft ephemeris by the subroutine 33, READN. When SPASM has processed all the data in its HBANK from the previous spacecraft ephemeris record, the next record is then read into the HBANK by READN. After a new record is read by READN the flag words in this record are examined in the derivative box and if they reflect a discontinuity in the integration an appropriate comment is written on SYSOUI. The trajectory is terminated by calling subroutine 1, ABORT, Section VI, if the last data record is passed, as a backup precaution. Hence a user should terminate a trajectory through the phasing capability and not allow SFPRO to run out of data. Unless the run is aborted, the derivative box returns control to SPASM.
III. MACHINE AND SYSTEM CONFIGURATION

There are two computer systems in use at the Jet Propulsion Laboratory. One is the standard IBM 7094 IBSYS job-shop system. It is used for daily checkout and production. The other system is the JPL SFOF system, which is used to process spacecraft data and to allow input, output, and control at remote user areas.

SFPRO, under JPTRAJ, satisfies all the requirements of both systems and can therefore be used in any of the various modes of operation. Core storage is allocated as follows:

<table>
<thead>
<tr>
<th>Octal Locations</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-3777</td>
<td>IBSYS</td>
</tr>
<tr>
<td>4000-21077</td>
<td>SFOF</td>
</tr>
<tr>
<td>21100-22277</td>
<td>JPTRAJ</td>
</tr>
<tr>
<td>22300-77777</td>
<td>SFPRO</td>
</tr>
</tbody>
</table>
IV. INPUT

A. INPUT CAPABILITY

Data in the SFPRO link of a JPTRAJ source deck is input by JPTRAJ just prior to the execution of SFPRO. JPTRAJ does this with the aid of SFPRO's symbol table. In addition, data can come from other links in the JPTRAJ source deck by proper use of the JPTRAJ "WANT" and "USE" control cards. Here again, JPTRAJ uses SFPRO's symbol table. SFPRO has no input subroutine so that when JPTRAJ transfers control to SFPRO all input is completed (i.e., there is no on-line input capability in SFPRO). This restriction is circumvented by using "WANT" control cards and a link named TRIO (Ref. 11, Section VIII).

The binary tape-read subroutines EPHSET and EPHEM have been included in SFPRO for reading the n-body ephemeris tape.

Sense switches 4 and 6 on the 7094 console may be used to input a request to SFPRO for on-line output. Section V describes the output one may request and the setting of the switches.
B. INPUT DEFINITION
<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>TYPE</th>
<th>EXPLANATION</th>
<th>UNITS</th>
<th>NOM. VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCD</td>
<td>BCD</td>
<td>TWO LINES (40 WORDS) OF PAGE HEADING</td>
<td>BLANKS</td>
<td></td>
</tr>
<tr>
<td>FIX</td>
<td>FIX</td>
<td>NON-EXECUTIVE PAGING OF DOMINANT BODY</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>TRAJ01</td>
<td>TRAJ01</td>
<td>RUN I.S., USED WITH S00AP=1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>FIX</td>
<td>FIX</td>
<td>SAME TYPE OPTION</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>FIX</td>
<td>FIX</td>
<td>INPUT N-SAVE EVERY NT+STEP</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>NO</td>
<td>NO</td>
<td>PHYSICAL FILE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>OCT</td>
<td>OCT</td>
<td>TIME AVERAGING ADDED TO TIME PAST END</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>OCT</td>
<td>OCT</td>
<td>OCT STATIONS IN 31 TO 35 13 13 15 15 47 41 08 81, 75 76 02</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>OCT</td>
<td>OCT</td>
<td>MAXIMUM OF FIVE STATIONS</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>PUBL0X</td>
<td>PUBL0X</td>
<td>PUBLIC INFORMATION AND BOARD UNITS</td>
<td>DEC</td>
<td>49.3</td>
</tr>
<tr>
<td>PUBL0X</td>
<td>PUBL0X</td>
<td>SCALE FACTOR</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>PUB0X</td>
<td>PUB0X</td>
<td>HORIZONTAL LOCATION OF SUN</td>
<td>12.0</td>
<td></td>
</tr>
<tr>
<td>PUB0X</td>
<td>PUB0X</td>
<td>VERTICAL LOCATION OF SUN</td>
<td>8.0</td>
<td></td>
</tr>
<tr>
<td>CANS03</td>
<td>CANS03</td>
<td>FLO 19500 UNIT CARTESIAN BODY-CARDAN X</td>
<td>-0.00354293</td>
<td></td>
</tr>
<tr>
<td>CANS02</td>
<td>CANS02</td>
<td>FLO 19500 UNIT CARTESIAN BODY-CARDAN Y</td>
<td>-0.00354293</td>
<td></td>
</tr>
<tr>
<td>CANS01</td>
<td>CANS01</td>
<td>FLO 19500 UNIT CARTESIAN BODY-CARDAN Z</td>
<td>-0.00354293</td>
<td></td>
</tr>
<tr>
<td>TARG030</td>
<td>TARG030</td>
<td>LAUNCH EPOCH</td>
<td>1980.0</td>
<td></td>
</tr>
<tr>
<td>VGROUP</td>
<td>VGROUP</td>
<td>VGROUP PRINT FLAG AT VIEW PERIODS</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>VGROUP</td>
<td>VGROUP</td>
<td>OCT CONIC PRINT FLAG AT VIEW PERIODS</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>DEPRT1</td>
<td>DEPRT1</td>
<td>FIX NON-ZERO PUTS OUTPUT OF G4s203 MOB</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>DEPRT1</td>
<td>DEPRT1</td>
<td>PRINT SWITCH NON-ZERO-PRINT EVERY CASE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>DEPRT1</td>
<td>DEPRT1</td>
<td>PRINT GROUP AT EACH END-OF-STEP</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>DEPRT1</td>
<td>DEPRT1</td>
<td>OCT CONIC GROUP AT EACH END-OF-STEP</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>DEPRT2</td>
<td>DEPRT2</td>
<td>FIX OCT-DEP. VAR, 1-PRINT 42-PRINT</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>DEPRT2</td>
<td>DEPRT2</td>
<td>OCT LOCATION OF DEPENDENT VARIABLE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>DEPRT2</td>
<td>DEPRT2</td>
<td>FLO VALUE OF DEPENDENT VARIABLE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>DEPRT2</td>
<td>DEPRT2</td>
<td>ON-LINE OUTPUT CONTROL</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>DEPRT2</td>
<td>DEPRT2</td>
<td>0=NO REMOTE CONTROL, NO ON-LINE PRINT</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>DEPRT2</td>
<td>DEPRT2</td>
<td>1=REMOTE CONTROL, HANG FOR S.S. SITTING</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>DEPRT2</td>
<td>DEPRT2</td>
<td>2=REMOTE PRINT ON-LINE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>DEPRT2</td>
<td>DEPRT2</td>
<td>3=REMOTE PRINT IN-LINE</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

The 40 PHASE PARAMETERS MUST BE INPUT INTO THE PROPER BUFFERS AS FOLLOWS

WHERE XXXXX IS REPLACED BY
MOPHS TO MOPH FOR MGS
VEMPH TO VEMPH FOR VENUS
HAPPH TO HAPPH FOR MARS
MOPH0 TO MOPH0 FOR ALL OTHER TARGET BODIES

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>TYPE</th>
<th>EXPLANATION</th>
<th>UNITS</th>
<th>NOM. VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIX</td>
<td>FIX</td>
<td>PRINT AT START OF PHASE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>FIX</td>
<td>FIX</td>
<td>DO NOT PRINT AT START OF PHASE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>FIX</td>
<td>FIX</td>
<td>SET TPRT+PHASE START USE OLD TPRT</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>FIX</td>
<td>FIX</td>
<td>PRIME AT END NOT LAST PHASE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>FIX</td>
<td>FIX</td>
<td>DO NOT PRINT AT END NOT LAST PHASE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>FIX</td>
<td>FIX</td>
<td>DO PRINT AT END NOT LAST PHASE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>BCD BODY FROM WHICH TO COMPUTE X FOR X TEST</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>FLO VALUE OF X TO END PHASE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>BCD BODY FROM WHICH TO COMPUTE R, FOR R+X TEST</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>FLO VALUE OF R TO TURN ON R+X TEST</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>VALUE TURN ON TEST WHEN BODYP=PROBE=R OR, THAN (+ VALUE)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>VALUE TURN ON TEST WHEN BODYP=PROBE=R LESS THAN (+ VALUE)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>BCD CENTRAL BODY FOR INTEGRATION</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>SEG POPMIZE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>FIX NO. OF STEPSIZE DOUBLES</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>BCD BODY USED IN POPMIZE FOR STEPSIZE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>SEG PRIMRT END</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>SEG PRINT DELTA 1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>SEG PRINT END 1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>SEG PRINT DELTA 2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>SEG PRINT END 2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>SEG PRINT DELTA 2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>SEG PRINT END 3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>SEG PRINT DELTA 3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>SEG ODD PRINT 1</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+1</td>
<td>XXXXX+1</td>
<td>SEG ODD PRINT 2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+27</td>
<td>XXXXX+27</td>
<td>OCT GROUP PRINT FLAGS WHERE THE FORMAT OF THE OCTAL WORD IS</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+27</td>
<td>XXXXX+27</td>
<td>BCD X M C D T EL R 0 0 0 J</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>XXXXX+28</td>
<td>XXXXX+28</td>
<td>OCT STATION PRINTS 53 STATIONS IN TWO WORDS, MAX 5 AT A TIME</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

12 STATIONS ARE FLAGGED IN FIRST WORD, 1 IN SECOND AS FOLLOWS
59 31 12 69 61 14 13 15 47 41 08 81, 75 76 02
FRQ÷5 FLU ABI
FRQ÷4 FLO
FRQ_B FLU A3I l.O
FRO*|

NOTE...HERE ARE XXXXXXXSTABCO,*3
STABCO÷2 FLO
FRQ÷30 ELD SFT
FRQ÷6
FRQ÷3 FLO
FRQ÷||

JPL TECHNICAL MEMORANDUM NO. 33-199

STATE

TABLE.

THE EPOCH
DEFINITION

HERE ARE MANY MORE SYMBOLS IN THE SYMBOL
TABLE. THE FOLLOWING TABLE GIVES THE ADDITIONAL SYMBOLS,
WHERE A NUMBER INDICATES WHETHER THE
DATA IS INPUT TO SYNO OR OUTPUT FROM SYNO.

SYMBOL I/O TYPE EXPLANATION

HTO O FLO A.T EARTH EQUATORIAL
HQU O FLO A.T EARTH EQUATORIAL
HQC O FLO A.T ECLIPTIC
HRC O FLO A.T ECLIPTIC
HBC O FLO A.T ECLIPTIC
BTO O FLO B.T TARGET ORBITAL PLANE
BBK O FLO B.T TARGET ORBITAL PLANE
BTD O FLO B.T TARGET TRUE EQUATORIAL PLANE

END WORD FRACTIONAL PART OF A DAY
LONGY O GEODETIC LATITUDE OR S/C
TE30 O FLO INJECTION EPOCH SEC PAST JAN 1, 1950 SEC
XOP O FLO 62-WORD BUFFER CONTAINING 7
MULTIPLIERSposição VECTORS FOLLOWED

12

4
C. JPTRAJ RESTRICTIONS

SFPRO operates under the JPTRAJ monitor, which imposes three programming requirements. SFPRO satisfies these requirements by providing:

1. A four-word Program Control Block (PCB) located at entry "......".
2. A Symbol Table, which immediately follows the PCB.
3. A zero (normal return via JEXIT) or a one (error return via ABORT) in the accumulator upon return to JPTRAJ.

A detailed description of the JPTRAJ programming requirements is found in Ref. 4 (Section VIII).
1. Program Control Block

```
...... DCI L-IDPROC
   ZERD L-1
   ZERD LST
   TRA NTA

CLASS 1, 2, 3 ERROR RETURN
LENGTH OF SYMBOL TABLE
```
## Symbol Table

<table>
<thead>
<tr>
<th>ORG</th>
<th>EQU</th>
<th>BEGINNING OF SYMBOL TABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SYM</td>
<td>VENPM</td>
<td>SYM VENPM</td>
</tr>
<tr>
<td>SYM</td>
<td>VENPM</td>
<td>SYM VENPM</td>
</tr>
<tr>
<td>SYM</td>
<td>VENPM</td>
<td>SYM VENPM</td>
</tr>
<tr>
<td>SYM</td>
<td>VENPM</td>
<td>SYM VENPM</td>
</tr>
<tr>
<td>SYM</td>
<td>MARPH1</td>
<td>SYM MARPH1</td>
</tr>
<tr>
<td>SYM</td>
<td>MARPH2</td>
<td>SYM MARPH2</td>
</tr>
<tr>
<td>SYM</td>
<td>MARPH3</td>
<td>SYM MARPH3</td>
</tr>
<tr>
<td>SYM</td>
<td>MARPH4</td>
<td>SYM MARPH4</td>
</tr>
<tr>
<td>SYM</td>
<td>MARPH5</td>
<td>SYM MARPH5</td>
</tr>
<tr>
<td>SYM</td>
<td>MARPH6</td>
<td>SYM MARPH6</td>
</tr>
<tr>
<td>SYM</td>
<td>MARPH7</td>
<td>SYM MARPH7</td>
</tr>
<tr>
<td>SYM</td>
<td>STAKEO</td>
<td>SYM STAKEO</td>
</tr>
<tr>
<td>SYM</td>
<td>FEF</td>
<td>SYM FEF</td>
</tr>
<tr>
<td>SYM</td>
<td>XEF</td>
<td>SYM XEF</td>
</tr>
<tr>
<td>SYM</td>
<td>TARR1</td>
<td>SYM TARR1</td>
</tr>
<tr>
<td>SYM</td>
<td>LAMAV</td>
<td>SYM LAMAV</td>
</tr>
<tr>
<td>SYM</td>
<td>SCALE</td>
<td>SYM SCALE</td>
</tr>
<tr>
<td>SYM</td>
<td>GRAS</td>
<td>SYM GRAS</td>
</tr>
<tr>
<td>SYM</td>
<td>RADOPT</td>
<td>SYM RADOPT</td>
</tr>
<tr>
<td>SYM</td>
<td>RADOPT</td>
<td>SYM RADOPT</td>
</tr>
<tr>
<td>SYM</td>
<td>LAMAV</td>
<td>SYM LAMAV</td>
</tr>
<tr>
<td>SYM</td>
<td>FLA442</td>
<td>SYM FLA442</td>
</tr>
<tr>
<td>SYM</td>
<td>RUNJDL</td>
<td>SYM RUNJDL</td>
</tr>
<tr>
<td>SYM</td>
<td>MPTRDL</td>
<td>SYM MPTRDL</td>
</tr>
<tr>
<td>SYM</td>
<td>SATEL</td>
<td>SYM SATEL</td>
</tr>
<tr>
<td>SYM</td>
<td>ADT</td>
<td>SYM ADT</td>
</tr>
<tr>
<td>SYM</td>
<td>NEWVO</td>
<td>SYM NEWVO</td>
</tr>
<tr>
<td>SYM</td>
<td>MLOFG</td>
<td>SYM MLOFG</td>
</tr>
<tr>
<td>SYM</td>
<td>MLAS</td>
<td>SYM MLAS</td>
</tr>
<tr>
<td>SYM</td>
<td>TAPES</td>
<td>SYM TAPES</td>
</tr>
<tr>
<td>SYM</td>
<td>OPTINT</td>
<td>SYM OPTINT</td>
</tr>
<tr>
<td>SYM</td>
<td>MLFPH</td>
<td>SYM MLFPH</td>
</tr>
<tr>
<td>SYM</td>
<td>MLAAT</td>
<td>SYM MLAAT</td>
</tr>
<tr>
<td>SYM</td>
<td>LAUNCH</td>
<td>SYM LAUNCH</td>
</tr>
<tr>
<td>SYM</td>
<td>PUBLIC</td>
<td>SYM PUBLIC</td>
</tr>
<tr>
<td>SYM</td>
<td>PRTEP</td>
<td>SYM PRTEP</td>
</tr>
<tr>
<td>SYM</td>
<td>CAMSF</td>
<td>SYM CAMSF</td>
</tr>
</tbody>
</table>

LENGTH OF SYMBOL TABLE

WHERE SYM IS DEFINED AS FOLLOWS

<table>
<thead>
<tr>
<th>MACRO</th>
<th>Z SYM</th>
<th>X,Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOT</td>
<td>1,Y</td>
<td></td>
</tr>
<tr>
<td>IF</td>
<td>1,Y</td>
<td></td>
</tr>
<tr>
<td>MSG</td>
<td>1,X</td>
<td></td>
</tr>
<tr>
<td>SFF</td>
<td>1,Y</td>
<td></td>
</tr>
<tr>
<td>TIS</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

END
D. COMMON MAP AND LOAD MAP
JPL TECHNICAL MEMORANDUM NO. 33-199

...
<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>7462</td>
<td>CZ, COMMON 1</td>
</tr>
<tr>
<td>7463</td>
<td>CZ, COMMON 1</td>
</tr>
<tr>
<td>7464</td>
<td>CZ, COMMON 1</td>
</tr>
<tr>
<td>7465</td>
<td>CZ, COMMON 1</td>
</tr>
<tr>
<td>7466</td>
<td>CZ, COMMON 1</td>
</tr>
<tr>
<td>7467</td>
<td>CZ, COMMON 1</td>
</tr>
<tr>
<td>7471</td>
<td>VARIOUS COMMON 1</td>
</tr>
<tr>
<td>7472</td>
<td>T, COMMON 1</td>
</tr>
<tr>
<td>7473</td>
<td>T, COMMON 1</td>
</tr>
<tr>
<td>7474</td>
<td>T, COMMON 1</td>
</tr>
<tr>
<td>7475</td>
<td>T, COMMON 1</td>
</tr>
<tr>
<td>7476</td>
<td>T, COMMON 1</td>
</tr>
<tr>
<td>7477</td>
<td>T, COMMON 1</td>
</tr>
<tr>
<td>7480</td>
<td>T, COMMON 1</td>
</tr>
<tr>
<td>7481</td>
<td>T, COMMON 1</td>
</tr>
<tr>
<td>7482</td>
<td>HBRAN COMMON 1</td>
</tr>
<tr>
<td>7483</td>
<td>COMMON 8</td>
</tr>
<tr>
<td>7484</td>
<td>COMMON 35</td>
</tr>
<tr>
<td>7485</td>
<td>COMMON 35</td>
</tr>
<tr>
<td>7486</td>
<td>XARCFP COMMON 35</td>
</tr>
<tr>
<td>7487</td>
<td>COMMON 35</td>
</tr>
<tr>
<td>7488</td>
<td>COMMON 35</td>
</tr>
<tr>
<td>7490</td>
<td>COMMON 35</td>
</tr>
<tr>
<td>7491</td>
<td>COMMON 35</td>
</tr>
<tr>
<td>7492</td>
<td>COMMON 35</td>
</tr>
<tr>
<td>7493</td>
<td>COMMON 35</td>
</tr>
<tr>
<td>7494</td>
<td>COMMON 35</td>
</tr>
<tr>
<td>7495</td>
<td>COMMON 35</td>
</tr>
</tbody>
</table>

### Notes
- **COMMON 35** appears multiple times, suggesting it might be a placeholder or a specific variable used in the context of the technical memorandum.
- The text on the page indicates a technical discussion on velocity coordinates, true equator, and Earth-fixed Cartesian systems.
- The memorandum seems to discuss buffers and their usages related to coordinate systems and equations.
JPL TECHNICAL MEMORANDUM NO. 33-199

73753 EMSA COMMON 1
73752 ILSM COMMON 1
73751 SWSM COMMON 1
73747 M1SA COMMON 1
73754 PSIP COMMON 1
73749 EMPS COMMON 1
73764 SWSM COMMON 1
73774 SPSM COMMON 1
73782 EPSM COMMON 1
73740 TISP COMMON 1
73739 RAD COMMON 1
73736 RASS COMMON 1
73730 RASS COMMON 1
73734 RASS COMMON 1
73728 MVE COMMON
73725 MVE COMMON
73722 RIVG COMMON 1
73711 R1MAG COMMON 1
73709 R1MAG COMMON 1
73708 M12 COMMON 1
73707 M12 COMMON 1
73706 M1A COMMON 1
73705 M1A COMMON 1
73704 M1A COMMON 1
73703 M1A COMMON 1
73702 M1A COMMON 1
73701 M1A COMMON 1
73700 M1A COMMON 1
73698 SRA COMMON
73697 SRA COMMON
73694 S1R1 COMMON 1
73692 S1R1 COMMON 1
73690 S1R1 COMMON 1
73687 S1R1 COMMON 1
73685 S1R1 COMMON 1
73683 S1R1 COMMON 1
73680 S1R1 COMMON 1
73677 S1R1 COMMON 1
73675 S1R1 COMMON 1
73673 S1R1 COMMON 1
73670 S1R1 COMMON 1
73667 S1R1 COMMON 1
73665 S1R1 COMMON 1
73663 S1R1 COMMON 1
73660 S1R1 COMMON 1
73657 S1R1 COMMON 1
73655 S1R1 COMMON 1
73653 S1R1 COMMON 1
73650 S1R1 COMMON 1
73647 S1R1 COMMON 1
73645 S1R1 COMMON 1
73642 S1R1 COMMON 1
73639 S1R1 COMMON 1
73637 S1R1 COMMON 1
73635 S1R1 COMMON 1
73633 S1R1 COMMON 1
73630 S1R1 COMMON 1
73627 S1R1 COMMON 1
73624 S1R1 COMMON 1
73621 S1R1 COMMON 1
73619 S1R1 COMMON 1
73616 S1R1 COMMON 1
73613 S1R1 COMMON 1
73610 S1R1 COMMON 1
73607 S1R1 COMMON 1
73604 S1R1 COMMON 1
73601 S1R1 COMMON 1
73598 S1R1 COMMON 1
73595 S1R1 COMMON 1
73592 S1R1 COMMON 1
73589 S1R1 COMMON 1
73586 S1R1 COMMON 1
73583 S1R1 COMMON 1
73579 S1R1 COMMON 1
73576 S1R1 COMMON 1
73573 S1R1 COMMON 1
73570 S1R1 COMMON 1
73567 S1R1 COMMON 1
73564 S1R1 COMMON 1
73561 S1R1 COMMON 1
73558 S1R1 COMMON 1
73555 S1R1 COMMON 1
73552 S1R1 COMMON 1
73549 S1R1 COMMON 1
73546 S1R1 COMMON 1
73543 S1R1 COMMON 1
73540 S1R1 COMMON 1
73537 S1R1 COMMON 1
73534 S1R1 COMMON 1
73531 S1R1 COMMON 1
73528 S1R1 COMMON 1
73525 S1R1 COMMON 1
73522 S1R1 COMMON 1
73519 S1R1 COMMON 1
73516 S1R1 COMMON 1
73513 S1R1 COMMON 1
73510 S1R1 COMMON 1
73507 S1R1 COMMON 1
73504 S1R1 COMMON 1
73501 S1R1 COMMON 1
73498 S1R1 COMMON 1
73495 S1R1 COMMON 1
73492 S1R1 COMMON 1
73489 S1R1 COMMON 1
73486 S1R1 COMMON 1
73483 S1R1 COMMON 1
73480 S1R1 COMMON 1
73477 S1R1 COMMON 1
73474 S1R1 COMMON 1
73471 S1R1 COMMON 1
73468 S1R1 COMMON 1
73465 S1R1 COMMON 1
73462 S1R1 COMMON 1
73459 S1R1 COMMON 1
73456 S1R1 COMMON 1
73453 S1R1 COMMON 1
73450 S1R1 COMMON 1
73447 S1R1 COMMON 1
73444 S1R1 COMMON 1
73441 S1R1 COMMON 1
73438 S1R1 COMMON 1
73435 S1R1 COMMON 1
73432 S1R1 COMMON 1
73429 S1R1 COMMON 1
73426 S1R1 COMMON 1
73423 S1R1 COMMON 1
73420 S1R1 COMMON 1
73417 S1R1 COMMON 1
73414 S1R1 COMMON 1
73411 S1R1 COMMON 1
73408 S1R1 COMMON 1
73405 S1R1 COMMON 1
73402 S1R1 COMMON 1
73399 S1R1 COMMON 1

19
ENTRY POINTS TO SUBROUTINES REQUESTED FROM LIBRARY.

ENTRY NAME       ENTRY ADDR.       TRANSFER VECTORS   LOAD ADDR.   OCTAL LENGTH   DECIMAL LENGTH   COMMON BREAK

ENTRY                  RENAME      MAPPING         RETURN                   OCTAL       DECIMAL

LOGIC                  LOGIC       "NONE"          22562                00074         00040         77151
LX                     LX          "NONE"          22566                00052         00042         77151
SIN                    SIN         "NONE"          23750                00207         00190         77151
COS                    COS         "NONE"          23753                00051         00030         77151
CROSS                   CROSS      SUNT            24167                00003         00004         77151
PROD                   PROD        24170
UNIT                   UNIT        24171
ATAN                   ATAN        "NONE"          24272                00051         00057         77151
DAYS                   DAYS        FLYT            24363                00003         00023         77151
ADD                    ADD         "NONE"          24414                00051         00042         77151
FIX                    FIX         "NONE"          24444                00007         00010         77151
FLOAT                  FLOAT       24724
ECLIP                  ECLIP       24776                00003         00046         77151
RWIN                   RWIN        25040                00310         00000         77151
RVOUT                  RVOUT       25053
GMA                    GMA         25364                00019         00064         77151
GEDLAT                  GEDLAT     SUNT            25466                00056         00046         77151
GETFRA                  GETFRA     PROD            25544                00048         00038         77151
SPACE                   SPACE       AREGS           25612                00020         00020         77151
EARTH                   EARTH      SVOUT           25734
CLOCK                   CLOCK      SVIN            26040                00013         00075         77151
ECLIP                   ECLIP      CROSS           26153                00045         00037         77151
MCMUW                   MCMUW      PROD            26153                00045         00037
ARCSEC                   ARCSEC     "NONE"          26220                00040         00040         77151
ECF                    ECF         26256
RACH                   RACH        26473
IER                    IER         26473
ROSE                   ROSE        26474
BREVO                   BREVO      26492
DIST                   DIST        26632                00063         00051         77123
PATH                   PATH        26632
TIME1                   TIME1      26652
TIME2                   TIME2      26734                00046         00029         77123
LAUNCH                  LAUNCH     INJEU           27164
RECHO                   RECHO       27402                00043         00027
RECON                   RECON       27452
SEGATE                  SEGATE     "NONE"          27521
SPANN                   SPANN       "NONE"          27537
REKGC                   REKGC       "NONE"          27557
E. INPUT FORMS
<table>
<thead>
<tr>
<th>NAME</th>
<th>VALUE</th>
<th>DATE</th>
<th>EXPLANATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAGBCD</td>
<td></td>
<td>12-1-64</td>
<td>PAGE HEADING</td>
</tr>
<tr>
<td>PAGBCD + 3V</td>
<td></td>
<td></td>
<td>(A SECOND LINE OF PAGE HEADING IS</td>
</tr>
<tr>
<td>PAGBCD + 6V</td>
<td></td>
<td></td>
<td>AVAILABLE BY INPUT INTO</td>
</tr>
<tr>
<td>PAGBCD + 9V</td>
<td></td>
<td></td>
<td>PAGBCD + 2O THROUGH PAGBCD + 39</td>
</tr>
<tr>
<td>PAGBCD + 12V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAGBCD + 15V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAGBCD + 18V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FAZFLG</td>
<td></td>
<td></td>
<td>FIX 1 NON-ZERO=AUTOMATIC PHASING</td>
</tr>
<tr>
<td>RUNID</td>
<td></td>
<td></td>
<td>BCD (TRAJO) RUN I.D.</td>
</tr>
<tr>
<td>PLÔTFQ</td>
<td></td>
<td></td>
<td>FIX 0 SAVE TAPE FLAG AND FREQ. BY</td>
</tr>
<tr>
<td>PLÔTFQ + 1</td>
<td></td>
<td></td>
<td>FIX 1 PHYSICAL FILE NO.</td>
</tr>
<tr>
<td>PLÔTFQ + 2</td>
<td></td>
<td></td>
<td>FIX 0 TIME INCREMENT ADDED TO TIME</td>
</tr>
<tr>
<td>PLÔTFQ + 3</td>
<td></td>
<td></td>
<td>FIX 0 STATIONS (MAXIMUM OF FIVE)</td>
</tr>
<tr>
<td>PUBLIC</td>
<td></td>
<td></td>
<td>FLO 49.3 I. ROTATION ANGLE DEG</td>
</tr>
<tr>
<td>PUBLIC + 1</td>
<td></td>
<td></td>
<td>FLO 0.45E-7 S SCALE FACTOR BOARD</td>
</tr>
<tr>
<td>PUBLIC + 2</td>
<td></td>
<td></td>
<td>FLO 12.5 US LOC. SUN-HORIZONTAL</td>
</tr>
<tr>
<td>PUBLIC + 3</td>
<td></td>
<td></td>
<td>FLO 8.0 VS LOC. SUN-VERTICAL BOARD</td>
</tr>
<tr>
<td>CAN50</td>
<td></td>
<td></td>
<td>FLO BODY-CONNECTED UNIT 1950.0</td>
</tr>
<tr>
<td>LAUNCH</td>
<td></td>
<td></td>
<td>SEG 0.0 LAUNCH EPÖCH</td>
</tr>
<tr>
<td>TARGAD</td>
<td></td>
<td></td>
<td>FLO 0.0 ALT. ABOVE TARGET TO END RUN</td>
</tr>
<tr>
<td>VDGROD</td>
<td></td>
<td></td>
<td>OCT 0.0 PRINT GROUP CONIC FLAGS</td>
</tr>
<tr>
<td>FLAG42</td>
<td></td>
<td></td>
<td>OCT 0.0 PRINT GROUP CONIC FLAGS</td>
</tr>
<tr>
<td>PRTSWX</td>
<td></td>
<td></td>
<td>OCT 0.0 PRINT GROUP CONIC FLAGS</td>
</tr>
<tr>
<td>PRTSTP</td>
<td></td>
<td></td>
<td>OCT 0.0 PRINT GROUP CONIC FLAGS</td>
</tr>
<tr>
<td>DEPOPT</td>
<td></td>
<td></td>
<td>OCT 0.0 OCT 0.0 OCT 0.0 OCT 0.0 OCT</td>
</tr>
<tr>
<td>DEPOPT + 1</td>
<td></td>
<td></td>
<td>OCT 0.0 OCT 0.0 OCT 0.0 OCT 0.0 OCT</td>
</tr>
<tr>
<td>DEPOPT + 2</td>
<td></td>
<td></td>
<td>OCT 0.0 OCT 0.0 OCT 0.0 OCT 0.0 OCT</td>
</tr>
<tr>
<td>OPTSWT</td>
<td></td>
<td></td>
<td>OCT 0.0 OCT 0.0 OCT 0.0 OCT 0.0 OCT</td>
</tr>
<tr>
<td>NAME</td>
<td>VALUE</td>
<td>EXPLANATION</td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>--------</td>
<td>-------------</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **I**: Moon, Venus, Mars, Earth, Sun, Saturn, Jupiter
- **2**: Print at start of phase
- **3**: Reset track to start
- **4**: Print at end, last phase
- **5**: Print at end, not last phase
- **6**: Print at end, not last phase
- **7**: Integration central body
- **BDDHHMMSSFFF**: Body from which to compute step size
- **BDDHHMMSSFFF**: Body from which to compute test
- **FL0**: Value of R to end phase
- **FL0**: Value of R to turn on test
- **19**: Equatorial
- **21**: Ecliptic
- **23**: Group print (all)
- **25**: Group print (all but B, R)
- **27**: Station prints (maximum of 5)
- **29**: View periods (maximum of 5)
- **34**: Shadow parameter flag
- **39**: Equinox (1950.0) = true of date

**Explanation**: 12-1-64
<table>
<thead>
<tr>
<th>NAME</th>
<th>VALUE</th>
<th>TYPE</th>
<th>NOMINAL VALUE</th>
<th>EXPLANATION</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRQ+1/</td>
<td>$930.156E+1$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRQ+2/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRQ+3/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRQ+4/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRQ+5/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRQ+6/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRQ+7/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRQ+8/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRQ+9/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRQ+10/</td>
<td>$2.0E+0$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRQ+11/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRQ+12/</td>
<td>$6.0E+1$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRQ+13/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRQ+14/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRQ+15/</td>
<td>$2.0E+2$</td>
<td>FL0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STACRD-4/</td>
<td>$-1.0E+0$</td>
<td>FL0</td>
<td></td>
<td>ELEV. ANGLE TO START STATION PRINTS</td>
<td></td>
</tr>
<tr>
<td>STACRD-3/</td>
<td>$5.0E-6$</td>
<td>FL0</td>
<td></td>
<td>ELEV. TOLERANCE FOR VIEW PERIODS</td>
<td></td>
</tr>
<tr>
<td>STACRD-2/</td>
<td>$5.0E-6$</td>
<td>FL0</td>
<td></td>
<td>ELEV. RATE TOLERANCE FOR VIEW PERIODS</td>
<td></td>
</tr>
<tr>
<td>STACRD-1/</td>
<td>$5.0E-6$</td>
<td>FL0</td>
<td></td>
<td>ELEV. ANGLE TO START, END VIEW PERIODS</td>
<td></td>
</tr>
<tr>
<td>BCDO</td>
<td></td>
<td>FL0</td>
<td></td>
<td>STATION A NAME: FOUR BCD WORDS</td>
<td></td>
</tr>
<tr>
<td>STACRD-9/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td>STATION A COORD, LAT, LONG, CODE, DUMMY</td>
<td></td>
</tr>
<tr>
<td>STBCD+1/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td>STATION B NAME</td>
<td></td>
</tr>
<tr>
<td>STACRD+9/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td>STATION B COORD.</td>
<td></td>
</tr>
<tr>
<td>STBCD+9/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td>STATION C NAME</td>
<td></td>
</tr>
<tr>
<td>STACRD+9/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td>STATION C COORD.</td>
<td></td>
</tr>
<tr>
<td>STBCD+9/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td>STATION D NAME</td>
<td></td>
</tr>
<tr>
<td>STACRD+9/</td>
<td>$1.0E+0$</td>
<td>FL0</td>
<td></td>
<td>STATION D COORD.</td>
<td></td>
</tr>
</tbody>
</table>
F. SPACECRAFT EPHEMERIS TAPE FORMAT
TAPE 10 RECORD

<table>
<thead>
<tr>
<th>BUFFER</th>
<th>NUMBER OF NAME PARAMETERS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUNID</td>
<td>1</td>
<td>BCD S/C EPHEMERIS IDENTIFICATION</td>
</tr>
<tr>
<td>FLDWRD</td>
<td>1</td>
<td>CURRENT STATUS FLAG WORD</td>
</tr>
<tr>
<td>SCFDIR</td>
<td>1</td>
<td>DATA RECORD FORMAT FLAG</td>
</tr>
<tr>
<td>SCBCD</td>
<td>40</td>
<td>SPACE PAGE HEADING</td>
</tr>
<tr>
<td>TARGCD</td>
<td>1</td>
<td>BCD TARGET NAME</td>
</tr>
<tr>
<td>INJDCD</td>
<td>1</td>
<td>BCD INJECTION CENTRAL BODY NAME</td>
</tr>
<tr>
<td>INJTP</td>
<td>1</td>
<td>TYPE OF INJECTION CONDITIONS</td>
</tr>
<tr>
<td>INJ1</td>
<td>2</td>
<td>SERAGPSL INJECTION EPOCH</td>
</tr>
<tr>
<td>INJX</td>
<td>3</td>
<td>INJECTION CONDITIONS</td>
</tr>
<tr>
<td>INJOT</td>
<td>4</td>
<td>DELTA TIME ADDED TO INJ</td>
</tr>
<tr>
<td>INJUX</td>
<td>5</td>
<td>INJECTION EQUINOX</td>
</tr>
<tr>
<td>MNOPT</td>
<td>6</td>
<td>MOTOR DYNAMICS INPUT PARAMETERS</td>
</tr>
<tr>
<td>RADOPY</td>
<td>6</td>
<td>RADIATION PRESSURE INPUT PARAMETERS</td>
</tr>
<tr>
<td>GASOYT</td>
<td>7</td>
<td>GAS JETS DENSITY INPUT PARAMETERS</td>
</tr>
<tr>
<td>NMOOD</td>
<td>8</td>
<td>BODY TO REPLACE SATURN OPTION</td>
</tr>
<tr>
<td>TARAD</td>
<td>9</td>
<td>TABLE OF BODY RADIUS</td>
</tr>
<tr>
<td>NKX</td>
<td>10</td>
<td>N-BODY GRS</td>
</tr>
<tr>
<td>LUNCAV</td>
<td>11</td>
<td>LUNAR POTENTIAL CONSTANTS</td>
</tr>
<tr>
<td>OMEGAD</td>
<td>12</td>
<td>ROTATION RATE OF THE EARTH</td>
</tr>
<tr>
<td>DT</td>
<td>13</td>
<td>DIFFERENCE ET - UT</td>
</tr>
<tr>
<td>GMN0Z</td>
<td>14</td>
<td>GMN'S USED FOR EPHEMERIS GENERATION</td>
</tr>
<tr>
<td>RHEREG</td>
<td>15</td>
<td>JUPITR EQUINOX</td>
</tr>
<tr>
<td>TMT</td>
<td>16</td>
<td>TIME OF DAY S/C EPHEMERIS GENERATION</td>
</tr>
<tr>
<td>RMD</td>
<td>17</td>
<td>MACHINE USED IN S/C EPHEMERIS GENERATION</td>
</tr>
<tr>
<td>SYODAY</td>
<td>18</td>
<td>DATE OF S/C EPHEMERIS GENERATION</td>
</tr>
<tr>
<td>DELTA</td>
<td>19</td>
<td>JD 1950.0 - JD 0 HR JAN 1, 1950</td>
</tr>
<tr>
<td>WHATE</td>
<td>20</td>
<td>FLAG TO DESIGNATE FREQUENCY OF COMPUTATION OF MATRICES</td>
</tr>
<tr>
<td>NUTEPH</td>
<td>21</td>
<td>FLAG TO DESIGNATE WHERE TO GET NUTATIONS</td>
</tr>
<tr>
<td>SCRTY</td>
<td>22</td>
<td>EPOCH TO START WRITING S/C EPHEMERIS</td>
</tr>
<tr>
<td>SCNMTY</td>
<td>23</td>
<td>EPOCH TO STOP WRITING S/C EPHEMERIS</td>
</tr>
<tr>
<td>CX</td>
<td>24</td>
<td>INJECTION CONDITIONS MEAN 1950.0 EARTH EQ.</td>
</tr>
</tbody>
</table>

TAPE DATA RECORD

<table>
<thead>
<tr>
<th>BUFFER</th>
<th>NUMBER OF NAME PARAMETERS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUNID</td>
<td>1</td>
<td>BCD S/C EPHEMERIS IDENTIFICATION</td>
</tr>
<tr>
<td>FLDWRD</td>
<td>1</td>
<td>CURRENT STATUS FLAG WORD</td>
</tr>
<tr>
<td>SCFDIR</td>
<td>1</td>
<td>DATA RECORD FORMAT FLAG</td>
</tr>
<tr>
<td>SCBCD</td>
<td>40</td>
<td>SPACE PAGE HEADING</td>
</tr>
<tr>
<td>TARGCD</td>
<td>1</td>
<td>BCD TARGET NAME</td>
</tr>
<tr>
<td>INJDCD</td>
<td>1</td>
<td>BCD INJECTION CENTRAL BODY NAME</td>
</tr>
<tr>
<td>INJTP</td>
<td>1</td>
<td>TYPE OF INJECTION CONDITIONS</td>
</tr>
<tr>
<td>INJ1</td>
<td>2</td>
<td>SERAGPSL INJECTION EPOCH</td>
</tr>
<tr>
<td>INJX</td>
<td>3</td>
<td>INJECTION CONDITIONS</td>
</tr>
<tr>
<td>INJOT</td>
<td>4</td>
<td>DELTA TIME ADDED TO INJ</td>
</tr>
<tr>
<td>INJUX</td>
<td>5</td>
<td>INJECTION EQUINOX</td>
</tr>
<tr>
<td>MNOPT</td>
<td>6</td>
<td>MOTOR DYNAMICS INPUT PARAMETERS</td>
</tr>
<tr>
<td>RADOPY</td>
<td>6</td>
<td>RADIATION PRESSURE INPUT PARAMETERS</td>
</tr>
<tr>
<td>GASOYT</td>
<td>7</td>
<td>GAS JETS DENSITY INPUT PARAMETERS</td>
</tr>
<tr>
<td>NMOOD</td>
<td>8</td>
<td>BODY TO REPLACE SATURN OPTION</td>
</tr>
<tr>
<td>TARAD</td>
<td>9</td>
<td>TABLE OF BODY RADIUS</td>
</tr>
<tr>
<td>NKX</td>
<td>10</td>
<td>N-BODY GRS</td>
</tr>
<tr>
<td>LUNCAV</td>
<td>11</td>
<td>LUNAR POTENTIAL CONSTANTS</td>
</tr>
<tr>
<td>OMEGAD</td>
<td>12</td>
<td>ROTATION RATE OF THE EARTH</td>
</tr>
<tr>
<td>DT</td>
<td>13</td>
<td>DIFFERENCE ET - UT</td>
</tr>
<tr>
<td>GMN0Z</td>
<td>14</td>
<td>GMN'S USED FOR EPHEMERIS GENERATION</td>
</tr>
<tr>
<td>RHEREG</td>
<td>15</td>
<td>JUPITR EQUINOX</td>
</tr>
<tr>
<td>TMT</td>
<td>16</td>
<td>TIME OF DAY S/C EPHEMERIS GENERATION</td>
</tr>
<tr>
<td>RMD</td>
<td>17</td>
<td>MACHINE USED IN S/C EPHEMERIS GENERATION</td>
</tr>
<tr>
<td>SYODAY</td>
<td>18</td>
<td>DATE OF S/C EPHEMERIS GENERATION</td>
</tr>
<tr>
<td>DELTA</td>
<td>19</td>
<td>JD 1950.0 - JD 0 HR JAN 1, 1950</td>
</tr>
<tr>
<td>WHATE</td>
<td>20</td>
<td>FLAG TO DESIGNATE FREQUENCY OF COMPUTATION OF MATRICES</td>
</tr>
<tr>
<td>NUTEPH</td>
<td>21</td>
<td>FLAG TO DESIGNATE WHERE TO GET NUTATIONS</td>
</tr>
<tr>
<td>SCRTY</td>
<td>22</td>
<td>EPOCH TO START WRITING S/C EPHEMERIS</td>
</tr>
<tr>
<td>SCNMTY</td>
<td>23</td>
<td>EPOCH TO STOP WRITING S/C EPHEMERIS</td>
</tr>
<tr>
<td>CX</td>
<td>24</td>
<td>INJECTION CONDITIONS MEAN 1950.0 EARTH EQ.</td>
</tr>
</tbody>
</table>
V. OUTPUT

A. SAVE TAPE FORMAT
JPL TECHNICAL MEMORANDUM NO. 33-199

VARIABLES STORED ON THE TRAJECTORY SAVE TAPE ARE:
 REFERENCED TO A FIXED HORIZON TARGETCENTRIC COORDINATE SYSTEM.
 ALL UNITS ARE MADE UP OF WHOLE DEGREES UNLESS STATED

VAR. NO. DESCRIPTION
1-3 DOUBLE PRECISION TIME IN SECONDS PAST 1950.0
4 TIME IN SECONDS PAST INJECTION
5 TARGET BODY NUMBER
6-8 GEODESIC EARTH-PROBE POSITION VECTOR
9-11 GEODESIC EARTH-PROBE VELOCITY VECTOR
12 GEODESIC LONGITUDE OF THE PROBE
13 GEODESIC LONGITUDE OF THE PROBE-POSITION VECTOR MAGNITUDE
14 DECLINATION OF THE PROBE
15 RIGHT ASCENSION OF THE PROBE
16 GEODESIC EARTH-PROBE VELOCITY VECTOR MAGNITUDE
17 INERTIAL PATH ANGLE
18 INERTIAL AZIMUTH ANGLE
19 ALTITUDE OF PROBE ABOVE EARTH
20 ALTITUDE OF PROBE ABOVE EARTH CENTER
21 RT. ASCENSION OF THE EARTH IN THE S/C COORDINATE SYSTEM
22 DECLINATION OF THE TARGET IN THE S/C COORDINATE SYSTEM
23 RT. ASCENSION OF THE TARGET IN THE S/C COORDINATE SYSTEM
24 HELIOCENTRIC EARTH-PROBE POSITION VECTOR MAGNITUDE
25 HELIOCENTRIC EARTH-PROBE VELOCITY VECTOR MAGNITUDE
26 HELIOCENTRIC LONGITUDE OF THE PROBE
27 ALTITUDE OF PROBE ABOVE ECLIPTIC PLANE
28 HELIO-1, SUN-PROBE-POSITION VECTOR MAGNITUDE
29 HELIO-1, SUN-PROBE-POSITION VECTOR MAGNITUDE
30 EARTH-PROBE-SUN ANGLE
31 EARTH-PROBE-TARGET ANGLE
32 EARTH-PROBE-NEAR LIMB OF TARGET ANGLE
33 SUN-EARTH-PROBE ANGLE
34 SUN-TARGET-PROBE ANGLE
35 SUN-TARGET-PROBE VELOCITY VECTOR MAGNITUDE
36 EARTH-PROBE VELOCITY VECTOR MAGNITUDE
37 EARTH-PROBE-SUN ANGLE
38 EARTH-PROBE-SUN ANGLE
39 TARGET-PROBE-SUN ANGLE
40 CLOSER TO EARTH ANGLE
41 MOON CLOCK ANGLE EARTH CENTER
42 MOON CLOCK ANGLE EARTH CENTER
43 MOON CLOCK ANGLE EARTH CENTER
44 TARGET CLOCK ANGLE EARTH CENTER
45 TARGETCENTRAL TARGET-PROBE VELOCITY VECTOR MAGNITUDE
46 ALTITUDE OF PROBE ABOVE TARGET
47 ANGULAR SEMI DIAMETER OF TARGET
48 SELENCENTRIC MOON-PROBE POSITION VECTOR
49 SELENCENTRIC MOON-PROBE VELOCITY VECTOR
50 SELENCENTRIC MOON-PROBE VELOCITY VECTOR
51 SELENCENTRIC VENUS-PROBE POSITION VECTOR
52 SELENCENTRIC VENUS-PROBE VELOCITY VECTOR
53 SELENCENTRIC MARS-PROBE POSITION VECTOR
54 SELENCENTRIC MARS-PROBE VELOCITY VECTOR
55 SELENCENTRIC SATURN-PROBE POSITION VECTOR
56-64 GEODESIC JUPITER-PROBE POSITION VECTOR
57 GEODESIC JUPITER-PROBE VELOCITY VECTOR
58 GEODESIC JUPITER-PROBE VELOCITY VECTOR
59 GEODESIC JUPITER-PROBE VELOCITY VECTOR
60-72 GEODESIC PROBE-PROBE-PROBE VELOCITY VECTOR
61-63 GEODESIC PROBE-PROBE-PROBE VELOCITY VECTOR
64-65 GEODESIC ANGULAR VELOCITY VECTOR
66-67 GEODESIC ANGULAR VELOCITY VECTOR
68-69 GEODESIC ANGULAR VELOCITY VECTOR
70-72 ZERO

* VARIABLES STORED ON THE TRAJECTORY SAVE TAPE UNLESS STATED.
* REFERENCED TO A FIXED HORIZON TARGETCENTRIC COORDINATE SYSTEM.
* AT A VIEWING STATION (MAXIMUM OF FIVE STATIONS)

<table>
<thead>
<tr>
<th>STAT. 1</th>
<th>STAT. 2</th>
<th>STAT. 3</th>
<th>STAT. 4</th>
<th>STAT. 9</th>
<th>VARIABLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>79-7E</td>
<td>109-112</td>
<td>145-146</td>
<td>191-194</td>
<td>217-220</td>
<td>1-4 STATION NAME; BGD</td>
</tr>
<tr>
<td>7F</td>
<td>113</td>
<td>149</td>
<td>155</td>
<td>187</td>
<td>9</td>
</tr>
<tr>
<td>78</td>
<td>112</td>
<td>153</td>
<td>178</td>
<td>184</td>
<td>6</td>
</tr>
<tr>
<td>79</td>
<td>114</td>
<td>151</td>
<td>187</td>
<td>226</td>
<td>7</td>
</tr>
<tr>
<td>80</td>
<td>116</td>
<td>152</td>
<td>188</td>
<td>224</td>
<td>8</td>
</tr>
<tr>
<td>81</td>
<td>115</td>
<td>153</td>
<td>189</td>
<td>229</td>
<td>9</td>
</tr>
<tr>
<td>82</td>
<td>117</td>
<td>154</td>
<td>190</td>
<td>226</td>
<td>10</td>
</tr>
<tr>
<td>83</td>
<td>119</td>
<td>155</td>
<td>191</td>
<td>227</td>
<td>11</td>
</tr>
<tr>
<td>84</td>
<td>120</td>
<td>156</td>
<td>192</td>
<td>228</td>
<td>12</td>
</tr>
<tr>
<td>85</td>
<td>121</td>
<td>157</td>
<td>193</td>
<td>229</td>
<td>13</td>
</tr>
<tr>
<td>86</td>
<td>122</td>
<td>158</td>
<td>194</td>
<td>230</td>
<td>14</td>
</tr>
<tr>
<td>87</td>
<td>123</td>
<td>159</td>
<td>195</td>
<td>231</td>
<td>15</td>
</tr>
<tr>
<td>88</td>
<td>124</td>
<td>160</td>
<td>196</td>
<td>232</td>
<td>16</td>
</tr>
<tr>
<td>89</td>
<td>125</td>
<td>161</td>
<td>197</td>
<td>233</td>
<td>17</td>
</tr>
<tr>
<td>90</td>
<td>128</td>
<td>162</td>
<td>198</td>
<td>234</td>
<td>18</td>
</tr>
<tr>
<td>91</td>
<td>127</td>
<td>163</td>
<td>199</td>
<td>235</td>
<td>19</td>
</tr>
<tr>
<td>92</td>
<td>128</td>
<td>164</td>
<td>200</td>
<td>236</td>
<td>20</td>
</tr>
<tr>
<td>93</td>
<td>129</td>
<td>165</td>
<td>201</td>
<td>237</td>
<td>21</td>
</tr>
<tr>
<td>94</td>
<td>130</td>
<td>166</td>
<td>202</td>
<td>238</td>
<td>22</td>
</tr>
<tr>
<td>95</td>
<td>131</td>
<td>167</td>
<td>203</td>
<td>239</td>
<td>23</td>
</tr>
<tr>
<td>96</td>
<td>132</td>
<td>168</td>
<td>204</td>
<td>240</td>
<td>24</td>
</tr>
<tr>
<td>97</td>
<td>133</td>
<td>169</td>
<td>205</td>
<td>241</td>
<td>25</td>
</tr>
<tr>
<td>98</td>
<td>134</td>
<td>170</td>
<td>206</td>
<td>242</td>
<td>26</td>
</tr>
<tr>
<td>99</td>
<td>135</td>
<td>171</td>
<td>207</td>
<td>243</td>
<td>27</td>
</tr>
<tr>
<td>100</td>
<td>136</td>
<td>172</td>
<td>208</td>
<td>244</td>
<td>28</td>
</tr>
<tr>
<td>101</td>
<td>137</td>
<td>173</td>
<td>209</td>
<td>245</td>
<td>29</td>
</tr>
<tr>
<td>102</td>
<td>138</td>
<td>174</td>
<td>210</td>
<td>246</td>
<td>30</td>
</tr>
<tr>
<td>103</td>
<td>139</td>
<td>175</td>
<td>211</td>
<td>247</td>
<td>31</td>
</tr>
<tr>
<td>104</td>
<td>140</td>
<td>176</td>
<td>212</td>
<td>248</td>
<td>32</td>
</tr>
<tr>
<td>105</td>
<td>141</td>
<td>177</td>
<td>213</td>
<td>249</td>
<td>33</td>
</tr>
<tr>
<td>106</td>
<td>142</td>
<td>178</td>
<td>214</td>
<td>250</td>
<td>34</td>
</tr>
<tr>
<td>107</td>
<td>143</td>
<td>179</td>
<td>215</td>
<td>251</td>
<td>35</td>
</tr>
<tr>
<td>108</td>
<td>144</td>
<td>180</td>
<td>216</td>
<td>252</td>
<td>36</td>
</tr>
</tbody>
</table>

36
B. PRINTED OUTPUT FORMAT AND DEFINITIONS
CONSTANTS

LINE A
CASE NO. 1 1959-YMRB35-SFMRD (DATE) (PAGE NO.)
LINE B
FIRST LINE OF PAGE OUT OF SPACE 1
LINE C
SECOND LINE OF PAGE OUT OF SPACE 1
LINE D
THIRD LINE OF PAGE OUT OF SPACE 1
LINE E
FOURTH LINE OF PAGE OUT OF SPACE 1
LINE F
DOUBLE PRECISION EPHEMERIDES TAPES - EPHEM
LINE G
S/C EPHEMERIDES WRITTEN TIME (DATE) RUN # 1
LINE H
G GRavitational Coefficient for the earth in KM/SEC^2
J Coefficient of the second harmonic in earth's oblateness
H Coefficient of the third harmonic in earth's oblateness
D Coefficient of the fourth harmonic in earth's oblateness
RE Earth radius to be used in the earth's oblate potential, KM
RM Earth radius to convert lunar ephemeris to KM
LINE I
GE Universal gravitational constant for lunar oblateness, KM^3/SEC^2
G Moments of inertia of MOON for lunar oblate potential, KG-KM^2
R
C One rotation rate of the earth in degrees
AU Astronomical Unit to convert planetary ephemerides to KM
LINE J
GMW Gravitational Coefficient for the moon in KM^3/SEC^2
GMS Gravitational Coefficient for the sun in KM^3/SEC^2
GMA Gravitational Coefficient for Venus in KM^3/SEC^2
GMN Gravitational Coefficient for Mars in KM^3/SEC^2
GMS Gravitational Coefficient for Saturn in KM^3/SEC^2
LINE K
GB Earth gravitational coefficient, CM^3/DAY^2
G B Mass of moon, used with ephemerides, NPM^2
GB Mass of earth, used with ephemerides, NPM^2
H B Coefficient of the second harmonic in mars oblateness
HA Coefficient of the third harmonic in mars oblateness
DA Coefficient of the fourth harmonic in mars oblateness
RA Mars radius to be used in the mars oblate potential, KM

ACCELERATIONS

LINE L IF SOLAR RADIATION PRESSURE IS REQUESTED: RADIATION PRESSURE INPUT
LINE M IF SOLAR RADIATION PRESSURE IS REQUESTED: AREA OF SPACECRAFT, SQUARE METERS
LINE N MULTIPLE OF PERCENT OF REFLECTED RADIANT ENERGY
LINE O MASS OF SPACECRAFT, KG
LINE P GRI constant COEFFICIENT OF POLYNOMIAL, RADIANS^2-SQUARE METERS
LINE Q C GYR LINEAR COEFFICIENT OF POLYNOMIAL, RADIANS^3/SQUARE METERS/DEG
LINE R SC SOLAR RADIATION CONSTANT, KG-KM^2/SQUARE SEC-6
LINE S IF GAS JETS ARE REQUESTED: ATTITUDE CONTROL INPUT
LINE T IF GAS JETS ARE REQUESTED: GAS FLAG
LINE U IF GAS JETS ARE REQUESTED: GAS REFERENCE BODY
LINE V IF GAS JETS ARE REQUESTED: GAS START TIME SEG. YMMMDDDH
LINE W IF GAS JETS ARE REQUESTED: GAS DELTA T ADDED TO START TIME, SEC
LINE X IF GAS JETS ARE REQUESTED: GAS END TIME SEG. YMMMDDDH
LINE Y IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE Z IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE A IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE B IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE C IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE D IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE E IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE F IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE G IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE H IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE I IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE J IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE K IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE L IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE M IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE N IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE O IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE P IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE Q IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE R IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE S IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE T IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE U IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE V IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE W IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE X IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE Y IF GAS JETS ARE REQUESTED: GAS NAME, KG
LINE Z IF GAS JETS ARE REQUESTED: GAS NAME, KG

38
INJECTION CONDITIONS

LINE A
INJECTION CONDITIONS (EQUINOX) (TARGET) (SP SEC PAST 1950) (JDI) (CALENDAR DATE)

LINE B
(INCLUDES ONE OF THE 4 LINES BELOW)
(CENTRAL BODY)

• IF COORDINATES ARE INERTIAL CARTESIAN
  V0 VERTICAL EQUATORIAL CARTESIAN POSITION, KM
  V1 VERTICAL EQUATORIAL CARTESIAN VELOCITY, KM/SEC

• IF COORDINATES ARE SPHERICAL INERTIAL
  radial DISTANCE, KM
  g0 RIGHT ASCENSION, Deg
  v VERTICAL EQUATORIAL VELOCITY, KM/SEC

• IF COORDINATES ARE EARTH-FIXED OR SELECTOR
  (CENTRAL BODY)
  THE GEOCENTRIC POSITION OF THE SUN, KM
  THE GEOCENTRIC VELOCITY OF THE SUN, KM/SEC

• IF COORDINATES ARE ENERGY-ASYMPTOTE
  (CENTRAL BODY)
  THE GEOCENTRIC VELOCITY OF THE TARGET BODY, KM/SEC

LINE C
(TYPE) (CARTESIAN, SPHERICAL, EARTH-FIXED, SELECTOR, ENERGY-ASYMPTOTE, PSEUDO-ASYMPTOTE)
(TIME PAST INJECTION, SP SEC PAST 1950, SEC)
(GEOCENTRIC LATITUDE, Deg)
(GEOCENTRIC SPEED OF MOON, KM/SEC)

LINE D
(DATE AND TIME OF RUN) (CENTRAL BODY) (EQUATORIAL MOTION)
(GEOCENTRIC)

TIME PAST INJECTION (EQUINOX) (SP SEC PAST 1950) (JDI) (CALENDAR DATE)

GEOCENTRIC (COORDINATE PLANE)

LINE A
x VERTICAL EQUATORIAL CARTESIAN POSITION, KM
y z VERTICAL EQUATORIAL CARTESIAN VELOCITY, KM/SEC

LINE B
r radial DISTANCE, KM
declination, deg
right ascension, deg
vertical EQUATORIAL VELOCITY, KM/SEC

LINE C
r radial DISTANCE, KM
latitude, deg
longitude, deg
velocity EQUATORIAL, KM/SEC

LINE D
x5 THE GEOCENTRIC POSITION OF THE SUN, KM
y5 z5 THE GEOCENTRIC VELOCITY OF THE SUN, KM/SEC

LINE E
xw THE GEOCENTRIC POSITION OF THE MOON, KM
yw zw THE GEOCENTRIC VELOCITY OF THE MOON, KM/SEC

LINE F
xv THE GEOCENTRIC POSITION OF THE TARGET BODY, KM
yv zv THE GEOCENTRIC VELOCITY OF THE TARGET BODY, KM/SEC

LINE G
r5 EARTH-SUN DISTANCE, KM
v5 GEOCENTRIC VELOCITY OF SUN, KM/SEC
kw EARTH-MOON DISTANCE, KM
vk GEOCENTRIC VELOCITY OF MOON, KM/SEC

CONTINUED ON NEXT PAGE
### HELIOCENTRIC

**LINE A**
- Vernal Equinox Cartesian Position, km
- Vernal Equinox Cartesian Velocity, km/sec

**LINE B**
- Sun-Probe Radius, km
- Lat Celestial Latitude - On Declination - Of the Probe, deg
- Sun Celestial Longitude - On Right Ascension - Of the Probe, deg
- Inertial Speed, km/sec
- Path Angle, deg
- Azimuth Angle, deg

**LINE C**
- X: Heliocentric Position of the Earth, km
- Y: Heliocentric Velocity of the Earth, km/sec

**LINE D**
- X: Heliocentric Position of the Target, km
- Y: Heliocentric Velocity of the Target, km/sec

**LINE E**
- Lat Celestial Latitude - On Declination - Of the Earth, deg
- Lon Celestial Longitude - On Right Ascension - Of the Earth, deg
- Inertial Speed: Target with Respect to the Sun, km/sec

**LINE F**
- EPS Earth-Probe-Sun Angle, deg
- ESP Earth-Sun-Probe Angle, deg
- GEP Earth-Probe-Earth Angle, deg
- GEP Earth-Moon-Probe Angle, deg
- MEP Moon-Earth-Probe Angle, deg

**LINE G**
- MPS Moon-Probe-Sun Angle, deg
- MSP Moon-Sun-Probe Angle, deg
- SPM Sun-Moon-Probe Angle, deg
- SEM Sun-Earth-Moon Angle, deg
- EMS Earth-Moon-Sun Angle, deg
- ESM Earth-Sun-Moon Angle, deg

**LINE H**
- (Not printed if Target = Moon)
- EPS Earth-Probe-Target Angle, deg
- ESP Earth-Target-Probe Angle, deg
- TEP Target-Earth-Probe Angle, deg
- TPS Target-Probe-Sun Angle, deg
- TPM Target-Sun-Probe Angle, deg
- SMP Sun-Probe-Probe Angle, deg

**LINE I**
- USE EPN and SPN are printed if Target = Moon
- SET Sun-Earth-Target Angle, deg
- STE Sun-Target-Earth Angle, deg
- EST Earth-Sun-Target Angle, deg
- PMP Probes-Distance, km
- SPM Probe-Moon Distance, km
- SMP Sun-Probe-Near Limb of Earth Angle, deg

**LINE J**
- SCF Clock Angle of Earth, deg
- GCF Clock Angle of Target, deg
- SFP Probes-Near Limb of Target Angle, deg
- CFP Canopus-Target Angle, deg

**LINE K**
- REP Earth Probes-Distance, km
- VFP Velocity of the Probe with Respect to Earth, km/sec
- CFP Canopus-Probe-Earth Angle, deg
- CPF Canopus-Probe-Sun Angle, deg

---

**HELICENTRIC (COORDINATE PLANE)**

**LINE A**
- X: Vernal Equinox Cartesian Position, km
- Y: Vernal Equinox Cartesian Velocity, km/sec

**LINE B**
- X: Sun-Probe Radius, km
- Y: Lat Celestial Latitude - On Declination - Of the Probe, deg
- Z: Sun Celestial Longitude - On Right Ascension - Of the Probe, deg
- V: Inertial Speed, km/sec
- W: Path Angle, deg
- T: Azimuth Angle, deg

**LINE C**
- X: Heliocentric Position of the Earth, km
- Y: Heliocentric Velocity of the Earth, km/sec

**LINE D**
- X: Heliocentric Position of the Target, km
- Y: Heliocentric Velocity of the Target, km/sec

**LINE E**
- X: Lat Celestial Latitude - On Declination - Of the Earth, deg
- Z: Lon Celestial Longitude - On Right Ascension - Of the Earth, deg
- V: Inertial Speed: Target with Respect to the Sun, km/sec

**LINE F**
- EPS Earth-Probe-Sun Angle, deg
- ESP Earth-Sun-Probe Angle, deg
- GEP Earth-Probe-Earth Angle, deg
- GEP Earth-Moon-Probe Angle, deg
- MEP Moon-Earth-Probe Angle, deg

**LINE G**
- MPS Moon-Probe-Sun Angle, deg
- MSP Moon-Sun-Probe Angle, deg
- SPM Sun-Moon-Probe Angle, deg
- SEM Sun-Earth-Moon Angle, deg
- EMS Earth-Moon-Sun Angle, deg
- ESM Earth-Sun-Moon Angle, deg

**LINE H**
- (Not printed if Target = Moon)
- EPS Earth-Probe-Target Angle, deg
- ESP Earth-Target-Probe Angle, deg
- TEP Target-Earth-Probe Angle, deg
- TPS Target-Probe-Sun Angle, deg
- TPM Target-Sun-Probe Angle, deg
- SMP Sun-Probe-Probe Angle, deg

**LINE I**
- USE EPN and SPN are printed if Target = Moon
- SET Sun-Earth-Target Angle, deg
- STE Sun-Target-Earth Angle, deg
- EST Earth-Sun-Target Angle, deg
- PMP Probes-Distance, km
- SPM Probe-Moon Distance, km
- SMP Sun-Probe-Near Limb of Earth Angle, deg

**LINE J**
- SCF Clock Angle of Earth, deg
- GCF Clock Angle of Target, deg
- SFP Probes-Near Limb of Target Angle, deg
- CFP Canopus-Target Angle, deg

**LINE K**
- REP Earth Probes-Distance, km
- VFP Velocity of the Probe with Respect to Earth, km/sec
- CFP Canopus-Probe-Earth Angle, deg
- CPF Canopus-Probe-Sun Angle, deg

---

**40**
TARGETICENTRIC

LINE A
X TARGET-CENTERED VERNAL EQUINOX POSITION, KM
Y
Z
DX
DY
DZ
LINE B
X RADIUS FROM TARGET CENTER, KM
DEC DECLEINATION - OR CELESTIAL LATITUDE, DEG
RA RIGHT ASCENSION - OR CELESTIAL LONGITUDE, DEG
V SPEED RELATIVE TO THE TARGET, KM/SEC
PATH TARGET-BODY PATH ANGLE, DEG
AZ TARGET-BODY AZIMUTH ANGLE, DEG
LINE C
X RADIUS FROM TARGET CENTER, KM
LAT TARGET-CENTERED LATITUDE, DEG
LON TARGET-CENTERED LONGITUDE, DEG
V SPEED RELATIVE TO THE TARGET, KM/SEC
PATH TARGET-BODY PATH ANGLE, DEG
AZ TARGET-BODY AZIMUTH ANGLE, DEG
LINE D
X RADIUS FROM TARGET CENTER, KM
LAT TARGET-CENTERED LATITUDE, DEG
LON TARGET-CENTERED LONGITUDE, DEG
V SPEED RELATIVE TO THE TARGET, KM/SEC
PATH TARGET-BODY PATH ANGLE, DEG
AZ TARGET-BODY AZIMUTH ANGLE, DEG
LINE E
X ALTITUDE ABOVE THE TARGET BODY SURFACE, KM
SHA SUN'S SHADOW PARAMETER, KM
SUN'S SHADOW PARAMETER, KM
ILLUMINATED CRESTORNT ENTION VIEWING ANGLE, DEG
ELP = ECLIPSE DOT (WHERE -53 x DRTF W = 150 Z24) X = M63
SA = INTS U = 10.013 A = 31.533
SH = SHADOW PARASITIC DEG/SEC
PATH ANGULAR VELOCITY, DEG/SEC
AZ ANGULAR SEMIDIAMETER OF TARGET AS SEEN FROM SRC, DEG
LINE F
HGE RIGHT ASCENSION OF EARTH IN SPACECRAFT COORDINATE SYSTEM, DEG
SVP DECLINATION OF TARGET IN SPACECRAFT COORDINATE SYSTEM, DEG
MARS RIGHT ASCENSION OF TARGET IN SPACECRAFT COORDINATE SYSTEM, DEG
MARS-PROBE-EARLY LIMB OF TARGET ANGLE, DEG

THE FOLLOWING ADDITIONAL LINES ARE PRINTED
IF MARS IS THE TARGET, ALL VARIABLES ARE
REFERENCED TO A MARS EQUATORIAL EQUATORIAL
COORDINATE SYSTEM OR TO A MARS FIXED COORDINATE
SYSTEM

LINE H
AXECECENTRIC EQUATORIAL COORDINATES

LINE I
X MARS EQUATORIAL, MARS-PROBE POSITION, KM
Y
Z
DX
DY
DZ

LINE J
X MARS EQUATORIAL, MARS-PROBE VELOCITY, KM/SEC
Y
Z

LINE K
X RADIUS FROM MARS CENTER, KM
DEC DECLINATION, DEG
RA RIGHT ASCENSION, DEG
V SPEED RELATIVE TO MARS, KM/SEC
PATH ANGULAR VELOCITY RELATIVE TO MARS, DEG
AZ TARGET-BODY AZIMUTH ANGLE, DEG
LINE L
X RADIUS FROM MARS CENTER, KM
LAT MARS-FIXED LATITUDE, DEG
LONG MARS-FIXED LONGITUDE, DEG
V SPEED RELATIVE TO ROTATING MARS, KM/SEC
PATH ANGULAR VELOCITY RELATIVE TO MARS, DEG
AZ TARGET-BODY AZIMUTH ANGLE, DEG

LINE M
X MARS RIGHT ASCENSION, DEG
DEC DECLINATION, DEG
RA RIGHT ASCENSION RELATIVE TO MARS, DEG
DEC DECLINATION RELATIVE TO MARS, DEG
LON LONGITUDE OF THE EARTH, DEG
LON LONGITUDE OF THE EARTH, DEG
LATITUDE OF THE EARTH, DEG

41
JPL TECHNICAL MEMORANDUM NO. 33-199

GEO-3 HELIO OR TARGET CONIC

GROUP A

(BODY CONIC)

EPOCH OF PERICENTER PASSAGE (TOP SEC PAST 1900) (JDATE (CALENDAR DATE)

LINE A

SMA SEMIMAJOR AXIS, KM

ECG ECCENTRICITY, UNLESS

B MAGNITUDE OF B VECTOR, KM

SLR SEMILATUS RECTUM, KM

APC APOCENTER DISTANCE, KM

AGC CLOSEST APPROACH DISTANCE, KM

LINE B

K VALUE HYPERBOLIC EXCESS VELOCITY AT APOGEE FOR ELLIPSE, KMS/SEC

CJ TWICE TOTAL ENERGY PER UNIT MASS AS VIS VIVA INTEGRAL, KME2/SEC2

C MICR ANGULAR MOMENTUM, KM2/SEC

TPP TIME FROM PERICENTER PASSAGE, SEC

TF TIME FROM INJ TO PERICENTER PASSAGE IN HRS FOR EARTH-MOON TRAJ., IN DAYS OTHERWISE

PER PERIOD, IN DAYS EXCEPT DAYS IF HELIO, PRINTED ONLY IF C3 IS -

LTF LINEARIZED TIME-OF-FLIGHT IN HRS FOR EARTH-MOON TRAJ, IN DAYS OTHERWISE PRINTED ONLY IF C3 IS *

LINE C

TA TRUE ANOMALY, DEG

MIA MAXIMUM TRUE ANOMALY, DEG

MA MEAN ANOMALY, DEG

LINE D

EJZ ANGLE BETWEEN IN. ASYMPTOTE AT TARG AND EARTH VECTOR, DEG

EJZ ANGLE BETWEEN IN. ASYMPTOTE AT TARG AND SUN VECTOR, DEG

EJZ ANGLE BETWEEN IN. ASYMPTOTE AT TARG AND CANOPUS VECTOR, DEG

DF ANGLE BETWEEN IMPACT VECTORS, DEG

IMPACT RADIUS, KM

GP ANGLE BETWEEN IN. ASYMPTOTE AND ITS PROJ. ON DRAKE PLANE, DEG

GROUPS B, C, D

ALL VECTORS REFERENCED TO I Plane

LINE A

X BODY-PROBE POSITION VECTOR IN COORD. SYSTEM GIVEN ABOVE, KM

Y Z BODY-PROBE VELOCITY VECTOR IN COORD. SYSTEM GIVEN ABOVE, KMS/SEC

LINE B

E Plane DECLINATION OF PROBE ORBIT PLANE TO PLANE GIVEN ABOVE, DEG

H Plane LONGITUDE OR RIGHT ASCENSION OF ASCENDING NODE, DEG

P Plane ORBIT PLANE ORIGIN TO PERICENTER, DEG

MX UNIT M VECTOR

MY UNIT N VECTOR

MZ UNIT Z VECTOR

LINE C

WX UNIT W VECTOR

WY UNIT Y VECTOR

WZ UNIT Z VECTOR

LINE D

U UNIT U VECTOR

VQ UNIT Q VECTOR

VAR UNIT R VECTOR

LINE E

BU UNIT B VECTOR

BV UNIT V VECTOR

BT UNIT T VECTOR

LINE F

FS UNIT F VECTOR

SF UNIT S VECTOR

LINE G

SLO UNIT SVECTOR

SLO2 UNIT SVECTOR

LINE H

ETE ANGLE BETWEEN T AND PROJ. OF EARTH-TARG VECTOR ON R-T PLANE, DEG

ETS ANGLE BETWEEN T AND PROJ. OF EARTH-TARG VECTOR ON C-T PLANE, DEG

ETC ANGLE BETWEEN R AND PROJ. OF CANOPUS-TARG VECTOR ON R-T PLANE, DEG

LAP DEGREE DECLINATION OF ASYMPTOTE, DEG

LINE I

RAP RIGHT ASCENSION OF ASYMPTOTE, DEG

LINE J

BTA COMPONENT OF B, WHERE BTA FOR EARTH EQU., BTA FOR ELLIPSE

BTA B COMPONENT OF B, KM

BTA MAGNITUDE OF B, KM

LINE K

THD DIRECTION ANGLE OF IMPACT PARAMETER IN R-T PLANE MEASURED FROM T VECT0R IN (+) PLANE

42
OUTPUT DESIGNATING BEGINNING OF TRAJECTORY BURN

LINE A
ZERO TIME PAST INJECTION (EQUINOX) (OP SEC PAST 1950) (JD) (CALENDAR DATE)
LINE B
START BURN

OUTPUT DESIGNATING END OF TRAJECTORY BURN

LINE A
ZERO TIME PAST INJECTION (EQUINOX) (OP SEC PAST 1950) (JD) (CALENDAR DATE)
LINE B
END BURN

OUTPUT DESIGNATING BEGINNING OF GAS JET COMPUTATION

LINE A
ZERO TIME PAST INJECTION (EQUINOX) (OP SEC PAST 1950) (JD) (CALENDAR DATE)
LINE B
START GAS JETS

OUTPUT DESIGNATING END OF GAS JET COMPUTATION

LINE A
ZERO TIME PAST INJECTION (EQUINOX) (OP SEC PAST 1950) (JD) (CALENDAR DATE)
LINE B
END GAS JETS

SHADOW PARAMETERS

* WHEN PROBE ENTERS, LEAVES IS IN, OR OUT OF A BODYS SHADOW
ONE OF THE FOLLOWING SET OF TWO LINES WILL BE OUTPUT

LINE A
ZERO TIME PAST INJECTION (EQUINOX) (OP SEC PAST 1950) (JD) (CALENDAR DATE)
LINE B
PROBE IS ENTERING (BODYS) SHADOW

LINE A
ZERO TIME PAST INJECTION (EQUINOX) (OP SEC PAST 1950) (JD) (CALENDAR DATE)
LINE B
PROBE IS LEAVING (BODYS) SHADOW

LINE A
ZERO TIME PAST INJECTION (EQUINOX) (OP SEC PAST 1950) (JD) (CALENDAR DATE)
LINE B
PROBE IS IN (BODYS) SHADOW

LINE A
ZERO TIME PAST INJECTION (EQUINOX) (OP SEC PAST 1950) (JD) (CALENDAR DATE)
LINE B
PROBE IS OUT OF (BODYS) SHADOW
If public information is requested the following five lines are printed:

<table>
<thead>
<tr>
<th>Line A</th>
<th>Public Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line B</td>
<td>St. miles</td>
</tr>
<tr>
<td>Line C</td>
<td>St. miles/miles</td>
</tr>
<tr>
<td>Line D</td>
<td>St. miles/miles</td>
</tr>
<tr>
<td>Line E</td>
<td>St. miles</td>
</tr>
<tr>
<td>Line F</td>
<td>St. miles</td>
</tr>
</tbody>
</table>

**Line A**

**Line B**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude of probe above earth</td>
<td>St. miles</td>
</tr>
<tr>
<td>Altitude of probe above target</td>
<td>St. miles</td>
</tr>
<tr>
<td>Pt. target probe distance</td>
<td>St. miles</td>
</tr>
<tr>
<td>Rps sun probe distance</td>
<td>St. miles</td>
</tr>
<tr>
<td>Arc distance along path of the trajectory</td>
<td>St. miles</td>
</tr>
</tbody>
</table>

**Line C**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vsc geocentric [inertial] speed of probe</td>
<td>St. miles/miles</td>
</tr>
<tr>
<td>Vsc targetcentric [inertial] speed of probe</td>
<td>St. miles/miles</td>
</tr>
<tr>
<td>Lat geocentric latitude of probe</td>
<td>Deg.</td>
</tr>
<tr>
<td>Long geocentric longitude of probe</td>
<td>Deg.</td>
</tr>
</tbody>
</table>

**Line D**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Board units</td>
<td></td>
</tr>
</tbody>
</table>

**Line E**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up horizontal position of probe</td>
<td>Board units</td>
</tr>
<tr>
<td>Vr vertical position of probe</td>
<td>Board units</td>
</tr>
<tr>
<td>Ue horizontal position of earth</td>
<td>Board units</td>
</tr>
<tr>
<td>Vr vertical position of target</td>
<td>Board units</td>
</tr>
</tbody>
</table>

**Line F**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Station prints</td>
<td></td>
</tr>
<tr>
<td>(Time past injection) (equinox) (up sec past 1950) (JD) (calendar date)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line A</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Geod. radius of probe, km</td>
</tr>
<tr>
<td>b</td>
<td>Lat. geod. latitude, deg.</td>
</tr>
<tr>
<td>c</td>
<td>Lng. geod. longitude, deg.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line B</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minutes from injection</td>
<td></td>
</tr>
<tr>
<td>Ha</td>
<td>Local hour angle of probe, deg.</td>
</tr>
<tr>
<td>Dec</td>
<td>Local declination of probe, deg.</td>
</tr>
<tr>
<td>El</td>
<td>Elevation angle of probe, deg.</td>
</tr>
<tr>
<td>Az</td>
<td>North azimuth of probe, deg.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line C</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cac clock angle of camopus, deg.</td>
<td></td>
</tr>
<tr>
<td>Can clock angle of moon, deg.</td>
<td></td>
</tr>
<tr>
<td>Cnt clock angle of target, deg.</td>
<td></td>
</tr>
<tr>
<td>Pts probe-station-sun angle, deg.</td>
<td></td>
</tr>
<tr>
<td>Pts probe-station-moon angle, deg.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line D</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ut</td>
<td>Time correction for frequencies, hours</td>
</tr>
<tr>
<td>Dde</td>
<td>Declination rate, deg/sec</td>
</tr>
<tr>
<td>Daz</td>
<td>Azimuth rate, deg/sec</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line E</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bt</td>
<td>Ephemeris time correction, hours</td>
</tr>
<tr>
<td>Dde</td>
<td>Declination rate, deg/sec</td>
</tr>
<tr>
<td>Daz</td>
<td>Azimuth rate, deg/sec</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line F</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rdi</td>
<td>Radius of the station, km</td>
</tr>
<tr>
<td>Dpe</td>
<td>Geod. north geocentric latitude of the station, deg.</td>
</tr>
<tr>
<td>Dpe</td>
<td>Long. east longitude of the station, deg.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line G</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pt</td>
<td>Time for light to travel from station to probe (sec.)</td>
</tr>
<tr>
<td>Dpe</td>
<td>Polarization angle, deg.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line H</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rfr</td>
<td>Beacon reference frequency, cps</td>
</tr>
<tr>
<td>Rfr</td>
<td>One way beacon frequency, cps</td>
</tr>
<tr>
<td>Rfr</td>
<td>Two way beacon frequency, cps</td>
</tr>
<tr>
<td>Rfr</td>
<td>Transponder beacon frequency, cps</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line I</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dpe</td>
<td>Beacon reference frequency, cps</td>
</tr>
<tr>
<td>Dpe</td>
<td>One way beacon frequency, cps</td>
</tr>
<tr>
<td>Dpe</td>
<td>Two way beacon frequency, cps</td>
</tr>
</tbody>
</table>

**Line J**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dpe</td>
<td>Transponder beacon reference frequency, cps</td>
</tr>
<tr>
<td>Dpe</td>
<td>Ground beacon frequency, cps</td>
</tr>
<tr>
<td>Dpe</td>
<td>Beacon frequency, cps</td>
</tr>
</tbody>
</table>

**Line K**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dpe</td>
<td>One way beacon frequency, cps</td>
</tr>
<tr>
<td>Dpe</td>
<td>Two way beacon frequency, cps</td>
</tr>
</tbody>
</table>

**Line L**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dpe</td>
<td>Beam beacon frequency, cps</td>
</tr>
<tr>
<td>Dpe</td>
<td>One way beacon frequency, cps</td>
</tr>
<tr>
<td>Dpe</td>
<td>Two way beacon frequency, cps</td>
</tr>
</tbody>
</table>

**Line M**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dpe</td>
<td>Transponder beacon reference frequency, cps</td>
</tr>
<tr>
<td>Dpe</td>
<td>Transponder beacon frequency, cps</td>
</tr>
<tr>
<td>Dpe</td>
<td>Transponder beacon reference frequency, cps</td>
</tr>
<tr>
<td>Dpe</td>
<td>Transponder beacon frequency, cps</td>
</tr>
</tbody>
</table>

**Line N**

<table>
<thead>
<tr>
<th>Field</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dpe</td>
<td>Transponder beacon reference frequency, cps</td>
</tr>
<tr>
<td>Dpe</td>
<td>Transponder beacon frequency, cps</td>
</tr>
<tr>
<td>Dpe</td>
<td>Transponder beacon reference frequency, cps</td>
</tr>
<tr>
<td>Dpe</td>
<td>Transponder beacon frequency, cps</td>
</tr>
</tbody>
</table>
C. JOB-SHOP OUTPUT CAPABILITY

1. In the job-shop mode of operation, printed output is put on tape SYSOU1. Or, by proper use of input parameter FLAG42, the output is put on low density tape SYSPL1. The latter tape can be processed by the S-C 4020 High-Speed Microfilm Recorder. Subroutine PROUT is utilized to produce the line images for SYSOU1 or SYSPL1.

2. Output also appears on the 7094 on-line printer. The progress of the trajectory and the occurrence of errors are noted. Subroutine ERPRT is utilized to produce the on-line print. Additional on-line print capability is available by proper use of the 7094 console sense switches or by input. A minimum on-line print (defined as on-line printing of injection conditions, phase changes and encounter conditions) is obtained by depressing sense switch 6. A detailed or fine on-line print (defined as the duplication, on-line, of all output on SYSOU1 or SYSPL1) is obtained by depressing sense switches 4 and 6. The sense switches, hence the on-line print request, may be changed at will during the computation of the trajectory. If desired, input parameter OPTSWT may be used to preset the on-line print request in the source deck.

3. The trajectory SAVE tape may be put on high density binary tape SYSCK2. Input parameters located at PLOTFQ control the generation of the SAVE tape.

4. Debugging output (SNAP) may be used (Ref. 4, Section VIII). SFPRO's FILE control card must have the following format:

```
<table>
<thead>
<tr>
<th>Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>$</td>
</tr>
</tbody>
</table>
```
D. SFOF OUTPUT CAPABILITY

The SFOF output capability is similar to the job-shop output capability. The normal output is put on SYSOU1. The on-line output control and printing are done at remote user area 5, instead of at the 7094 console and printer. The progress of the trajectory and the occurrence of errors are printed on the remote administrative printer. The minimum or fine print of the trajectory is printed on the remote SC-3070 printer. This minimum or fine on-line SC-3070 print is controlled by the remote console option switches 33 and 35 (corresponding to sense switches 4 and 6). If desired, input parameter OPTSWT may be used to preset the on-line print request in the source deck.

The spacecraft ephemerides are treated the same as in the job-shop mode but the debugging output capability (SNAP) does not exist.
VI. SUBROUTINES

SFPRO is made up of 43 closed subroutines, some of which have more than one entry and perform more than one function. Many subroutines have not changed in function from Ref. 1 (Section VIII) but the documentation was repeated in this Technical Memorandum (TM 33-199) for completeness. All subroutines were documented according to the following specifications:

IDENTIFICATION

Entry name(s)
Programmer(s)
Coding language
Date

PURPOSE

Defines the task performed by this subroutine.

RESTRICTIONS

Cites the error conditions, external buffers used, COMMON used, subroutines used, etc., (COMMON names and subroutine names are capitalized).

METHOD

Gives a detailed description of how the subroutine accomplishes its task.
Includes a flow chart when applicable.

USE

Defines all calling sequences, including the definition and use of input and output parameters.

CODING INFORMATION

Gives the decimal and octal sizes of the subroutine excluding COMMON storage or external buffer storage.

REFERENCES

Gives Requests for Programming (RFP) number, Inter-Office Memoranda (IOM's) and technical references if applicable.
IDENTIFICATION

ABORT/ERPRT/JEXIT/PRSET/....../TIME

Nicholas S. Newhall, JPL
IBM 7094 Fap
December 2, 1964

PURPOSE

To handle communication between SFPRO and the various systems, I/O devices, switches, flags and subroutines.

RESTRICTIONS

a. Entries RUNID, PRTSWX, FLAG42, COMTRJ, COMTRK and COMFLG are provided for those input parameters.
b. The on-line printer is sensed to obtain the date and time-of-day if the parameter EXPORT is zero.
c. The print flags are in COMMON locations SPIA, ..., SP3C, EJCTA, EJCTB, EJCTC, 37HED, PRFLG and PRTSWT.
d. Subroutines TYPWRT and PROUT are used for on-line printing.

METHOD

a. PRSET examines the input flags, the 7094 sense-switches, the SFOF mode cell SFMODE, and user area option switches in order to set the appropriate COMMON print flags for PROUT.
b. ERPRT prints the on-line messages. The 7094 on-line printer or the remote user area administrative printer will print the message, depending on the contents of parameter SFMODE.
c. TIME provides the user with the BCD time-of-day in the AC and the computer code letter A, B or C left adjusted in the MQ and followed by blanks.
d. JEXIT prints "END TRAJECTORY (SFPRO)", closes the output files used by PROUT and returns control to JPTRAJ with a zero in the accumulator, designating a normal return.
e. ABORT prints "END TRAJECTORY (SFPRO)", closes the output files used by PROUT and returns control to JPTRAJ with a one in the accumulator, designating the error return.
f. ....... is the location of the Program Control Block (PCB) and contains the information JPTRAJ needs to set up for and transfer control to SFPRO.
USE

Calling sequences:

a. CALL PRSET
   return

b. TSX $ERPRT, 4, N
   PZE A, B
   return

where

   A, ..., A+(B-1) contain BCD text
   B is the number of words of text, B ≤ 12
   N = 0 means message not printed off-line
   = 2 means message printed off-line after a double space
   = 3 means message printed off-line after a page eject.

c. CALL TIME
   return

d. CALL JEXIT
   (transfers control to JPTRAJ)

e. CALL ABORT
   (transfers control to JPTRAJ)

CODING INFORMATION

Length of subroutine is 757(10) or 1365(8) words.
IDENTIFICATION

ADD
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To perform double precision addition of two double precision floating point numbers.

RESTRICTIONS

a. If the numbers involved are sufficiently large so as to cause overflow, erroneous results will be obtained.
b. Uses COMMON to COMMON + 3.

METHOD

The contents of the AC-MQ registers and/or the contents of specified cells in core storage (see USE) are added using the DFAD machine instruction. The high order part of the result is placed in the AC and the low order part in the MQ.

USE

Calling sequences:

a. CALL ADD
   return
   Enter with one of the double precision numbers in the AC-MQ and the other number in COMMON and COMMON + 1. Exit with the result in the AC-MQ.

b. CALL ADD, YI, 0
   TSX YI, 0
   TSX 0, 0
   return
   Enter with one of the double precision numbers in the AC-MQ and the other number in YI and YI + 1. Exit with the result in the AC-MQ.

c. CALL ADD, YI, ZI
   TSX YI, 0
   TSX ZI, 0
   return
   Enter with one of the double precision numbers in YI and YI + 1 and the other number in ZI and ZI + 1. Exit with the result in the AC-MQ.

CODING INFORMATION

Length of the subroutine is 25(10) or 31(8) words.
IDENTIFICATION

ARCOS/ARSIN
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To compute arcsine x or arccosine x for a floating point, single precision x, in degrees.

RESTRICTIONS

If |x| > 1.0 the result will be ±90.0 for the arcsine, taking the same sign as the argument, and will be 180.0 for the arccosine for a negative argument and 0.0 for the arccosine for a positive argument.

METHOD

\[
\sin^{-1} x = \frac{\pi}{2} - \sqrt{1 - x^2} F(x), \quad \cos^{-1} x = \sqrt{1 - x^2} F(x)
\]

where

\[
F(x) = \sum_{i=0}^{7} C_i x^i,
\]

and

\[
C_0 = 1.570796327, \quad C_4 = 0.0308918810
\]
\[
C_1 = -0.2145988016, \quad C_5 = -0.0170881256
\]
\[
C_2 = 0.0889789874, \quad C_6 = 0.0066700901
\]
\[
C_3 = -0.0501743046, \quad C_7 = -0.0012624911
\]

Accuracy: 7 significant decimal digits.

USE

Enter with the argument in the accumulator. Exit with the result in the accumulator in degrees.

Calling sequences:

for arccosine:

CLA X
CALL ARCOS
return

for arcsine:

CLA X
CALL ARSIN
return

CODING INFORMATION

Length of subroutine is 96(10) or 140(8) words.
IDENTIFICATION

ARTAN
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To compute arctangent (y/x) in degrees for floating point, single precision x and y.

RESTRICTIONS

Uses COMMON to COMMON + 4.

METHOD

The following Rand approximating polynomial is used:

\[
\arctan \left( \frac{y}{x} \right) = \arctan \left( \frac{D}{4} \right) + \sum_{i=0}^{7} C_{2i+1} \left( \frac{D-1}{D+1} \right)^{2i+1}
\]

where:

\[
\begin{align*}
C_1 &= 0.9999993329 & C_9 &= 0.0964200441 \\
C_3 &= -0.3332985605 & C_{11} &= -0.0559098861 \\
C_5 &= 0.1994653599 & C_{13} &= 0.0218612288 \\
C_7 &= -0.1390853351 & C_{15} &= -0.0040540580
\end{align*}
\]

Accuracy: 7 significant figures.

USE

Enter with y in the accumulator and x in the MQ. Exit with Arctan (y/x) in the accumulator in degrees normalized to lie in the range 0 to 360.

Calling sequence:

\[
\begin{align*}
\text{CLA} & \quad \text{Y} \\
\text{LDQ} & \quad \text{X} \\
\text{CALL} & \quad \text{ARTAN} \\
\text{return}
\end{align*}
\]

CODING INFORMATION

Length of subroutine is 57(10) or 71(8) words.
IDENTIFICATION

BCDNO/NEWBCD
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To replace a BCD word (the name of a celestial body) in the accumulator with a fixed point number scaled 35. This number will be used as a reference number in locating data pertinent to that body.

RESTRICTIONS

a. An error is possible if the BCD word is not recognized (see USE), in which case a comment to this effect is printed and control is given to ABORT.
b. ERPRT, PROUT and ABORT may be called.
c. NEWBCD is provided so that SATURN may be replaced by some other body name.

METHOD

The accumulator is compared with each of seven BCD words until equality occurs. Each comparison is counted and, at equality, this count, in fixed point scaled 35, replaces the accumulator.

USE

Calling sequence:

CALL (BCD word)
CALL BCDNO
return

If (BCD word) = EARTH return with accumulator = 0
     MOON = 1
     SUN = 2
     VENUS = 3
     MARS = 4
     SATURN = 5
     JUPITE = 6

CODING INFORMATION

Length of subroutine is 36(10) or 44(8) words.
IDENTIFICATION

CHANGE

Peter S. Fisher, JPL

IBM 7094 Fap

December 2, 1964

PURPOSE

To call PRINTD with special group and conic print flags.

RESTRICTIONS

The subroutines SPRAY and PRINTD are called, and GROP and ORBETT are referenced indirectly.

METHOD

The current group and conic print flags are saved and the desired replacements are substituted. SPRAY is called to prepare the GROPS flags for PRINTD and then PRINTD is called. Then the group and conic flags are reset and SPRAY is again called to restore the GROPS flags.

USE

Calling sequence:

CALL CHANGE
OCT A
OCT B
return

where A is one word of twelve octal digits (designating the desired group options) and B is one word of twelve octal digits (designating the desired conic options).

CODING INFORMATION

Length of subroutine is 28(10) or 34(8) words.
IDENTIFICATION

CLASS
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To calculate conic orbital elements.

RESTRICTIONS

a. CLASS is a subset of a rectangular-to-orbital elements package and uses other subroutines in the package.
b. COMMON through COMMON+3 are used.
c. An error can occur if the input value of \( c_3 \) is zero.
d. Subroutines SQRT, ACOS and SIN are called.
e. Location HARMN is referenced indirectly to obtain the Earth's oblateness constants.

METHOD

The following sketch illustrates the relationship between the orbital elements and the reference \( \hat{P}, \hat{Q}, \hat{W} \) and \( \bar{X}, \bar{Y}, \bar{Z} \) frames:

\[
\begin{align*}
\sin \Omega &= \frac{W_x}{\sin i} \\
\cos \Omega &= \frac{-W_y}{\sin i}
\end{align*}
\]

where \( 0 \leq \Omega < 360 \text{ deg} \) for the right ascension of the ascending node.
\[
\begin{align*}
\sin \omega &= \frac{P_z}{\sin \mathfrak{i}} \\
\cos \omega &= \frac{Q_z}{\sin \mathfrak{i}}
\end{align*}
\]

where \(0 \leq \omega < 360\) deg for the argument of the pericenter.

The formulas for \(\Omega\) may be derived by constructing the unit vector \(\hat{N}\) at the ascending node:

\[
\hat{N} = \frac{\hat{U} \times \hat{W}}{|\hat{U} \times \hat{W}|}
\]

where \(\hat{U} = (0, 0, 1)\) and \(\sin \mathfrak{i} = |\hat{U} \times \hat{W}|\). \(\hat{N}\) is then projected onto the X and Y axes to give the formulas for the cosine and the sine.

Next, the auxiliary unit vector \(\hat{M} = \hat{W} \times \hat{N}\) is constructed so that \(\omega\) is given by:

\[
\begin{align*}
\sin \omega &= \hat{P} \cdot \hat{M} = \hat{P} \cdot (\hat{W} \times \hat{N}) = -\hat{N} \cdot (\hat{W} \times \hat{P}) = -\hat{N} \cdot \mathfrak{Q} \\
\cos \omega &= \hat{P} \cdot \hat{N}
\end{align*}
\]

The conic parameters are given by the standard formulas for \(c_1 \neq 0\):

\[
\begin{align*}
q &= \frac{p}{1 + \epsilon} & \text{the closest approach distance} \\
\frac{V}{p} &= \frac{\mu (1 + \epsilon)}{c_1} & \text{the velocity at closest approach} \\
\frac{V_a}{c_1} &= \frac{\mu (1 - \epsilon)}{c_1} & \text{velocity at farthest departure} (c_3 < 0) \\
V_h &= \sqrt{c_3} & \text{hyperbolic excess velocity} (c_3 > 0) \\
q_2 &= a (1 + \epsilon) & \text{farthest departure distance} (c_3 < 0) \\
p &= \frac{2\pi}{\mathfrak{n}} & \text{the period}
\end{align*}
\]

For an Earth satellite, the quantities \(\dot{\omega}\) and \(\dot{\Omega}\) are also computed:

\[
\begin{align*}
\dot{\omega} &= \frac{nJa^2}{p^2} \left(2 - \frac{5}{2} \sin^2 \mathfrak{i}\right) \\
\dot{\Omega} &= -\frac{nJa^2}{p^2} \cos \mathfrak{i}
\end{align*}
\]
where

\[ J \]
\[ a_0 \]
\[ n \]
\[ p \]

is the coefficient of the second harmonic in the Earth's oblateness expression

is the Earth radius, km

is the mean motion, rad/sec

is the semilatus rectum, km

so that \( \delta \) and \( \Omega \) may be converted to deg/day for output.

**USE**

Calling sequence:

```
CALL CLASS
PZE A, B
PZE C
NOP
error return
normal return
```

where

A, ..., A+8 contain the input vectors \( \hat{F}, \hat{Q}, \hat{W} \).

B, ..., B+7 contain the input parameters \( c_1, c_3, \mu, x, 1 - \epsilon \) \( a, p \) and \( n \), respectively, as computed by JEKYL.

C, ..., C+9 contain the output parameters:

- \( i \), inclination, radians
- \( \Omega \), right ascension of the ascending node, radians
- \( \omega \), argument of pericenter, radians
- \( q \), closest approach distance, km
- \( V_p' \), velocity at closest approach, km/sec
- \( V_a' \) (or \( V_h \) if \( c_3 > 0 \)), velocity at farthest departure (or hyperbolic excess velocity), km/sec
- \( q_2' \) (or zero if \( c_3 > 0 \)), farthest departure distance, km
- \( P \), period, sec
- \( \dot{\omega} \), derivative of \( \omega \), deg/day
- \( \dot{\Omega} \), derivative of \( \Omega \), deg/day

The error exit will be taken if the input \( c_3 \) is zero.

**CODING INFORMATION**

Length of subroutine (includes CLASS as a subset) is 1226 (10) or 2312 (8) words.
REFERENCE

IDENTIFICATION

JEKYL
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To compute the $\hat{P}$, $\hat{Q}$ and $\hat{W}$ vectors, the epoch of closest approach, and $c_1$ and $c_3$ from cartesian position and velocity vectors.

RESTRICTIONS

a. COMMON through COMMON+f4 are used.
b. An error can occur if the logarithm or square root of a negative number is attempted.
c. Subroutines SQRT, UNIT, CROSS and LN are called.
d. JEKYL is a subset of a rectangular-to-orbital-elements package and uses several other subroutines in the package.
e. COMMON locations ECCEN, IMINE, AVAL, PVAL, NORB, NU, JECAN and MENAN are used.

METHOD

Given the cartesian position and velocity vectors $\vec{R}$ and $\vec{V}$ compute:

$$p = \frac{R^2V^2 - (RR)^2}{\mu}$$

the semilatus rectum

where

$$RR = \vec{R} \cdot \vec{V}$$

$$c_1 = \sqrt{R^2V^2 - (R\dot{R})^2}$$

the angular momentum

$$\frac{1}{a} = \frac{2\mu - RV^2}{R\mu}$$

$$c_3 = -\frac{\mu}{a}$$

the "energy" or vis viva integral

At this point a test is made with the help of the I.D. input to determine whether or not $a$ is an acceptable parameter. $a^*$ is defined by
The motion is considered parabolic and \( c_3 \) is set to zero whenever \( |a| > a^* \).

\[
1 - \epsilon^2 = \frac{p}{a}
\]

\[
\epsilon = \sqrt{1 - \left( 1 - \epsilon^2 \right)}
\]

\[
\begin{align*}
\cos \nu &= \frac{p - R}{\epsilon R} \\
\sin \nu &= \frac{R}{\epsilon} \sqrt{\frac{p}{R}}
\end{align*}
\]

true anomaly

\[
q = \frac{p}{1 + \epsilon}
\]

closest approach distance

\[
\hat{w} = \frac{R \times \vec{V}}{c_1}
\]

unit angular momentum vector

\[
\hat{U}_1 = \frac{R}{R}
\]

\[
\hat{V}_1 = \frac{R}{c_1} \vec{V} - \frac{\dot{R}}{c_1} \vec{R}
\]

\[
\hat{P} = \cos \nu \hat{U}_1 - \sin \nu \hat{V}_1
\]

\[
\hat{Q} = \sin \nu \hat{U}_1 + \cos \nu \hat{V}_1
\]

If \( c_3 \neq 0 \), \( T - T_p \) is computed from Kepler's equation according to the sign of \( a \):

If \( a > 0 \):

\[
\begin{align*}
\cos E &= \frac{R}{p} \left( \cos \nu + \epsilon \right) \\
\sin E &= \frac{R}{p} \sqrt{1 - \epsilon^2} \sin \nu
\end{align*}
\]
M = E - \epsilon \sin E

if 1 - \epsilon > 0.1 or if 1 - \epsilon \leq 0.1 and \left| \sin E \right| > 0.1

M = (1 - \epsilon) \sin E + \left( \frac{\sin^3 E}{6} + \frac{3 \sin^5 E}{40} \right)

if 1 - \epsilon \leq 0.1 and \cos E > 0, \left| \sin E \right| \leq 0.1

M = n(T - T_p)

where

n = \sqrt{\mu a}^{-3/2}

if a < 0:

\sinh F = \frac{R \dot{R}}{\epsilon \sqrt{|a|}}

M = \epsilon \sinh F - F

if \epsilon - 1 > 0.1 or if \epsilon - 1 \leq 0.1 and \left| \sinh F \right| > 0.1

M = (\epsilon - 1) \sinh F - \left( \frac{3 \sinh^5 F}{40} - \frac{\sinh^3 F}{6} \right)

if \epsilon - 1 \leq 0.1 and \left| \sinh F \right| \leq 0.1

M = n(T - T_p)

where

n = \sqrt{|a|}^{-3/2}

If c_3 = 0, the formula for the parabola is used:

M = \sqrt{\mu}(T - T_p) = qD + \frac{1}{6} D^3

where

D = R \dot{R}/\sqrt{\mu} = \sqrt{2q} \tan \nu/2

USE

Calling sequence:

CALL JEKYL
PZE 0, A
PZE B, C
error return
normal return

where

A
contains the \( \mu \) (gravitational coefficient) of the body from which the
input position and velocity vectors are measured.

A+1
contains an integer I.D. used in the parabola test: 0 = planets
1 = Moon
2 = Sun

B, B+1, B+2
contain the input cartesian position vector, \( \mathbf{R} \).

C, C+1, C+2
contain the input cartesian velocity vector, \( \mathbf{V} \).

D, \ldots, D+8
contain the output unit vectors \( \mathbf{P}, \mathbf{Q}, \mathbf{W} \).

E
contains the input epoch \( T \).

F
contains the output epoch of closest approach, \( T_p \).

G, G+1, G+2
contain the output \( \Delta T = T - T_p \), the angular momentum, \( c_1 \), and the
energy or vis viva integral, \( c_3 \).

In addition, the following quantities are computed and stored in the COMMON locations
given:

<table>
<thead>
<tr>
<th>Location</th>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECCEN</td>
<td>( \epsilon )</td>
<td>eccentricity</td>
</tr>
<tr>
<td>lMINE</td>
<td>1-( \epsilon )</td>
<td>1 minus eccentricity</td>
</tr>
<tr>
<td>AVAL</td>
<td>( a )</td>
<td>semimajor axis</td>
</tr>
<tr>
<td>PVAL</td>
<td>( p )</td>
<td>semilatus rectum</td>
</tr>
<tr>
<td>NORB</td>
<td>( n )</td>
<td>mean motion</td>
</tr>
<tr>
<td>NU</td>
<td>( \nu )</td>
<td>true anomaly</td>
</tr>
<tr>
<td>JECAN</td>
<td>E(or F)</td>
<td>eccentric anomaly</td>
</tr>
<tr>
<td>MENAN</td>
<td>M</td>
<td>mean anomaly</td>
</tr>
</tbody>
</table>

The error exit is taken if a negative square root is attempted or if the logarithm of a
negative number is attempted.

CODING INFORMATION

Length of subroutine (includes JEKYL as a subset) is 714(10) or 2312(8) words.

REFERENCE

Report No. 32-223, Revision 1, Jet Propulsion Laboratory, Pasadena, California,
September 1, 1962.
IDENTIFICATION

SPECL
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To compute the reference unit vectors $\hat{R}$, $\hat{S}$, $\hat{T}$, and $\bar{B}$ and the impact parameters $B \cdot T$, $B \cdot R$.

RESTRICTIONS

a. COMMON through COMMON+3 are used.
b. Subroutines SQRT, ARCOS and SIN are called.
c. COMMON location PVAL and ECCEN are used.
d. SPECL is a subset of a rectangular-to-orbital-elements package and uses several other subroutines in the package.
e. External locations SAVA, INJTYCP and RMAX are referenced indirectly.
f. An error will occur if a negative square root is attempted.

METHOD

The computation of the $\hat{S}$ and $\bar{B}$ vectors depends on the value of the eccentricity, $\epsilon$:

a. $\epsilon \geq 1$, the hyperbolic case with $a < 0$:

$$\hat{S} = \begin{cases} \frac{1}{\epsilon} \hat{P} + \frac{\sqrt{\epsilon^2 - 1}}{\epsilon} \hat{Q} & \text{for the incoming asymptote} \\ -\frac{1}{\epsilon} \hat{P} + \frac{\sqrt{\epsilon^2 - 1}}{\epsilon} \hat{Q} & \text{for the outgoing asymptote} \end{cases}$$

$$\bar{B} = \begin{cases} \frac{|a| (\epsilon^2 - 1)}{\epsilon} \hat{P} - \frac{|a| \sqrt{\epsilon^2 - 1}}{\epsilon} \hat{Q} & \text{for the incoming asymptote} \\ \frac{|a| (\epsilon^2 - 1)}{\epsilon} \hat{P} + \frac{|a| \sqrt{\epsilon^2 - 1}}{\epsilon} \hat{Q} & \text{for the outgoing asymptote} \end{cases}$$
b. $\epsilon < 1$, the elliptic case with $a > 0$

$$\hat{S} = \hat{p}$$

$$\hat{B} = a\sqrt{\epsilon^2 - 1} \hat{q}$$

for both the incoming and outgoing asymptote options.

The remaining two reference vectors $\hat{T}$ and $\hat{R}$ are given in either the hyperbolic or elliptic case by

$$\hat{T} = \left( \frac{S_y}{\sqrt{S_x^2 + S_y^2}}, \frac{-S_x}{\sqrt{S_x^2 + S_y^2}}, 0 \right)$$

$$\hat{R} = \hat{S} \times \hat{T}$$

**USE**

Calling sequence:

```plaintext
CALL SPECL
PZE A, B
PZE C
```

error return

normal return

Enter with the semimajor axis, $a$, in the AC and the eccentricity, $\epsilon$, in the MQ.

Where

- A, ..., A+8 contain the input vectors $\hat{p}$, $\hat{q}$, $\hat{w}$.
- B contains zero for reference to an incoming asymptote and 1 for reference to an outgoing asymptote.
- C, ..., C+14 contain the output $B \cdot T$, $B \cdot R$ and vectors $\hat{S}$, $\hat{B}$, $\hat{T}$ and $\hat{R}$, respectively.

The error return is taken if a negative square root is attempted.

**CODING INFORMATION**

Length of subroutine (includes SPECL as a subset) is 714(I0) or 2312(8) words.

**REFERENCE**

IDENTIFICATION

CLUCK
Peter S. Fisher, JPL
IBM 7094 Fap
December 2, 1964

PURPOSE

To compute the Canopus clock angle, Moon clock angle, and target clock angle.

RESTRICTIONS

The subroutines UNIT, CROSS, PROD, and ARTAN are called.

METHOD

Clock \( \alpha \triangleq \tan^{-1}\left( \frac{-\mathbf{A} \cdot \mathbf{C}}{\mathbf{B} \cdot \mathbf{C}} \right) \)

where:

\[ \mathbf{A} = \frac{\mathbf{R}_{sp} \times \mathbf{R}_{ip}}{|\mathbf{R}_{sp} \times \mathbf{R}_{ip}|} \]

\[ \mathbf{B} = \frac{\mathbf{A} \times \mathbf{R}_{sp}}{|\mathbf{A} \times \mathbf{R}_{sp}|} \]

\[ \mathbf{C} = \frac{\mathbf{N} \times \mathbf{R}_{sp} \times \mathbf{R}_{sp}}{|\mathbf{N} \times \mathbf{R}_{sp} \times \mathbf{R}_{sp}|} \]

\( \mathbf{R}_{sp} \triangleq \) True of-date Sun-probe position vector

\( \mathbf{R}_{ip} \triangleq \) True of-date observation point-probe position vector

\( \mathbf{N} \triangleq \) True of-date target-probe position vector for the target clock angle

USE

Calling sequence:

Call CLUCK
PZE A, B
return

where A is the location of the input \( \mathbf{R}_{ip} \) vector and where B is the location where the three output clock angles will be stored.

CODING INFORMATION

Length of subroutine is 72(10) or 110(8) words
IDENTIFICATION

COS/SIN/QCOS/QSIN
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To compute sin x or cos x for a floating point, single precision x (x in radians or degrees).

RESTRICTIONS

a. Loops for large argument or small unnormalized argument.
b. Uses COMMOM to COMMON +2.

METHOD

The argument is reduced to a first quadrant equivalent and then a thirteenth order polynomial approximation, employing fixed point arithmetic, is used. The cosine is computed by first adding \(\pi/2\) to the argument.

USE

Enter with the argument in the accumulator.
Exit with the result in the accumulator.
Calling sequences:

for COS X

\[
\begin{align*}
X \text{ in radians} & \quad X \text{ in degrees} \\
CLA X & \quad CLA X \\
CALL QCOS & \quad CALL COS \\
\text{return} & \quad \text{return}
\end{align*}
\]

for SIN X

\[
\begin{align*}
X \text{ in radians} & \quad X \text{ in degrees} \\
CLA X & \quad CLA X \\
CALL QSIN & \quad CALL SIN \\
\text{return} & \quad \text{return}
\end{align*}
\]

CODING INFORMATION

Length of subroutine is 159(10) or 237(8) words.
IDENTIFICATION

CROSS/PROD/UNIT
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To compute: (1) the cross product of two vectors; or (2) the dot product of two vectors, or
the magnitude and magnitude squared of one vector; or (3) a unit vector.

RESTRICTIONS

a. All vectors must be stored BES 3.
b. In the calling sequences to the CROSS and UNIT option the location given for the output
   vector may be the same as the location given for an input vector.

METHOD

The vector operations of vector product and scalar product and the multiplication of a
vector by a scalar (1/|v| to obtain a unit vector) are performed in a manner indicated by
their definitions.

USE

Calling sequences:

a. To compute the vector product of two vectors \( \mathbf{C} = \mathbf{A} \times \mathbf{B} \):
   CALL CROSS
   PZE A, B
   PZE C
   return

b. To compute the scalar product of two vectors \( \mathbf{A} \cdot \mathbf{B} \):
   CALL PROD
   MZE A, B
   return
   Exit with the result in the accumulator.

c. To compute the magnitude and magnitude squared of a vector \( \mathbf{A} \):
   CALL PROD
   PZE A
   return
   Exit with the magnitude in the AC and the magnitude squared in the MQ.
d. To obtain a unit vector \( \mathbf{B} = \frac{\mathbf{A}}{|\mathbf{A}|} \):

\[
\text{CALL UNIT}
\]

\[
\text{PZE A, B}
\]

\[
\text{return}
\]

CODING INFORMATION

Length of subroutine is 66(10) or 102(8) words.
IDENTIFICATION

DAYS
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To convert the double precision floating point seconds located in the AC and MQ to single precision integer days and residual seconds.

RESTRICTIONS

a. A double precision number is assumed to be two floating point words.
b. Subroutines FIX, FLOAT, and ADD are called.
c. Uses COMMON to COMMON +5.

METHOD

The double precision seconds are divided by 86,400 and the integral part of the result in single precision replaces the MQ. The residual seconds replace the AC.

USE

Enter with the seconds in the AC and MQ in double precision floating point. Exit with the residual seconds in floating point in the AC and the integral days in floating point in the MQ.

Calling sequence:

CLA L(SECONDS A)
LDQ L(SECONDS B)
CALLL DAYS
return

CODING INFORMATION

Length of subroutine is 25(10) or 31(8) words.
IDENTIFICATION

DUMMY/EOS/CANCLK/DATCEL/RGGSAV/RGGSTR/EXPORT

JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To allow certain parameters to be defined at program load time, and to provide storage and definition of miscellaneous quantities.

METHOD

EOS, RGGSAV and RGGSTR are defined. CANCLK is a three-word buffer for clock angles. DUMMY is provided for name only. DATCEL contains the BCD date of loading of the program in a format as follows: YYMMDD. EXPORT is a flag which controls the sensing of the 7094 on-line printer to read the JPL printer board and clock. If EXPORT is non-zero, no sensing of the on-line printer is made by the program. This is to allow non-JPL installations to use the program even if their printer board or clock hardware is different.

USE

This subroutine is always left symbolic and is the first physical subroutine in the deck. This allows for the word DATCEL and other parameters to be updated at load time, if necessary.

CODING INFORMATION

Length of subroutine is 9(10) or 11(8) words.
IDENTIFICATION

EARTH/SPACE
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To rotate from space-fixed cartesian coordinates to Earth-fixed sphericals, and vice versa.

RESTRICTIONS

a. Subroutines COS, SIN, RVIN, RVOUT and MATRIX are called.
b. COMMON through COMMON+11 are used.
c. The COMMON locations GHA(T) and LOMEGA are assumed to contain the Greenwich hour angle in degrees and the Earth's rotation rate in radians/sec, respectively.

METHOD

At the epoch T a "space-fixed" cartesian coordinate system is defined, centered at the Earth with the X - Y plane the equator, the X axis the direction of the vernal equinox, and the Z axis the spin axis of the Earth. The "Earth-fixed" frame is obtained from the space-fixed by rotating about the Z axis by an angle \( \tau(T) \), the Greenwich hour angle of the vernal equinox, to bring the x axis in coincidence with the Greenwich meridian as shown in the following sketch:

The coordinates are then related by

\[
\begin{pmatrix}
  x \\
  y \\
  z
\end{pmatrix}
= \begin{pmatrix}
  \cos \tau(T) & \sin \tau(T) \\
  -\sin \tau(T) & \cos \tau(T)
\end{pmatrix}
\begin{pmatrix}
  X \\
  Y
\end{pmatrix}
\]

\( z = Z \),
and

\[
\begin{pmatrix}
x' \\
y' \\
z'
\end{pmatrix} = \begin{pmatrix}
\cos \tau(t) & \sin \tau(t) \\
-sin \tau(t) & \cos \tau(t)
\end{pmatrix} \begin{pmatrix}
x \\
y
\end{pmatrix} + \omega \begin{pmatrix}
-sin \tau(t) & \cos \tau(t) \\
-cos \tau(t) & -sin \tau(t)
\end{pmatrix} \begin{pmatrix}
x \\
y
\end{pmatrix}
\]

\[ \dot{z} = \dot{\tau} \]

where \( \omega \) is the rotation rate of the Earth.

The inverse transformation is

\[
\begin{pmatrix}
x \\
y
\end{pmatrix} = \begin{pmatrix}
\cos \tau(t) & -\sin \tau(t) \\
n \sin \tau(t) & \cos \tau(t)
\end{pmatrix} \begin{pmatrix}
x' \\
y'
\end{pmatrix}
\]

\[ Z = z \]

and

\[
\begin{pmatrix}
x' \\
y'
\end{pmatrix} = \begin{pmatrix}
\cos \tau(t) & -\sin \tau(t) \\
n \sin \tau(t) & \cos \tau(t)
\end{pmatrix} \begin{pmatrix}
x \\
y
\end{pmatrix} + \omega \begin{pmatrix}
-sin \tau(t) & \cos \tau(t) \\
-cos \tau(t) & -sin \tau(t)
\end{pmatrix} \begin{pmatrix}
x \\
y
\end{pmatrix}
\]

\[ \dot{z} = \dot{\tau} \]

SPACE performs the rotation from space-fixed cartesian to Earth-fixed spherical and then calls subroutine RVOUT to obtain the Earth-fixed spherical set.

EARTH calls subroutine RVIN to make the transformation from Earth-fixed spherical to Earth-fixed cartesian and then performs the rotation from Earth-fixed cartesian to space-fixed cartesian.

**USE**

Calling sequences:

a. To rotate from space-fixed cartesian coordinates to Earth-fixed sphericals:

\[
\text{CALL SPACE}
\]

\[
PZE \ A, B
\]

\[
PZE \ C, D
\]

where \( A, A+1, A+2 \) contain the input space-fixed cartesian position.

\( B, B+1, B+2 \) contain the input space-fixed cartesian velocity.

\( C, \ldots, C+5 \) contain the output Earth-fixed spherical set \( r, \phi, \theta, v, \gamma, \sigma \).

\( D, \ldots, D+5 \) contain the output Earth-fixed cartesian set \( x, y, z, \dot{x}, \dot{y}, \dot{z} \).
b. To rotate from Earth-fixed sphericals to space-fixed cartesian coordinates:

```plaintext
CALL EARTH
PZE A
PZE B, C
```

where A, ..., A+5 contain the input Earth-fixed spherical set r, φ, θ, ν, γ, σ.
B, B+1, B+2 contain the output space-fixed cartesian position coordinates X, Y, Z.
C, C+1, C+2 contain the output space-fixed cartesian velocity coordinates Ẍ, Ẏ, Ẑ.

and where both entries assume that COMMON location GHA(T) and LOMEGA contain the Greenwich hour angle in degrees and the Earth's rotation rate in radians/sec, respectively.

CODING INFORMATION

Length of subroutine is 112(10) or 160(8) words.

REFERENCE

IDENTIFICATION

ECLIP
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To rotate Earth equatorial coordinates to ecliptic and vice versa.

RESTRICTIONS

a. Subroutines SIN, COS and MATRIX are called.
b. COMMON+f0 through COMMON+12 are used.
c. The cell ET in COMMON is assumed to contain the mean or true obliquity of the ecliptic.

METHOD

The ecliptic plane is characterized by its inclination to the Earth's equator, \( \epsilon \), the obliquity of the ecliptic, and its ascending node on the Earth's equator, the vernal equinox, as shown in the following sketch:

\[
\begin{align*}
Z & \quad \epsilon \\
Y & \quad Y_\epsilon \\
X & \quad X_\epsilon
\end{align*}
\]

where \( X, Y, Z \) is the Earth equatorial frame and \( X_\epsilon, Y_\epsilon, Z_\epsilon \) is the ecliptic. The coordinates are related by

\[
\begin{pmatrix}
X_\epsilon \\
Y_\epsilon \\
Z_\epsilon
\end{pmatrix} =
\begin{pmatrix}
1 & 0 & 0 \\
0 & \cos \epsilon & \sin \epsilon \\
0 & -\sin \epsilon & \cos \epsilon
\end{pmatrix}
\begin{pmatrix}
X \\
Y \\
Z
\end{pmatrix}
\]

where \( \epsilon \) can be the mean or true obliquity.
USE

Calling sequence:

CALL ECLIP
PFX X,, Y
return

where

X-3, X-2, X-1 contain the input vector.
Y-3, Y-2, Y-1 contain the output vector.
PFX = PZE assumes equatorial input and rotates to ecliptic.
PFX = MZE assumes ecliptic input and rotates to equatorial.
X = Y is permitted.

And where the COMMON location ET contains the input true of-date obliquity or the mean 1950.0 obliquity.

CODING INFORMATION

Length of subroutine is 45(10) or 55(8) words.

REFERENCE

IDENTIFICATION

EFFECT
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To replace each of the output flags GROPS to GROPS +11 with a 0, 2, or 4 for the suppression, ecliptic, or equatorial output option, respectively.

RESTRICTIONS

a. It is assumed that subroutine SPRAY has previously been called so that GROPS to GROPS +11 contain the group output flags.

b. PHASE, GROPS and CODE, in COMMON, are used and GROPI is referenced indirectly.

METHOD

The value of PHASE is found to be 0, 1 or >1 according as the start-of-phase, normal, or end-of-phase print condition has been met at the print epoch. At the same time each flag will be a one digit octal integer. Each of the resulting 24 possible combinations is considered and each branch replaces the flag with 0, 2, or 4 scaled 35.

The following table summarizes the combinations and results:

<table>
<thead>
<tr>
<th>Initial value of octal flag</th>
<th>Resulting value of octal flag</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 for all values of PHASE</td>
</tr>
<tr>
<td>1</td>
<td>4 for all values of PHASE</td>
</tr>
<tr>
<td>2</td>
<td>2 for all values of PHASE</td>
</tr>
<tr>
<td>3</td>
<td>0 for all values of PHASE</td>
</tr>
<tr>
<td>4</td>
<td>2 for PHASE = 0, 0 otherwise</td>
</tr>
<tr>
<td>5</td>
<td>4 for PHASE = 0, 0 otherwise</td>
</tr>
<tr>
<td>6</td>
<td>2 for PHASE &gt; 1, 0 otherwise</td>
</tr>
<tr>
<td>7</td>
<td>4 for PHASE &gt; 1, 0 otherwise</td>
</tr>
</tbody>
</table>

USE

Calling sequence:

```
CALL EFFECT
return
```

CODING INFORMATION

Length of subroutine is 40(10) or 50(8) words.
IDENTIFICATION

EPHEM
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

The ephemeris interpolation routine EPHEM is designed to read a JPL Ephemeris Tape and to interpolate for the position and/or velocity of any subset of the planets and Moon at any Julian date within the time interval spanned by the tape.

The ephemeris data carried on tape are in heliocentric coordinates for the planets and geocentric coordinates for the Moon. EPHEM, however, may be used to obtain coordinates referenced to any of the bodies as center. In particular, data are furnished for the Earth-Moon barycenter rather than for the Earth, and EPHEM performs the necessary calculations for obtaining geocentric coordinates of the planets and Sun.

The data on the ephemeris tape and the results of the interpolation are expressed in the coordinate system of the mean Earth equator and equinox of 1950.0.

RESTRICTIONS

a. Subroutines READB, BSREC, REWIND are called.
b. A buffer of 1862 cells must be provided by the user for storage of the raw ephemeris from the tape. Buffers of 36, 13, and 150 cells are also required by EPHEM, as described in USE.
c. EPHEM makes extensive use of 7094 double precision instructions, hence all tables must start in even core locations.
d. The ephemeris tape must be in the format described in Appendix A of Ref. 1.

METHOD

Everett's formula

\[ x(T_j) = u x_0 + t x_1 + \frac{u(u^2 - 1)}{3!} \Delta_2 m x_0 + \frac{t(t^2 - 1)}{3!} \Delta_2 m x_1 + \frac{u(u^2 - 1)(u^2 - 4)}{5!} \Delta_4 m x_0 + \frac{t(t^2 - 1)(t^2 - 4)}{5!} \Delta_4 m x_1 \]

is used for interpolation, where

\[ T_j = \text{the desired Julian date, } T \leq T_j < T + h \]

\[ h = \text{step size of data} \]

\[ T = \text{point in time at which data are tabulated} \]
\[
t = \frac{(T_j - T)}{h}, \quad 0 \leq t \leq 1
\]
\[
u = 1 - t
\]
\[
x_0 = x(T)
\]
\[
x_1 = x(T + h)
\]
\[
\Delta^n_m = n^{th} \text{ modified difference}
\]

It is assumed that the Julian date specified by the user as the epoch for which data are requested is in Universal Time. Since the ephemerides are tabulated in Ephemeris Time, the specified epoch is modified by
\[
ET = UT + \Delta t
\]
to convert to Ephemeris Time.

Planetary coordinates for centers other than the Sun are obtained by the vector subtraction
\[
\vec{P} = \vec{P}_0 - \vec{C}
\]
where
\[
\vec{P} = \text{planetary coordinates referred to the desired center}
\]
\[
\vec{P}_0 = \text{planetary coordinates referred to the Sun}
\]
\[
\vec{C} = \text{heliocentric coordinates of the desired center}
\]

A similar vector subtraction is performed for velocity vectors.

Calculation of the heliocentric coordinates of the Earth and/or Moon or the geocentric or selenocentric coordinates of the Sun and planets requires additional manipulations.

Heliocentric lunar and Earth coordinates are obtained as
\[
\vec{M} = \vec{B} + \mu_m \vec{L}
\]
\[
\vec{E} = \vec{B} - \mu_e \vec{L}
\]
where
\[
\vec{M} = \text{heliocentric coordinates of the Moon}
\]
\[
\vec{E} = \text{heliocentric coordinates of the Earth}
\]
\[
\vec{B} = \text{heliocentric coordinates of the Earth-Moon barycenter}
\]
\[
\vec{L} = \text{geocentric coordinates of the Moon}
\]
\[
\mu_m = \frac{\mu_e}{\mu_e + \mu_M}
\]
\[
\mu_e = \frac{\mu_M}{\mu_e + \mu_M}
\]
\[ \mu_E = \text{the GM of the Earth} \]
\[ \mu_M = \text{the GM of the Moon} \]

Both \( \mu_E \) and \( \mu_M \) are obtained from TAB1, as described in the next section.

**USE**

The subroutine EPHEM may be used by either the FORTRAN II or the FAP programs. The calling sequence for a FORTRAN II program is

```
CALL EPHEM (JD, CENT, TAB1, TAB2, TAB3, TAB4, NTAPE)
```

and for the FAP program is

```
CALL EPHEM, JD, CENT, TAB1, TAB2, TAB3, TAB4, NTAPE
```

The arguments in the calling sequence are interpreted as follows:

- **JD** = double-precision floating point Julian date \( T_j \), assumed to be in Universal Time, at which data are required.
- **CENT** = control-word floating point integer identifying the desired center of the coordinate system according to the scheme given in Table 1.
- **TAB1** = 36-word table of physical constants with the structure given in Table 2.
- **TAB2** = 13 floating point integers that control the data output for each body according to the scheme given in Table 3. The control-word sequence is given in Table 4.
- **TAB3** = 1862-word buffer used by EPHEM to store a record of ephemeris data as it is read from the ephemeris tape.
- **TAB4** = 150-word block of storage containing the output information listed in Table 5. The control-word integer in TAB4 is interpreted as shown in Table 6.
- **NTAPE** = location of word containing a fixed-point number designating the logical tape unit on which the JPL Ephemeris Tape is mounted.

The nutations and nutation rates are always in units of radians and radians/day. The units of the planetary and lunar data are determined by the value of the output control word found in location TAB1 +34. If this single precision word is zero the output will be in kilometers and kilometers/sec; if this word is 1.0 the planetary data will be in AU and AU/day and the lunar data will be in "Earth-radii" and "Earth-radii"/day.

The output is always cartesian, referenced to the mean Earth equator and equinox of 1950.0.

**CODING INFORMATION**

a. When the routine is part of a new core load it will automatically rewind the ephemeris tape the first time called to allow it to retrieve the data in the identification records. This data defines the time span of data on the tape. The criterion for this rewind is comparison of the current tape unit designation with that of the previous call. Only if they are the same will a rewind not be issued. To preventrewinds when chain type jobs
are run, the entry TAPEX is provided. The six quantities starting at TAPEX may be "wanted" (see Ref. 2) from link to link in any compatible fashion to prevent rewinding. To deliberately cause a rewind, the entry EPTAPE is provided. If a zero is stored in this cell, the ephemeris tape will rewind the next time EPHEM is called.

b. Length of subroutine is 813(10) or 1455(8) words.

### Table 1. Central body identification

<table>
<thead>
<tr>
<th>Body</th>
<th>Control integer</th>
<th>Body</th>
<th>Control integer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>1.0</td>
<td>Neptune</td>
<td>8.0</td>
</tr>
<tr>
<td>Venus</td>
<td>2.0</td>
<td>Pluto</td>
<td>9.0</td>
</tr>
<tr>
<td>Earth</td>
<td>3.0</td>
<td>Sun</td>
<td>10.0</td>
</tr>
<tr>
<td>Mars</td>
<td>4.0</td>
<td>Moon</td>
<td>11.0</td>
</tr>
<tr>
<td>Jupiter</td>
<td>5.0</td>
<td>Earth-Moon</td>
<td></td>
</tr>
<tr>
<td>Saturn</td>
<td>6.0</td>
<td>barycenter</td>
<td>12.0</td>
</tr>
<tr>
<td>Uranus</td>
<td>7.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2. TAB1 structure

<table>
<thead>
<tr>
<th>Word in record</th>
<th>Physical constant and unit</th>
<th>Word format</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAB1</td>
<td>( k = \text{universal gravitational constant,} ) ( \text{AU}^{3/2}/\text{day} )</td>
<td>Double-precision</td>
</tr>
<tr>
<td>TAB1+2</td>
<td>GM of Mercury, km(^3)/sec(^2)</td>
<td>floating point</td>
</tr>
<tr>
<td>+4</td>
<td>GM of Venus, km(^3)/sec(^2)</td>
<td></td>
</tr>
<tr>
<td>+6</td>
<td>GM of Earth, km(^3)/sec(^2)</td>
<td></td>
</tr>
<tr>
<td>+8</td>
<td>GM of Mars, km(^3)/sec(^2)</td>
<td></td>
</tr>
<tr>
<td>+10</td>
<td>GM of Jupiter, km(^3)/sec(^2)</td>
<td></td>
</tr>
<tr>
<td>+12</td>
<td>GM of Saturn, km(^3)/sec(^2)</td>
<td></td>
</tr>
<tr>
<td>+14</td>
<td>GM of Uranus, km(^3)/sec(^2)</td>
<td></td>
</tr>
<tr>
<td>+16</td>
<td>GM of Neptune, km(^3)/sec(^2)</td>
<td></td>
</tr>
<tr>
<td>+18</td>
<td>GM of Pluto, km(^3)/sec(^2)</td>
<td></td>
</tr>
<tr>
<td>+20</td>
<td>GM of Sun, km(^3)/sec(^2)</td>
<td></td>
</tr>
<tr>
<td>+22</td>
<td>GM of Moon, km(^3)/sec(^2)</td>
<td></td>
</tr>
<tr>
<td>+24</td>
<td>Astronomical unit, km</td>
<td></td>
</tr>
<tr>
<td>+26</td>
<td>Earth radius for lunar ephemeris conversion, km</td>
<td></td>
</tr>
<tr>
<td>+28</td>
<td>Speed of light, km/sec</td>
<td></td>
</tr>
</tbody>
</table>
Table 2 (Cont'd)

<table>
<thead>
<tr>
<th>Word in record</th>
<th>Physical constant and unit</th>
<th>Word format</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAB1+30 +32</td>
<td>Solar-flux constant, lb-force/m²</td>
<td>Double-precision floating point</td>
</tr>
<tr>
<td></td>
<td>Seconds per mean solar day</td>
<td>Double-precision floating point</td>
</tr>
<tr>
<td></td>
<td>Output-unit control word</td>
<td>Single-precision floating point</td>
</tr>
<tr>
<td></td>
<td>Δt = ET - UT, sec</td>
<td>Single-precision floating point</td>
</tr>
</tbody>
</table>

Table 3. TAB2 output control interpretation

<table>
<thead>
<tr>
<th>Control word</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>No data, this body</td>
</tr>
<tr>
<td>1.0</td>
<td>Position data only, this body</td>
</tr>
<tr>
<td>2.0</td>
<td>Velocity data only, this body</td>
</tr>
<tr>
<td>3.0</td>
<td>Both position and velocity data, this body</td>
</tr>
</tbody>
</table>

Table 4. TAB2 structure

<table>
<thead>
<tr>
<th>Word position</th>
<th>Body controlled</th>
<th>Word position</th>
<th>Body controlled</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAB2</td>
<td>Mercury</td>
<td>TAB2+7</td>
<td>Neptune</td>
</tr>
<tr>
<td>TAB2+1</td>
<td>Venus</td>
<td>+8</td>
<td>Pluto</td>
</tr>
<tr>
<td>+2</td>
<td>Earth</td>
<td>+9</td>
<td>Sun</td>
</tr>
<tr>
<td>+3</td>
<td>Mars</td>
<td>+10</td>
<td>Moon</td>
</tr>
<tr>
<td>+4</td>
<td>Jupiter</td>
<td>+11</td>
<td>Earth-Moon</td>
</tr>
<tr>
<td>+5</td>
<td>Saturn</td>
<td>+12</td>
<td>barycenter</td>
</tr>
<tr>
<td>+6</td>
<td>Uranus</td>
<td></td>
<td>Nutations</td>
</tr>
</tbody>
</table>
Table 5. TAB4 structure

<table>
<thead>
<tr>
<th>Word position</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAB4</td>
<td>Floating point control-word integer indicating type of error, if any</td>
</tr>
<tr>
<td>TAB4+1</td>
<td>Zero cell for double-precision compatibility</td>
</tr>
<tr>
<td>+2</td>
<td>Mercury position and velocity in double-precision floating point</td>
</tr>
<tr>
<td>+14</td>
<td>11 more sub-blocks of position and velocity data for each of the other bodies in double-precision floating point, each sub-block consisting of 12 words, in the same order as given in TAB2</td>
</tr>
<tr>
<td>+146</td>
<td>Nutation in longitude and nutation in latitude in single-precision floating point</td>
</tr>
<tr>
<td>+148</td>
<td>Nutation rates in single-precision floating point</td>
</tr>
</tbody>
</table>

Table 6. TAB4 error code interpretation

<table>
<thead>
<tr>
<th>Control word</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>Successful return</td>
</tr>
<tr>
<td>1.0</td>
<td>Specified date $T_j$ smaller than starting date of data available</td>
</tr>
<tr>
<td>2.0</td>
<td>$T_j$ greater than final date of data available</td>
</tr>
<tr>
<td>3.0</td>
<td>Reading error (redundancy)</td>
</tr>
<tr>
<td>4.0</td>
<td>A TAB2 control word is negative or greater than 3</td>
</tr>
<tr>
<td>5.0</td>
<td>CENTER control word is in error</td>
</tr>
</tbody>
</table>

REFERENCES


IDENTIFICATION

EPHSET/E. T./INTR1
Alan D. Rosenberg, JPL
IBM 7094 Fap
December 2, 1964

PURPOSE

a. EPHSET performs initialization of the calling sequence to the subroutine EPHEM.
b. INTR1 obtains positions and velocities of the Moon, Sun, and planets at a given epoch from the double precision JPL Ephemeris Tape and arranges this information in a manner compatible with the program SPACE. Results are referenced to the mean Earth equator and equinox of 1950.0.
c. E. T. converts a given universal time epoch to the corresponding ephemeris time epoch.

RESTRICTIONS

a. FIX, DAYS, EPHEM, GRUPPE, PROUT, ERPRT, ABORT and UNLOAD are called.
b. NEWBCD, TARAD, CENTR5, CENTE5, TAPEX and EPTAPE are external cells which are referenced.
c. Subroutine INTR1 has the following error conditions:
   1. Unknown central body reference for EPHEM: (CENTER).
   2. Unknown control word for EPHEM: (CONTRL).
   3. Redundancy reading ephemeris tape: (REDUN).
   4. Input epoch earlier than data on ephemeris tape: (EARLY).
   5. Input epoch later than data on ephemeris tape: (LATE).

   The word in parenthesis above is printed in the error message: PLANETARY EPHEMERIS ERROR = (error word) on a device appropriate to the mode of SFOF operation and always on the off-line output.

   Conditions 1. and 2. cause CALL ABORT in SFOF mode 4 and non-SFOF mode of operation, and TSX ENDSYS, 4 in SFOF mode 2. Conditions 3., 4., and 5. allow one re-try in mode 4 and non-SFOF mode by pressing START, then CALL ABORT in case of a second failure. In SFOF mode 2, TSX ENDSYS, 4 occurs and a comment TURN ON-----AFTER OPERATOR ACTION is printed, where the name of the program currently operating is inserted above.

d. The ephemeris tape is assumed to be mounted on SYSUT8, which corresponds to FORTRAN logical tape 12 and physical unit B6.
e. The COMMON cells T, KB0, XN, XN., CENTER, TARG, PRFLG, 37HED, SP1A, SP2A, SP3A, EJCTA, SP1B, SP2B, SP3B, EJCTB, SP1C, SP2C, EJCTC are referenced.
f. The system low-core cells (PAUSE, ENDSYS, SFMODE and JPTRAJ) are referenced.
g. The buffer NEWBOD through NEWBOD +3 and entry BODTAB are provided to allow substitution of any of the normally unused planets, i.e. Mercury, Neptune, Uranus and Pluto, in place of Saturn.
h. The buffers EGM, SCALE1, DUT and GRAV contain physical constants which may be modified by input. Entry NUTLOB has been provided so the computed nutations are accessible.

METHOD

a. INTR1 takes the double precision seconds past $0^h$ January 1, 1950 U. T. which it assumes to be in T and T+1, converts it to double precision Julian date and calls EPHM; upon return, the double precision positions and velocities of the bodies are rounded off and stored in the XN and XN buffers in COMMON. The nutation in longitude and obliquity and their rates in radians and radians/day are placed in NUTOBL through NUTOBL +3.
b. E. T. adds T, the double precision seconds past $0^h$ January 1, 1950 U. T. to $\Delta T$, the difference between Universal and Ephemeris time, and returns with the results in the AC-MQ.

USE

a. CALL EPHSET
   return
b. CALL INTR1
   return

Assumption is that T and T+1 contain the double precision seconds past $0^h$ January 1, 1950 U. T., and CENTER contains a fixed point integer scaled 35, of value 0 through 6, corresponding to the names EARTH, MOON, SUN, VENUS, MARS, SATURN, JUPITE, respectively.
c. CALL E. T.
   return

Assumption is as above for cells T and T+1. Results are double precision seconds past $0^h$ January 1, 1950 E. T. in the AC-MQ.

CODING INFORMATION

Length of subroutine is 2308(10) or 4404(8) words.

REFERENCE

Cary, C.; Inter-Office Memorandum 312. 3-176, Physical Constants and Other Parameters to be used in MA-C Computations-Updated Version, October 30, 1964.
IDENTIFICATION

FIX/FLOAT
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To convert a single precision floating point number to a fixed point integer scaled 35 or vice versa.

RESTRICTIONS

Conversion will be made mod $2^{27}$.

METHOD

The unnormalized add and floating point add instructions are used with masks.

USE

Enter with the number to be converted in the accumulator. Exit with the result in the accumulator.

Calling sequences:

To float a fixed point integer:

```
CLA L(INTEGER)
CALL FLOAT
return
```

To fix a floating point number:

```
CLA L(NUMBER)
CALL FIX
return
```

CODING INFORMATION

Length of subroutine is 9(10) or 11(8) words.
IDENTIFICATION

FIXT/FLOT
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE
To compute the number of seconds that have elapsed since 0h January 1, 1950, given a
Greenwich Mean Time (GMT) between the years 1950 and 2000 or vice versa.

RESTRICTIONS
a. The locations YEAR to YEAR +6, in COMMON, are used in the FIXT option.
b. A double precision number is considered to be two floating point words.

METHOD
The double precision floating point number is decoded into the various lengths of time and
vice versa, taking into account leap years and leap centuries.

USE
a. GMT to seconds: on entrance the AC must contain YYMM0DDHH and the MQ must
   contain NNSSFFF, where
      YY = last two digits of the year
      MM = month of the year, January being 1
      0 = zero
      DD = days
      HH = hours
      NN = minutes
      SS = seconds
      FFF = milliseconds
   Exit with the double precision floating point seconds past 0h, January 1, 1950, in the
   AC and MQ. If YY = MM = 0, then (AC - MQ) is converted to an interval in double
   precision seconds.
   Calling sequence:
   CLA L(YYMM0DDHH)
   LDQ L(NNSSFFF)
   CALL FLOT
   return
b. Seconds to GMT: on entrance the AC and MQ must contain the double precision floating point seconds past 0h, January 1, 1950. Exit with the GMT in location YEAR to YEAR +6, where

YEAR = YY = last two digits of year
+1 = MM = month, January being 1
+2 = DD = days
+3 = HH = hours
+4 = NN = minutes
+5 = SS = seconds
+6 = FFF = milliseconds

YEAR through YEAR +5 are fixed point integers scaled 35. YEAR +6 is fixed point scaled 0.

Calling sequence:
CLA L(SECONDS A)
LDQ L(SECONDS B)
CALL FIXT
return

CODING INFORMATION

Length of subroutine is 175(10) or 257(8) words.
IDENTIFICATION

GEDLAT
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To compute $\phi'$, the geodetic latitude of the probe, and $\rho'$, the distance from the geocenter to the point on the surface of the Earth lying on the Earth-probe line.

RESTRICTIONS

a. Subroutines SIN and SQRT are called.
b. COMMON through COMMON+9 are used.

METHOD

a. $\phi'$ is given by:

$$\phi' = \phi + b_1 \sin 2\phi + b_2 \sin 4\phi + b_3 \sin 6\phi$$

where $\phi$ is the input geocentric latitude of the probe,

$$b_1 = 0.19456624 \text{ deg}$$
$$b_2 = 0.00033036 \text{ deg}$$
$$b_3 = 0.00000075 \text{ deg}.$$

b. $\rho'$ is given by:

$$\rho' = a \sqrt{1 - \epsilon^2 \sin^2 \phi}$$

where $\phi$ is the input geocentric latitude of the probe,

$$\epsilon^2 = 0.006768657997, \text{ eccentricity squared},$$

$$a = 6378.2064, \text{ equatorial radius, kilometers}.$$ 

USE

Calling sequence:

CALL GEDLAT
Enter with the geocentric latitude of the probe, \( \phi \), in the accumulator in degrees.
Exit with the geodetic latitude of the probe, \( \phi' \), in the AC in degrees and the radius, \( \rho' \), in the MQ in kilometers.

CODING INFORMATION

Length of subroutine is 46(10) or 56(8) words.

REFERENCE

IDENTIFICATION

GETTER
JPL Staff
IBM 7094 Fap

PURPOSE

To compute, in floating point, the angle, in degrees, between two vectors, where each vector is the difference of two other vectors.

RESTRICTIONS

a. All vectors must be stored BES 3.
b. Subroutines ARCOS and PROD are called.
c. The formula used to compute the angle does not hold, in general, for unit vectors since

\[
\frac{\mathbf{A} - \mathbf{B}}{|\mathbf{A} - \mathbf{B}|} \neq \frac{\hat{\mathbf{A}} - \hat{\mathbf{B}}}{|\hat{\mathbf{A}} - \hat{\mathbf{B}}|}
\]

for all \(\mathbf{A}, \mathbf{B}\) where \(\hat{\cdot}\) signifies a unit vector.

METHOD

The desired angle is computed using the following formula:

\[
\text{ANGLE} = \text{ARCOS} \left( \frac{(\mathbf{A} - \mathbf{B}) \cdot (\mathbf{C} - \mathbf{B})}{|\mathbf{A} - \mathbf{B}| |\mathbf{C} - \mathbf{B}|} \right)
\]

Note: For \(\mathbf{B} = \mathbf{0}\), either \(\mathbf{A}\) or \(\mathbf{C}\) may be unit vectors and give a correct result.

USE

Calling sequence:

\[
\text{CALL GETTER PZE A,, C PZE B,, D return}
\]

The angle between the vectors \(\mathbf{A} - \mathbf{B}\) and \(\mathbf{C} - \mathbf{B}\) is computed in degrees and stored in \(D\).

CODING INFORMATION

Length of subroutine is 37(10) or 45(8) words.
IDENTIFICATION

GHA
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To compute the Earth's rotation rate and the Greenwich hour angle of the vernal equinox.

RESTRICTIONS

a. COMMON locations T, T+1, NUTRA, LOMEGA, OMEGA and GHA(T) contain input and output quantities.
b. COMMON through COMMON+6 are used.
c. Subroutines DAYS, FIX and FLOAT are called.

METHOD

The mean value of the Greenwich hour angle is computed as follows:

\[ \tau_m(T) = 100°.07554260 + 0°.9856473460 \, d + (2°.9015) \times 10^{-13} \, d^2 + \omega \, t \text{ (mod 360 deg)} \]

\[ 0 \leq \tau_m(T) < 360 \text{ deg} \]

where

T is the epoch under consideration in U.T.
d is integer days past 0 hr January 1, 1950
t is seconds past 0 hr of epoch T
\( \omega \) is the Earth's rotation rate and is given by:

\[ \omega = \frac{0.00417807417}{1 + (5.21) \times 10^{-13} \, d} \text{ deg/sec.} \]

Given the nutation in right ascension, \( \delta a \), the true value of the hour angle is:

\[ \tau(T) = \tau_m(T) + \delta a \]

USE

Calling sequence:

\[ \text{CALL GHA} \]
\[ \text{return} \]

where

T, T+1 contain the input double precision seconds past 0 hr January 1, 1950 U.T.
NUTRA contains \( \delta a \), the input nutation in right ascension in degrees.
OMEGA contains the output Earth's rotation rate in deg/sec.
LOMEGA contains the output Earth's rotation rate in rad/sec.
GHA(T) contains the output true Greenwich hour angle in degrees.

CODING INFORMATION

Length of subroutine is 68(10) or 104(8) words.
IDENTIFICATION

GRUPPE
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To maintain a count of the number of lines of output made on a page and to use this count to control page ejects.

RESTRICTIONS

Subroutine SEITE is called to give the page eject and page heading.

METHOD

If the print suppress flag indicates no printing, the subroutine exits. N, the number of lines of output that are going to be printed in the following group, is added to the current line count C. If N + C > 63 subroutine SEITE is called to get a page eject and page heading. If N + C ≤ 63, N + C becomes the new line count C.

USE

Calling sequence:

CALL GRUPPE
PZE N

where N is the number of lines of output that will be requested before the next CALL GRUPPE.

CODING INFORMATION

Length of subroutine is 14(10) or 16(8) words.
IDENTIFICATION

INTRAN
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To print the initial conditions found in the identification record of the spacecraft ephemeris tape as the heading information for the trajectory to be processed.

RESTRICTIONS

a. Subroutines DAYS, E.T., ROTEQ, MNA, GHA, GRUPPE, TIME2 and PROUT are used.
b. Entries PHL, RMAX, INJBCD, INJTY, INJX, INJY, INJZ, INJDX, INJDY, INJDZ, INJEQX, HARMN2, GASOPT and CENTR5 are provided for storage of data from the spacecraft ephemeris identification record.
c. GRAV, LUNGRV, SCALE1, RADOPT, BRNOPT, RUNID and EPHSET are referenced indirectly to locate quantities for printing.

METHOD

INTRAN prints the physical constants, injection conditions and other quantities which determine the trajectory integrated by SPACE. This information comes to SFPRO in the identification record of the spacecraft ephemeris.

USE

Calling sequence:

CALL INTRAN
return

CODING INFORMATION

Length of subroutine (includes INTRAN as a subset) is 728(10) or 1330(8) words.
IDENTIFICATION

NUTATE
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To update the precession A and nutation N matrices and apply the product matrix NA to
the Earth-probe vector.

RESTRICTIONS

a. NUTATE is a subset of a rotation package and uses other parameters in the package.
b. MNAET is tested to determine if the .1 day delta-time option is to be used in com-
puting the N matrix. A zero MNAET forces recomputation of N.
c. Locations XEP, CC, (NA), AA and TARG (epoch in days past 0 hr January 1 1950),
in COMMON, are referenced.
d. Subroutines ROTEQ, MNA and MATRIX are called.
e. COMMON through COMMON+2 are used.
f. NUTMAT, the location of the nutation matrix, is referenced indirectly.

METHOD

Subroutine ROTEQ is called to update the A matrix. The N matrix is updated if
MNAET = 0 or if MNAET is non-zero and time has increased by .1 day since the last
computation. N is updated by calling subroutine MNA. Then subroutine MATRIX is called
to form the product NA. The CC+3 vector is then multiplied by NA to give the Earth-
probe position vector in the space fixed Earth true equator and equinox of date coordinate
system (XEP).

USE

Calling sequence:

CALL NUTATE
return

CODING INFORMATION

Length of subroutine (includes NUTATE as a subset) is 728(10) or 1330(8) words.
IDENTIFICATION

RESET
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE
To set the obliquity of the ecliptic to the 1950.0 value and to set the NA matrix to unity.

RESTRICTIONS
a. RESET is a subset of a rotation package and uses other parameters in the package.
b. COMMON locations ET and (NA) are used.

METHOD
The mean obliquity of 1950.0 is put into ET and the (NA) matrix is set to unity so any use of these quantities will cause the results to be in the mean 1950.0 coordinate system.

USE
Calling sequence:

CALL RESET
return

CODING INFORMATION
Length of subroutine (includes RESET as a subset) is 728(10) or 1330(8) words.
IDENTIFICATION

ROT
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To update the planetary ephemerides, the Greenwich hour angle and the \((n\text{-body})\)-probe vector and to rotate several sets of vectors to the output coordinate system.

RESTRICTIONS

a. ROT is a subset of a rotation package and uses other subroutines in the package.
b. Subroutines INTR1, GHA, UNIT, MATRIX, RESET and NUTATE are called.
c. Location EQUNX1 is referenced indirectly.
d. CX, CX., QX, QX., XN, XN., CS2, (NA), XEP, XEP., X, X., S2, CANOP, XN1, XN.1, XOP, XOP. and VAFLG, in COMMON, are used.

METHOD

a. The planetary ephemerides are updated by calling subroutine INTR1.
b. Subroutine NUTATE is called (which calls MNA to update the nutation in rt. ascension and the \(M\) and \(N\) matrices) and then GHA is called to compute the current value of the true Greenwich hour angle.
c. The true of-date Earth-probe position and velocity vector are computed and stored in XEP and XEP. .
d. RESET is called if the output equinox is 1950.0.
e. The \(X\), \(X\.), \(S1\), \(S2\), CANOP, and the variational coefficients are rotated to the desired output reference system, determined by the contents of location EQUNX1.
f. The Earth-(n-body) position and velocity vectors are formed.
g. The \(N\) and \(A\) matrices are recomputed, if RESET was called earlier.

USE

Calling sequence:

\[
\text{CALL } \text{ROT} \\
\text{return}
\]

CODING INFORMATION

Length of subroutine (includes ROT as a subset) is 728(10) or 1330(8) words.
IDENTIFICATION

LN/LOG10
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To compute \( \log_{10} x \) or \( \log_e x \) for a floating point, single precision \( x \).

RESTRICTIONS

a. An error will occur if \( x \leq 0 \).
b. Uses COMMON to COMMON +3.

METHOD

Represent \( x \) as \( 2^k F \) where \( \frac{1}{2} \leq F < 1 \).

Therefore, \( \log_e x = \log_e (2^k F) = k \log_e 2 + \log_e F \).

The following continued fraction is used to compute \( \log_e F \):

\[
\log_e F = \log_e 0.725 + \frac{r}{0.725 + \frac{r}{2 + \frac{r}{3.625 + \frac{r}{5.075 + \frac{r}{0.5}}}}}
\]

where \( r = (F - 0.725) \).

\( \log_{10} x \) is computed by obtaining \( \log_e x \), using the above approximation, and then using the relation:

\[
\log_{10} x = (\log_e x) (\log_{10} e)
\]

Accuracy: This method gives 26 significant binary digits except near \( x = 1 \), where the result is accurate to 26 binary places.

USE

Enter with a floating point argument in the accumulator, exit with the floating point logarithm in the accumulator.

Calling sequences:

For \( \log_e x \):

\[
\text{CLA} \quad X \\
\text{CALL} \quad \text{LN} \\
\text{error return} \\
\text{normal return}
\]

For \( \log_{10} x \):

\[
\text{CLA} \quad X \\
\text{CALL} \quad \text{LOG10} \\
\text{error return} \\
\text{normal return}
\]

CODING INFORMATION

Length of subroutine is 59(10) or 73(8) words.
IDENTIFICATION

LOOP
Alan D. Rosenberg, JPL
IBM 7094 Fap
December 2, 1964

PURPOSE

To make calculations for view periods and station prints for designated stations, and to print the results of these calculations.

RESTRICTIONS

a. Subroutines called are PRSET, MATRIX, UNIT, PROD, CROSS, SIN, COS, ARSIN, ARCOS, CLUCK, GETTER, LOG10, GRUPPE, PROUT.
b. Cells referred to indirectly are GRAV and PLOTFQ.
c. The COMMON region is used including cells from COM through COM+199, and X0P, Cx., SP1B, SP1C, SP2B, SP2C, SP3B, SP3C, T(0), OMEGA, PRFLG, CENTER, GHA(T), and LOMEGA.

METHOD

Let the space-fixed geocentric cartesian coordinates of the probe referenced to the true equator and equinox of date be given as (X, Y, Z), and the corresponding velocity vector as (\dot{X}, \dot{Y}, \dot{Z}). For a station with coordinates (r_i, \phi_i, \theta_i) the program computes the topocentric quantities to be described herein. Sketch 1 illustrates the basic coordinate systems.

Sketch 1. Earth-fixed station coordinates
\( \tau(T) \) is the right ascension of the Greenwich meridian at epoch \( T \). \( r_i \) is the distance from the geocenter to the station, \( \phi_i \) is the geocentric north latitude, and \( \theta_i \) is the east longitude.

The subroutine LOOP, in its arithmetic calculations, first sets up the matrix shown below:

\[
\begin{bmatrix}
\cos \tau(T) & \sin \tau(T) & 0 \\
-sin \tau(T) & \cos \tau(T) & 0 \\
0 & 0 & 1
\end{bmatrix}
\]

This matrix is stored in locations SIMLAR +40, through SIMLAR +48, where \( \tau(T) \) is the right ascension of the Greenwich meridian at epoch \( T \). The Earth-fixed cartesian coordinates of the probe \((x, y, z)\) are found below:

\[
\begin{bmatrix}
x \\
y \\
z
\end{bmatrix} = \begin{bmatrix}
\cos \tau(T) & \sin \tau(T) & 0 \\
-sin \tau(T) & \cos \tau(T) & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix}
\]

\((X, Y, Z)\) are the geocentric true-of-date space fixed cartesian coordinates of the probe and are located in locations CAPX, CAPY, CAPZ, respectively.

The corresponding Earth-fixed velocity components \((\dot{x}, \dot{y}, \dot{z})\) are computed by the following operations:

\[
\begin{bmatrix}
\dot{x} \\
\dot{y} \\
\dot{z}
\end{bmatrix} = \begin{bmatrix}
\cos \tau(T) & \sin \tau(T) & 0 \\
-sin \tau(T) & \cos \tau(T) & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
\omega Y + \dot{X} \\
-\omega X + \dot{Y} \\
\dot{Z}
\end{bmatrix}
\]

where \( \omega \) is the rotation rate of the Earth.

The coordinates are stored in \( X \) through \( X + 2 \). The velocities are stored in \( X \) through \( X + 2 \).

The Earth-fixed cartesian coordinates of the station are:

\[
x_i = r_i \cos \phi_i \cos \theta_i \\
y_i = r_i \cos \phi_i \sin \theta_i \\
z_i = r_i \sin \phi_i
\]
The storage is arranged as follows:

- SIMLAR+3 \( \phi_i \)
- SIMLAR+4 \( \theta_i \)
- SIMLAR+5 \( r_i \)
- SIMLAR+11 \( \sin \phi_i \)
- SIMLAR+12 \( \cos \phi_i \)
- SIMLAR+13 \( \sin \theta_i \)
- SIMLAR+14 \( \cos \theta_i \)

where the sines and cosines of \( \phi_i \) and \( \theta_i \) are computed in LOOP.

The values of \( (x_i, y_i, z_i) \) are placed in SIMLAR+18---x

\[ +19 \rightarrow y_i \]

\[ +20 \rightarrow z_i \]

The topocentric coordinates of the probe are \( (x_{ip}, y_{ip}, z_{ip}) \) where

\[ x_{ip} = x - x_i \rightarrow \text{SIMLAR+15} \]
\[ y_{ip} = y - y_i \rightarrow \text{SIMLAR+16} \]
\[ z_{ip} = z - z_i \rightarrow \text{SIMLAR+17} \]

The magnitude of the slant range vector \( \mathbf{r}_{ip} \) is found by

\[ \rho = \sqrt{x_{ip}^2 + y_{ip}^2 + z_{ip}^2} \]

and is stored in RAD.

The slant range rate is stored in RDT and computed by the following equation:

\[ \dot{\rho} = \frac{x_{ip}\dot{x} + y_{ip}\dot{y} + z_{ip}\dot{z}}{\rho} \]

The topocentric hour angle-declination system is described in Sketches 2 and 3. In this system the \( x - y \) plane has been translated to the station and rotated through the angle \( \theta_i \) so that \( x' \) lies along the meridian, the \( z' \) axis remaining parallel to the \( z \) axis.

The azimuth-elevation topocentric coordinate system is constructed by rotating the \( x' \) and \( z' \) axis about the \( y' \) axis, causing the resultant \( x'' - y'' \) plane to be perpendicular to \( r_i' \) with the \( z'' \) axis pointing to the zenith. This system is illustrated in Sketches 4 and 5 following.
Sketch 2. Rotation to station meridian

Sketch 3. Local hour angle declination coordinate system

Sketch 4. Rotation to station latitude

Sketch 5. Azimuth-elevation coordinate system

The elevation angle and its sine and cosine are found as below:

\[ \sin \gamma_i = \frac{\vec{r}_i \cdot \vec{r}_{ip}}{|r_i|^p} \]

This expands to

\[ \sin \gamma_i = \frac{x_i x_{ip} + y_i y_{ip} + z_i z_{ip}}{|r_i|^p} \]

The angle \( \gamma_i \) and its cosine are then found. These quantities are stored as follows:

\[ \begin{align*}
\gamma_i & \text{ ELEV} \\
\sin \gamma_i & \text{ SIMLR+23} \\
\cos \gamma_i & \text{ SIMLR+24}
\end{align*} \]
The elevation rate, \( \dot{\gamma}_i \), is stored in location ELEVD and is computed as shown below:

\[
\dot{\gamma}_i = \frac{(x_i \dot{x}_i + y_i \dot{y}_i + z_i \dot{z}_i) - r_i \sin \gamma_i}{r_i \rho \cos \gamma_i}
\]

The local hour angle \( \alpha_i \) is computed as follows and stored in HA:

\[
\alpha_i = \theta_i - \arctan \frac{y_{ip}}{x_{ip}} \quad \text{when} \quad \arctan \frac{y_{ip}}{x_{ip}} \geq 0
\]

\[
\alpha_i = \theta_i - \arctan \frac{y_{ip}}{x_{ip}} + 360 \text{ deg} \quad \text{when} \quad \arctan \frac{y_{ip}}{x_{ip}} < 0
\]

The local hour angle rate \( \dot{\alpha}_i \) is found as shown below and stored in location HART:

\[
\dot{\alpha}_i = \frac{-x_{ip} \dot{y}_i + y_{ip} \dot{x}_i}{x_{ip}^2 + y_{ip}^2}
\]

In order to determine whether the probe is in view of a given station, the hour angle \( \alpha \) is used to form a function which will be evaluated to determine visibility.

Sketch 6. Determination of viewability of probe from an hour angle-declination station

The functions \( \alpha' \) and \( \alpha'' \) illustrated in Sketch 6 have these properties:

\[
0 \text{ deg} \leq \alpha \leq 360 \text{ deg}
\]

\[
+180 \text{ deg} \leq \alpha' \leq -180 \text{ deg}
\]

\[-85 \text{ deg} < \alpha'' \leq +95 \text{ deg}\]
When the station is an azimuth-elevation type, the above relationships are not used and the probe is assumed to be in view of a given station if the probe's elevation angle $\gamma_i$ is greater than 5 deg above the local horizon. For hour angle-declination stations if the absolute value of the function $a'$ is less than 50 deg, the elevation is assumed to be such that the probe will still be in view at the next iteration. If the value $|a'|$ is greater than 50 deg the function $a''$ is computed. As indicated on the above diagram, if 50 deg $\leq |a'| \leq 90$ deg, then correspondingly, 45 deg $\leq a'' \leq 5$ deg. If the relation $\min |a'', \gamma_i \geq 5 \text{deg}|$ is satisfied, the station is able to view the probe.

The value of either $\gamma_i$ or $a'$, depending on the above conditions, and the value of $a''$, and a code word are stored in a block of three locations, the location of the block being determined by the station from which the probe is being viewed.

If a view period event or a station print is to occur, further calculations must be made. The declination of the probe, $\delta_i$, is given as:

$$\delta_i = \arcsin \frac{z_{ip}}{\rho}$$

where

$$-90 \text{deg} \leq \delta_i \leq 90 \text{deg}$$

This is measured positive North. $\delta_i$ is stored in location DCL, $\sin \delta_i$ in SIMLAR+21 and $\cos \delta_i$ in SIMLAR+22.

The angular rate of declination, $\dot{\delta}_i$, is

$$\dot{\delta}_i = \frac{\dot{z} - \dot{\rho} \sin \delta_i}{\rho \cos \delta_i}$$

and is stored in DCD.

The quantities $\sigma_i$, $\phi_i$ are computed in the following manner:

$$\cos \sigma_i = \frac{z_{ip} \cos \phi_i - x_{ip} \sin \phi_i \cos \theta_i - y_{ip} \sin \phi_i \sin \theta_i}{\rho \cos \gamma_i}$$

and is stored in SIMLAR+25. The expression in the numerator above is equivalent to $-x''_{ip}$. $\sigma_i$ is then computed from the value of $\cos \sigma_i$ and stored in SIG.

If the quantity $y''_{ip} = y_{ip} \cos \theta_i - x_{ip} \sin \theta_i$ is negative, the value of $\sigma_i$ is between 180 and 360 deg and is formed by taking 360 deg - $\arccos (\cos \sigma_i)$. The value of $\sin \phi_i$ is calculated by the following:
\[
\hat{\phi}_i = \frac{x_i^n + \cos \gamma_i (\rho \cos \gamma_i - \rho \sin \gamma_i)}{\rho \cos \gamma_i \sin \gamma_i}
\]

and is stored in SIGD.

The vector \( \overrightarrow{R}_{ip} \) is determined by rotating the components of the topocentric coordinate system \( \overrightarrow{F}_{ip}(x'_{ip}, y'_{ip}, z'_{ip}) \) through the angle \( \tau(T) \) such that the resulting coordinate system is parallel to the true of date coordinate system which is input to LOOP \((X, Y, Z)\).

\[
\begin{pmatrix}
X_{ip} \\
Y_{ip} \\
Z_{ip}
\end{pmatrix} =
\begin{pmatrix}
\cos \tau(T) & -\sin \tau(T) & 0 \\
\sin \tau(T) & \cos \tau(T) & 0 \\
0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
x_{ip} \\
y_{ip} \\
z_{ip}
\end{pmatrix}
\]

The station-probe-Sun angle SPS is found by:

\[
SPS = \arccos \frac{\overrightarrow{C} \cdot \overrightarrow{R}_{ip}}{|\overrightarrow{R}_{ip}|}
\]

and is stored in cell SPS.

A four quadrant polarization angle is computed from the following formula and stored in a cell named POL:

\[
POL = \frac{(\overrightarrow{C} \times \overrightarrow{R}_{ip})^1 \cdot [\overrightarrow{R}_{ip} \times (\overrightarrow{R}_{ip} \times \overrightarrow{R})]^1}{(\overrightarrow{C} \times \overrightarrow{R}_{ip})^1 \cdot (\overrightarrow{R}_{ip} \times \overrightarrow{R})^1}
\]

The notations \((\overrightarrow{R})^1\) or \(\overrightarrow{R}^1\) indicate that unitization of the vector \(\overrightarrow{R}\) has taken place.

Herein follow the calculations of the Canopus, Moon, and target clock angles, which are accomplished using the following formula:

\[
N\text{-clock angle} = \arctan \left( -\frac{\left( \frac{\overrightarrow{N} \times \overrightarrow{R}_{sp}^1}{\overrightarrow{N} \times \overrightarrow{R}_{sp}^1} \right) \times \overrightarrow{R}_{sp}^1 \cdot \left( \overrightarrow{R}_{sp}^1 \times \overrightarrow{R}_{ip}^1 \right) \cdot \left( \overrightarrow{R}_{sp}^1 \times \overrightarrow{R}_{ip}^1 \times \overrightarrow{R}_{sp}^1 \right)}{\left( \frac{\overrightarrow{N} \times \overrightarrow{R}_{sp}^1}{\overrightarrow{N} \times \overrightarrow{R}_{sp}^1} \right) \times \overrightarrow{R}_{sp}^1 \cdot \left( \overrightarrow{R}_{sp}^1 \times \overrightarrow{R}_{ip}^1 \times \overrightarrow{R}_{sp}^1 \right)} \right)
\]

The vector \(\overrightarrow{N}\) denotes the vector from the station to the body to which the clock angle is referenced,

\[
\begin{aligned}
\overrightarrow{N} &= \overrightarrow{R}_{\text{ec}} \text{ for the Canopus clock angle } \text{CKC} \\
\overrightarrow{N} &= \overrightarrow{R}_{\text{em}} \text{ for the Moon clock angle } \text{CKM}
\end{aligned}
\]
\documentclass{article}
\usepackage{amsmath}
\begin{document}
\noindent
\textbf{JPL TECHNICAL MEMORANDUM NO. 33-199}

\[ \overline{N} = \overline{R}_{et} \text{ for the target clock angle CKT.} \]

\[ \overline{\text{sp}} \] in this formula denotes the true-of-date sun-probe position vector.

The probe-station-Sun angle (PSS) and the probe-station-Moon angle (PSM) are the angles between the probe-station vector and the Sun-station or Moon-station vectors, respectively. They are computed by:

\[ \text{PSS} = \left[ (\overline{\text{sp}} - \overline{\text{ip}})^{1} \cdot (-\overline{\text{ip}})^{1} \right] \]

\[ \text{PSM} = \left[ (\overline{\text{mp}} - \overline{\text{ip}})^{1} \cdot (-\overline{\text{ip}})^{1} \right] \]

where $\overline{\text{mp}}$ is the true-of-date Moon-probe position vector.

The light time correction (DELT) is the time in seconds which is required for light to travel the station-probe distance and is given by

\[ \text{DELT} = \frac{\rho}{c} \]

where $c$ is the finite speed of light.

The probe right ascension (PRA) is found by

\[ \text{PRA} = \arctan \left( \frac{Y_{ip}}{X_{ip}} \right) \]

where $X_{ip}$ and $Y_{ip}$ are components of $\overline{\text{ip}}$.

The method of calculation of various quantities associated with frequencies of spacecraft and tracking station transmitting and receiving equipment is indicated in the equations which follow.

The frequency calculations for L-band stations are as follows:

\[ \text{XA} = \frac{f_{a}}{A_{4i}^{2}} (1 + \rho/c), \text{ cps} \]

\[ \text{F1} = A_{6i} \left[ A_{11} + A_{21} f_{1} - A_{71} f_{1} (1 - \rho/c) \right], \text{ cps} \]

\[ \text{F2} = A_{6i} \left[ A_{4i} f_{1} (2 \rho/c) + A_{5i} \right], \text{ cps} \]

\[ \text{D1} = \text{F1}/30, \text{ cps} \]

\[ \text{D2} = \text{F2}/30, \text{ cps} \]

\[ \text{DF1} = A_{6i} A_{31} f_{1} (\rho/c), \text{ cps}^{2} \]

\[ \text{DF2} = A_{6i} A_{41} f_{1} (2 \rho/c), \text{ cps}^{2} \]

\end{document}
The calculations for L-S band stations are:

\[ XA = f_{rq}(1 + \frac{\dot{\beta}}{c}), \text{ cps} \]

\[ D1 = \left[ LSK1 + \frac{30}{96} \times 10^6 - \frac{LSFT}{96}(1 - \frac{\dot{\beta}}{c}) \right], \text{ cps} \]

\[ D2 = \left[ LSK1 + \frac{30}{96} \times 10^6 - \frac{240}{221} f_{rq}(1 - 2\frac{\dot{\beta}}{c}) \right], \text{ cps} \]

\[ F1 = 30 \, D1, \text{ cps} \]

\[ F2 = 30 \, D2, \text{ cps} \]

\[ DF1 = 30 \left[ \frac{LSFT}{96}(\frac{\dot{\beta}}{c}) \right], \text{ cps}^2 \]

\[ DF2 = 30 \left[ \frac{240}{221} f_{rq}(2\frac{\dot{\beta}}{c}) \right], \text{ cps}^2 \]

For S-band equipped stations, the equations are:

\[ XA = \text{same as for L-S band} \]

\[ D1 = \left[ \frac{240}{221} x 96 x SK1 - SFT(1 - \frac{\dot{\beta}}{c}) + 1 \times 10^6 \right], \text{ cps} \]

\[ D2 = \left[ \frac{240}{221} x 96 x f_{rq}(2\frac{\dot{\beta}}{c}) + 1 \times 10^6 \right], \text{ cps} \]

\[ F1 = 30 \, D1, \text{ cps} \]

\[ F2 = 30 \, D2, \text{ cps} \]

\[ DF1 = 30 x SFT(\frac{\dot{\beta}}{c}), \text{ cps}^2 \]

\[ DF2 = 30 x 96 \times \frac{240}{221} x f_{rq}(2\frac{\dot{\beta}}{c}), \text{ cps}^2 \]

The parameter which determines a station's type is the fifth cell of the station coordinate information for a given station. If this is zero the L-band equations will be used. If it is a fixed point 1 scaled 35, the L-S equations are used, and if it is a fixed point 2 scaled 35, the S-band equations are used. All stations have zero (L-band) as the canned value. This may be modified by input.
The quantity $\beta$, slant range acceleration of the probe with respect to the station will be computed only if the Earth was the central body for integration. Otherwise $\beta$ will appear as zero and the equations which contain $\beta$ will not be used. $\beta$ is obtained as follows:

First compute $\vec{t}$, the Earth-fixed probe acceleration vector

$$
\begin{pmatrix}
\ddot{X} \\
\ddot{Y} \\
\ddot{Z}
\end{pmatrix} =
\begin{pmatrix}
\cos \tau(T) & \sin \tau(T) & 0 \\
-\sin \tau(T) & \cos \tau(T) & 0 \\
0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
\dot{X} \\
\dot{Y} \\
\dot{Z}
\end{pmatrix} + 2\omega \begin{pmatrix}
-\dot{X} \\
-\dot{Y} \\
-\omega^2 \dot{Z}
\end{pmatrix}
$$

Now

$$\rho \ddot{\beta} = \frac{\ddot{r}_{ip} \cdot \dot{r}_{ip}}{r_{ip}} = \frac{\ddot{r}_{ip} \cdot \dot{r}}{r_{ip}}$$

differentiating and noting that $\ddot{r} = \ddot{r}_{ip}$ yields

$$\rho \ddot{\beta} + \beta^2 - \dddot{r}_{ip} \cdot \dddot{r}_{ip} + \dddot{r} \cdot \dddot{r}$$

then

$$\ddot{\beta} = \frac{\dddot{r}_{ip} \cdot \dddot{r}_{ip} + \dddot{r} \cdot \dddot{r} - \beta^2}{\rho}$$

$\ddot{\beta}$ is then stored in RDDT.

The remaining frequency equations are

$$BF1 = B_5 B_6 (1 + \beta/c) - 960 \times 10^6, \text{ cps}$$

$$DOFRAT = (\omega^2/c) \times 960 \times 10^6, \text{ cps}^2$$

$$SLOSS = K_1 + K_2 \log_{10}(K_3 \rho)$$

**USE**

Calling sequence

```
CALL LOOP
PZE X, Y
OP B, C
```

where $X$ is the location of the Earth-centered space fixed of date equatorial cartesian position vector of the probe. $Y$ is the corresponding coordinate of the velocity vector.
B contains binary code word which is used to determine which stations are to be considered. Each bit corresponds to a station in the station tables contained in LOOP. Each bit from right to left corresponds to the table entries from beginning to end of the tables.

C contains the unit probe-Sun vector in the same coordinate system as X (defined above). X, Y, and C are BSS 3.

OP is PZE for station prints, MZE for view periods, where appropriate buffering is performed.

The station coordinates and BCD identification are built into the subroutine with the values listed below:

59 JOBURG - MTS   AZEL
   -25.73521, 27.70403, 6375.6952, 0, 0

11 GOLDSTONE   HADEC
   35.208070, 243.15802, 6372.0341, 1, 0

12 GOLDSTONE ECHO   HADEC
   35.117400, 243.19428, 6371.8770, 1, 0

41 WOOMERA   HADEC
   -31.211865, 136.88727, 6372.6040, 1, 0

51 JOBURG - 85   HADEC
   -25.739277, 27.685181, 6375.4980, 1, 0

14 GOLDSTONE - 210   AZEL
   35.243770, 243.12129, 6372.1341, 0, 0

13 GOLDSTONE - 85   AZEL
   35.066620, 243.20507, 6372.2599, 0, 0

15 GOLDSTONE - 30   AZEL
   35.06615, 243.20853, 6372.2478, 0, 0

42 CANBERRA   HADEC
   -35.21963, 148.98028, 6371.6686, 1, 0

61 MADRID   HADEC
   40.238000, 355.75050, 6370.0868, 1, 0

08 CARNARVON   AZEL
   -24.75336, 113.71605, 6374.05, 0, 0

91 ANTIGUA   AZEL
   17.0355, 298.2072, 6376.3091, 0, 0

75 ASCENSION   AZEL
   -7.8991, 345.58760, 6377.8013, 0, 0
These are the values given in reference 2 with typographical errors corrected.

CODING INFORMATION

Length of subroutine in 1590 (10) or 3066 (8) words.

REFERENCES


IDENTIFICATION

MARSMM/MARSPC/MARFIX/MHA/PMAT/PPMAT

Alan D. Rosenberg, JPL
IBM 7094 Fap
December 2, 1964

PURPOSE

a. To compute the Mars hour angle and the matrices PMAT and PPMAT which rotate
   from a space-fixed mean Earth equator and equinox of 1950.0 coordinate system to a
   space-fixed Mars equatorial coordinate system, and from the latter system to a Mars-
   fixed Mars equatorial coordinate system, respectively.
b. To apply the PMAT matrix to an input vector.
c. To apply the PPMAT matrix to input position and velocity vectors.

RESTRICTIONS

a. Subroutines SIN, COS, CROSS, UNIT, FIX, FLOAT and MATRIX are called.
b. COMMON locations XN, XN., T and T+1 are assumed to contain the planetary positions
   and velocities and double precision seconds past 0 hr January 1, 1950, respectively.
c. MARSMM must be called before MARSPC or MARFIX may be called.
d. COMMON+4, COMMON+5 and cells 777648 through 777778 are used.
e. Entries MHA, PMAT and PPMAT are provided so the computed Mars hour angle and
   two rotation matrices are accessible.

METHOD

a. The orientation of the Mars spin axis is defined relative to the mean Earth equator and
   equinox of 1950.0 by the angles:

   \[ \alpha_0 = 317.7934 \text{ deg} \]
   \[ \delta_0 = 54.6575 \text{ deg} \]

   which correspond to the direction cosines:

   \[ \hat{P} = \cos \delta_0 \cos \alpha_0', \cos \delta_0 \sin \alpha_0', \sin \delta_0 \]

   A unit vector normal to the Mars-orbital plane is computed by:
where \( \mathbf{R}_{O\odot} \) and \( \mathbf{V}_{O\odot} \) are the Sun-Mars position and velocity vectors referenced to the Earth equator and equinox of 1950.0 coordinate system. Next, define

\[
\mathbf{\hat{N}} = \frac{\mathbf{R}_{O\odot} \times \mathbf{V}_{O\odot}}{|\mathbf{R}_{O\odot} \times \mathbf{V}_{O\odot}|}
\]

where \( \mathbf{\hat{N}} \) is a unit vector pointing toward the Sun.

Define the unit vectors \( \mathbf{\hat{i}}, \mathbf{\hat{j}}, \mathbf{\hat{k}} \) as follows:

\[
\mathbf{\hat{i}} = \frac{\mathbf{\hat{P}} \times \mathbf{\hat{N}}}{|\mathbf{\hat{P}} \times \mathbf{\hat{N}}|}
\]

\[
\mathbf{\hat{K}} = \mathbf{\hat{P}}
\]

\[
\mathbf{\hat{J}} = \mathbf{\hat{K}} \times \mathbf{\hat{I}}
\]

where \( \mathbf{\hat{I}}, \mathbf{\hat{J}}, \mathbf{\hat{K}} \) are the unit vectors defining the X, Y, Z axes, respectively, of the space-fixed Mars equator and equinox of 1950.0 coordinate system. Hence the matrix to rotate from the space-fixed Earth mean equator and equinox of 1950.0 frame to the space-fixed Mars equatorial frame is as follows:

\[
\mathbf{PMAT} = \begin{pmatrix}
\mathbf{I}_x & \mathbf{I}_y & \mathbf{I}_z \\
\mathbf{J}_x & \mathbf{J}_y & \mathbf{J}_z \\
\mathbf{K}_x & \mathbf{K}_y & \mathbf{K}_z
\end{pmatrix}
\]

Since no precession or nutation of the Mars equator has been defined, the above matrix is sufficient to express the relationship between the Earth and Mars equators as stated.

b. The rotation from a space-fixed Mars equatorial coordinate system to a Mars-fixed Mars equatorial coordinate system involves only a rotation about the Z-axis by the Mars hour angle, MHA:

\[
\text{MHA} = \text{MHA}_{\text{ref}} + \omega_M T_D
\]

where

\[
\text{MHA}_{\text{ref}} = 145.042501 \text{ deg}
\]

\[
\omega_M = \text{angular rotation rate}
\]

\[
= 350.891962 \text{ deg/day}
\]

\[
= 0.7088217655 \times 10^{-4} \text{ rad/sec}
\]

\[
T_D = \text{days past 0 hr January 1, 1950, U. T.}
\]
The rotation matrix is therefore:

\[
PPMAT = \begin{pmatrix}
\cos \text{MHA} & \sin \text{MHA} & 0 \\
-sin \text{MHA} & \cos \text{MHA} & 0 \\
0 & 0 & 1
\end{pmatrix}
\]

and position and velocity vectors may be expressed in the Mars-fixed Mars equatorial coordinate system as follows:

\[
\begin{align*}
(X) &= (PPMAT)(Y) \\
(x) &= (PPMAT)(\hat{X} + \omega_M \hat{Y}) \\
(y) &= (PPMAT)(\hat{Y} - \omega_M \hat{X}) \\
(z) &= (PPMAT)(\hat{Z})
\end{align*}
\]

MARSMM computes the Mars hour angle MHA and the two matrices PMAT and PPMAT.
MARSPC rotates an input vector from space-fixed Earth mean equator and equinox of 1950.0 coordinates to space-fixed Mars equatorial coordinates.
MARFIX rotates an input position and velocity vector from space-fixed Mars equatorial coordinates to Mars-fixed Mars equatorial coordinates.

USE

Calling sequences:

a. CALL MARSMM
   return
   Exit with the Mars hour angle computed and stored in MHA, the Earth-equatorial to Mars-equatorial rotation matrix stored row-wise in PMAT through PMAT+8 and the space-fixed Mars equatorial to Mars-fixed Mars equatorial rotation matrix stored row-wise in PPMAT through PPMAT+8.

b. CALL MARSPC
   PZE A,, B
   return
   where A, A+1, A+2 contain the input vector referenced to the space-fixed mean Earth equator and equinox of 1950.0 coordinate system.
B, B+1, B+2 contain the output vector referenced to the space-fixed Mars equatorial coordinate system and where the matrix used is assumed to have been previously computed and stored internally in PMAT through PMAT+8.

c. CALL MARFIX
   PZE A,, B
   return

where A, ..., A+5 contain the input position and velocity vectors referenced to the space-fixed Mars equatorial coordinate system.

B, ..., B+5 contain the output position and velocity vectors referenced to the Mars-fixed Mars equatorial coordinate system and where the matrix used is assumed to have been previously computed and stored internally in PPMAT through PPMAT+8.

CODING INFORMATION

Length of subroutine is 160(10) or 240(8) words.

REFERENCE

JPL Section 312 RFP 141, July 4, 1963.
IDENTIFICATION

MATRIX
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To perform the matrix multiplication $C = (A)(B)$.

RESTRICTIONS

a. The matrix $A$ must be $m \times 3$ and $B$ must be $3 \times n$.

b. MATRIX is a subset of a package of several subroutines.

METHOD

The multiplication is performed in the manner indicated by the mathematical definition of matrix multiplication.

USE

Calling sequence:

```plaintext
CALL   MATRIX
PZE    M, A
PZE    N, B
PZE    , , C
```

where

- $M$ contains the fixed point $m$ dimension of matrix $A$.
- $A$, $\cdots$, $A+8$ contain the $A$ matrix, stored row-wise with $A_{11}$ the first element.
- $N$ contains the fixed point $n$ dimension of matrix $B$.
- $B$, $\cdots$, $B+8$ contain the $B$ matrix, stored row-wise with $B_{11}$ the first element.
- $C$, $\cdots$, $C+8$ contain the matrix product $C = (A)(B)$, stored row-wise with $C_{11}$ the first element.

CODING INFORMATION

Length of subroutine (includes MATRIX as a subset) is 1046(10) or 2026(8) words.
IDENTIFICATION
MNA/MNA1/MNAMD/MNAMD1/NUTEPH/NUTLON/NUTOBL
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE
To rotate true Earth equator of-date coordinates to true lunar equator of-date coordinates and vice versa via the M and \( M \) matrices, and to form the matrix \( N \), which rotates mean Earth equator of-date coordinates to true Earth equator of-date coordinates.

RESTRICTIONS
a. MNA, et. al., is a subset of the lunar model package and uses other subroutines in the package.

b. The input parameter NUTEPH is an internal cell and is accessible via an entry. If NUTEPH is non-zero then the nutation in longitude and nutation in obliquity are computed. If NUTEPH is zero, then the nutations are obtained by interpolation of the nutation data on the double precision JPL Ephemeris Tapes obtained by calling subroutine ANTR1.

c. Entries NUTLON and NUTOBL have been provided so that the output parameters, nutation in longitude and nutation in obliquity, respectively, are accessible.

d. It is assumed that the matrix A, which rotates mean Earth equator of 1950.0 coordinates to mean Earth equator of-date coordinates, has been updated and is in COMMON locations AA through AA+8.

e. The output N matrix is stored in NUTMAT through NUTMAT+8 and is accessible via the entry NUTMAT, the output product matrix MNA is stored in COMMON locations (MNA) through (MNA)+8 and the output matrix M is stored in COMMON locations MM through MM+8.

f. \( \delta \alpha \), the nutation in right ascension used in the calculation of the true value of the Greenwich hour angle, is computed and stored in COMMON location NUTRA.

METHOD
a. The nutation matrix N: To describe the nutation of the Earth about its precessing mean equator, it is convenient to construct the nutation matrix N which relates the cartesian coordinates expressed in the true equator and equinox to those in the mean equator and equinox as shown in the following sketch:
where:

1. $\epsilon$ is the mean obliquity and is given by:

$$\epsilon = 23^\circ 4457587 - 0^\circ 01309404T - 0^\circ 0088 \times 10^{-4}T^2 + 0^\circ 0050 \times 10^{-4}T^3$$

where $T$ is the number of Julian centuries of 36,525 days past the epoch 0 hr January 1, 1950, E.T.

The nutations $\delta \epsilon$ and $\delta \psi$ may be obtained by interpolation of the nutation data on the double precision JPL Ephemeris Tapes or they may be computed as follows:

$$\Omega = 12^\circ 1127902 - 0^\circ 0529539222d + 20^\circ 795 \times 10^{-4}T + 20^\circ 81 \times 10^{-4}T^2$$
$$+ 0^\circ 02 \times 10^{-4}T^3$$

$$\zeta = 64^\circ 37545167 + 13^\circ 1763965268d - 11^\circ 31575 \times 10^{-4}T - 11^\circ 3015$$
$$\times 10^{-4}T^2 + 0^\circ 019 \times 10^{-4}T^3$$

$$\Gamma = 208^\circ 8439877 + 0^\circ 1114040803d - 0^\circ 010334T - 0^\circ 010343T^2$$
$$- 0^\circ 12 \times 10^{-4}T^3$$

$$L = 280^\circ 08121009 + 0^\circ 9856473354d + 3^\circ 03 \times 10^{-4}T + 3^\circ 03 \times 10^{-4}T^2$$

$$\Gamma = 282^\circ 08053028 + 0^\circ 470684 \times 10^{-4}d + 4^\circ 5525 \times 10^{-4}T + 4^\circ 575$$
$$\times 10^{-4}T^2 + 0^\circ 03 \times 10^{-4}T^3$$

where $T$ is the number of Julian centuries of 36,525 days past the epoch 0 hr January 1, 1950, E.T., and $d$ is the number of days past the same epoch. The program uses $d$ in double precision.

2. $\delta \psi$ is the nutation in longitude measured from the true vernal equinox at the $X'$ axis to the mean vernal equinox at the $X$ axis.
\[ \delta \psi = \Delta \psi + d\psi, \text{ where } \Delta \psi \text{ denotes the long period terms and } d\psi \text{ denotes the short period terms. They are given by:} \]

\[
\Delta \psi = -(47.8927 + 0.0482T) \times 10^{-4} \sin \Omega + 0.5800 \times 10^{-4} \sin 2 \Omega \\
- 3.5361 \times 10^{-4} \sin 2 L - 0.1378 \times 10^{-4} \sin (3 L - \Gamma) + 0.0594 \times 10^{-4} \\
\times \sin(L + \Gamma) + 0.0344 \times 10^{-4} \sin(2 L - \Omega) + 0.0125 \times 10^{-4} \sin(2 \Gamma' - \Omega) \\
+ 0.3500 \times 10^{-4} \sin(L - \Gamma) + 0.0125 \times 10^{-4} \sin(2 L - 2 \Gamma') \\

\]

\[ d\psi = - 0.5658 \times 10^{-4} \sin 2 \xi - 0.0950 \times 10^{-4} \sin(2 \xi - \Omega) - 0.0725 \times 10^{-4} \]

\[
\times \sin(3 \xi - \xi') + 0.0317 \times 10^{-4} \sin(3 \xi + \xi') + 0.0161 \times 10^{-4} \\
\times \sin(3 \xi - \Omega) + 0.0158 \times 10^{-4} \sin(3 \xi - \xi' - \Omega) - 0.0144 \times 10^{-4} \\
\times \sin(3 \xi + \xi' - 2L) - 0.0122 \times 10^{-4} \sin(3 \xi - \xi' - \Omega) + 0.1875 \times 10^{-4} \\
\times \sin(3 \xi - \xi' + 2 \xi' - 2L) + 0.0167 \times 10^{-4} \sin(2 \xi - 2 \xi') - 0.0089 \times 10^{-4} \\
\times \sin(4 \xi - 2L) \\
\]

3. \( \delta \xi \) is the nutation in obliquity. \( \delta \xi = \Delta \xi + d\xi \), where \( \Delta \xi \) denotes the long-period terms and \( d\xi \) the short-period terms. They are given by:

\[
\Delta \xi = 25.5844 \times 10^{-4} \cos \Omega - 0.2511 \times 10^{-4} \cos 2 \Omega + 0.5336 \times 10^{-4} \\
\times \cos 2 L + 0.0666 \times 10^{-4} \cos(3 L - \Gamma) - 0.0258 \times 10^{-4} \cos(L + \Gamma) \\
- 0.0183 \times 10^{-4} \cos(2 L - \Omega) - 0.0067 \times 10^{-4} \cos(2 \Gamma' - \Omega) \\
\]

\[ d\xi = 0.2456 \times 10^{-4} \cos 2 \xi + 0.0508 \times 10^{-4} \cos(2 \xi - \Omega) - 0.0369 \times 10^{-4} \]

\[
\times \cos(3 \xi - \xi') - 0.0139 \times 10^{-4} \cos(3 \xi + \xi') - 0.0086 \times 10^{-4} \\
\times \cos(3 \xi - \Omega) + 0.0083 \times 10^{-4} \cos(3 \xi - \xi' - \Omega) + 0.0061 \times 10^{-4} \\
\times \cos(3 \xi + \xi' - 2L) + 0.0064 \times 10^{-4} \cos(3 \xi - \xi' - \Omega) \\
\]

4. The true obliquity is computed as follows:

\[ \epsilon = \hat{\epsilon} + \delta \epsilon \]

5. \( \delta \alpha \) is the nutation in right ascension used in the calculation of the true value of the Greenwich hour angle of the vernal equinox and is given by:

\[ \delta \alpha = \delta \psi \cos \hat{\epsilon} \]

If \( N \) is defined in the sense

\[
\begin{pmatrix} X' \\ Y' \\ Z' \end{pmatrix} = N \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}
\]

118
where the primed system is the true equator and equinox and the unprimed is the mean equator and equinox, then the $N_{ij}$ are given by

\[
\begin{align*}
N_{11} &= \cos \delta \psi \\
N_{12} &= -\sin \delta \psi \cos \epsilon \\
N_{13} &= -\sin \delta \psi \sin \epsilon \\
N_{21} &= \sin \delta \psi \cos \epsilon \\
N_{22} &= \cos \delta \psi \cos \epsilon \cos \epsilon + \sin \epsilon \sin \epsilon \\
N_{23} &= \cos \delta \psi \cos \epsilon \sin \epsilon - \sin \epsilon \cos \epsilon \\
N_{31} &= \sin \delta \psi \sin \epsilon \\
N_{32} &= \cos \delta \psi \sin \epsilon \cos \epsilon - \cos \epsilon \sin \epsilon \\
N_{33} &= \cos \delta \psi \sin \epsilon \sin \epsilon + \cos \epsilon \cos \epsilon \\
\end{align*}
\]

Since $|\delta \psi| < 10^{-4}$ and $|\delta \epsilon| < 10^{-4}$, the $N_{ij}$ are expanded to first order in $\delta \psi$ and $\delta \epsilon$ to obtain a form which is better behaved for numerical calculation:

\[
N = \begin{pmatrix}
1 & -\delta \psi \cos \epsilon & -\delta \psi \sin \epsilon \\
\delta \psi \cos \epsilon & 1 & -\delta \epsilon \\
\delta \psi \sin \epsilon & \delta \epsilon & 1
\end{pmatrix}
\]

b. The true Earth equator of-date to true lunar equator of-date matrix, $M$:

The relationship between the two planes is shown in the following sketch:

where the $X'$, $Y'$, $Z'$ frame is the Earth's true equator and equinox; the $x$ - $y$ plane lies in Moon's true equator with $z$ completing the right-hand system by lying along the Moon's spin axis. $i$ is the inclination of the Moon's true equator to the Earth's true equator. $\omega'$ is the right ascension of the ascending node of the Moon's true equator; $\Lambda$ is the anomaly from the node to the $x$ axis; $\Delta$ is the anomaly from the node
to the ascending node of the Moon's true equator on the ecliptic; \( \epsilon \) is the true obliquity of the ecliptic; \( \delta \psi \) is the nutation in longitude; \( \Omega \) is the mean longitude of the descending node of the Moon's mean equator on the ecliptic; \( \psi \) is the mean longitude of the Moon; \( \eta \) is the inclination of the Moon's mean equator to the ecliptic; \( \sigma \) is the libration in the node; \( \tau \) is the libration in the mean longitude; and \( \rho \) is the libration in the inclination. The anomalies are related by \( \Lambda = \Delta - (\psi + \tau) - (\Omega + \sigma) \).

The librations are given by:

\[
\begin{align*}
\sigma \sin \eta &= -0.0302777 \sin \eta + 0.0127777 \sin(\eta + 2\omega) - 0.00305555 \sin(2\eta + 2\omega) \\
\tau &= -0.003333 \sin \eta + 0.0163888 \sin \eta + 0.0065 \sin 2\omega \\
\rho &= -0.0297222 \cos \eta + 0.0127777 \cos(\eta + 2\omega) - 0.00305555 \cos(2\eta + 2\omega) \\
\iota &= 1.535
\end{align*}
\]

The following expressions have been programmed for \( \eta \), \( \eta' \), and \( \omega \):

\[
\begin{align*}
\eta &= 215.54013 + 13.064992 \, \text{d} \\
\eta' &= 358.009067 + 0.9856005 \, \text{d} \\
\omega &= 196.745632 + 0.1643586 \, \text{d}
\end{align*}
\]

Evidently \( \eta = \psi - \Gamma' \), the mean anomaly of the Moon; \( \eta' = L - \Gamma \), the mean anomaly of the Sun; and \( \omega = \Gamma' - \Omega \), the argument of the perigee of the Moon. All quantities relate to mean motions of the Sun and the Moon.

\[
\begin{align*}
\cos i &= \cos(\Omega + \sigma + \delta \psi) \sin \epsilon \sin(\iota + \rho) + \cos \epsilon \cos(\iota + \rho), \quad 0 < i < 90^\circ \\
\sin \Omega' &= -\sin(\Omega + \sigma + \delta \psi) \sin(\iota + \rho) \csc i, \quad -90^\circ < \Omega' < 90^\circ \\
\sin \Delta &= -\sin(\Omega + \sigma + \delta \psi) \sin \iota \csc i \\
\cos \Delta &= -\sin(\Omega + \sigma + \delta \psi) \sin \iota \cos \epsilon - \cos(\Omega + \sigma + \delta \psi) \cos \Omega', \quad 0 \leq \Delta < 360^\circ \\
\Lambda &= \Delta + (\psi + \tau) - (\Omega + \sigma)
\end{align*}
\]

The two rectangular systems are related through \( \Lambda \), \( \Omega' \), and \( i \) by the rotation:

\[
\begin{bmatrix}
x' \\
y' \\
z'
\end{bmatrix} =
\begin{bmatrix}
m_{11} & m_{12} & m_{13} \\
m_{21} & m_{22} & m_{23} \\
m_{31} & m_{32} & m_{33}
\end{bmatrix}
\begin{bmatrix}
x \\
y \\
z
\end{bmatrix}
\]

where

\[
\begin{align*}
m_{11} &= \cos \eta' \sin \Omega' \cos i \\
m_{12} &= \cos \eta' \sin \Omega' \sin i
\end{align*}
\]
\[ \begin{align*}
m_{13} & = \sin \lambda \sin i \\
m_{21} & = -\sin \lambda \cos \Omega' - \cos \lambda \sin \Omega' \cos i \\
m_{22} & = -\sin \lambda \sin \Omega' + \cos \lambda \cos \Omega' \cos i \\
m_{23} & = \cos \lambda \sin i \\
m_{31} & = \sin \Omega' \sin i \\
m_{32} & = -\cos \Omega' \sin i \\
m_{33} & = \cos i
\end{align*} \]

Combining the above \( m_{ij} \) (M) rotation matrix with the N and A matrices gives the MNA matrix used to rotate a position vector from Earth mean equator of 1950.0 coordinates, \((X, Y, Z)\), to true lunar equator of-date coordinates, \((x, y, z)\):

\[
\begin{pmatrix}
X \\
Y \\
Z
\end{pmatrix} = \text{MNA} \begin{pmatrix}
X \\
Y \\
Z
\end{pmatrix}
\]

and inversely,

\[
\begin{pmatrix}
x \\
y \\
z
\end{pmatrix} = (\text{MNA})' \begin{pmatrix}
x \\
y \\
z
\end{pmatrix}
\]

for the position transformation in the other direction.

c. The derivative of \( M \), \( \dot{M} \): In computing \( \dot{M} \) the rates for the slowly varying angles \( \Omega' \) and \( i \) are taken to be zero.

Thus

\[
\begin{align*}
\dot{M}_{11} & = (-\sin \lambda \cos \Omega' - \cos \lambda \sin \Omega' \cos i)\lambda \\
\dot{M}_{12} & = (-\sin \lambda \sin \Omega' + \cos \lambda \cos \Omega' \cos i)\lambda \\
\dot{M}_{13} & = (\cos \lambda \sin i)\lambda \\
\dot{M}_{21} & = (-\cos \lambda \cos \Omega' + \sin \lambda \sin \Omega' \cos i)\lambda \\
\dot{M}_{22} & = (-\cos \lambda \sin \Omega' - \sin \lambda \cos \Omega' \cos i)\lambda \\
\dot{M}_{23} & = (-\sin \lambda \sin i)\lambda
\end{align*}
\]
\[ \begin{align*}
M_{31} &= 0 \\
M_{32} &= 0 \\
M_{33} &= 0
\end{align*} \]

From the formula
\[ \Lambda = \Delta + (\Omega + \tau) - (\Omega + \sigma) \]

obtain
\[ \dot{\Lambda} = \dot{\Delta} + \dot{\Omega} + \dot{\tau} - \dot{\Omega} - \dot{\sigma} \]

The adopted numerical expressions for the rates are
\[ \dot{\Lambda} = \frac{-\cos(\Omega + \sigma + \delta) \sin(\Omega + \delta)}{\sin \cos \Delta} \]

\[ \dot{\tau} = 0.266170762 \times 10^{-5} - 0.12499171 \times 10^{-13} \text{ T rad/sec} \]

\[ \dot{\Omega} = -0.1069698435 \times 10^{-7} + 0.23015329 \times 10^{-13} \text{ T rad/sec} \]

\[ \dot{\tau} = -0.1535272946 \times 10^{-9} \cos \gamma + 0.569494067 \times 10^{-10} \cos \gamma' \]
\[ + 0.579473484 \times 10^{-11} \cos 2\omega \text{ rad/sec} \]

\[ \dot{\delta} = -0.520642191 \times 10^{-7} \cos \gamma + 0.1811774451 \times 10^{-7} \cos(\gamma + 2\omega) \]
\[ -0.1064057858 \times 10^{-7} \cos(2\omega + 2\gamma) \text{ rad/sec} \]

To obtain velocity transformations the approximation is made that
\[ \dot{N} = \dot{\Lambda} = 0 \]

thus
\[ \begin{pmatrix}
\dot{x} \\
\dot{y} \\
\dot{z}
\end{pmatrix} = M_{31} \begin{pmatrix}
x \\
y \\
z
\end{pmatrix} + \dot{M}_{31} \begin{pmatrix}
x \\
y \\
z
\end{pmatrix} \]

and for the inverse transformation
A definition of the A matrix can be found in subroutine ROTEQ.

USE

Calling sequences:

a. Position vector transformation:
   CALL MNA or MNA1
   PZE 1,,A
   PZE n,,B
   where A, A+1, A+2 contain the input vector
   B, B+1, B+2 contain the output vector
   n = 0 rotates true lunar equator of-date to mean Earth equator
      of 1950.0
   = 1 rotates mean Earth equator of 1950.0 to true lunar equator
      of-date.

Enter with the fractional part of the day past 0 hr of the epoch, E. T., in the
AC and the integer days past 0 hr January 1, 1950, E. T., of the epoch T,
in the MQ.

It is assumed that the A matrix has been previously computed and stored in
COMMON locations AA through AA+8.

The N matrix is computed and stored in locations NUTMAT through NUTMAT+8.
The M matrix is computed and stored in COMMON locations MM through MM+8.
The product matrices NA and MNA are formed and stored in COMMON locations
(NA) through (NA)+8 and (MNA) through (MNA)+8, respectively. The nutation
in right ascension is computed and stored in COMMON location NUTRA. The
nutations in longitude and obliquity are stored in locations NUTLON and NUTOBL,
respectively.

If CALL MNA1 is used, the contents of MNAET are used to determine whether or
not the .01 day test is to be used as criteria for recomputing the matrices M and
N, MNAET = 0 forces recomputation.
b. Velocity vector transformation:

CALL MNAMD
PZE 1,, A
PZE 1,, B
PZE n,, C

where A, A+1, A+2 contain the input position vector
B, B+1, B+2 contain the input velocity vector
C, C+1, C+2 contain the output velocity vector

n = 0 rotates true lunar equator of-date to mean Earth equator
    of 1950.0
n = 1 rotates mean Earth equator of 1950.0 to true lunar equator
    of-date.

Enter with the fractional part of the day past 0 hr of the epoch, E. T., in the AC
and the integer days past 0 hr January 1, 1950, E. T. of the epoch T, in the MQ.

It is assumed that the A matrix has been previously computed and stored in
COMMON locations AA through AA+8.

The N matrix is computed and stored in locations NUTMAT through NUTMAT+8.
The M matrix is computed and stored in COMMON locations MM through MM+8.
The product matrices NA and MNA are formed and stored in COMMON locations
(NA) through (NA)+8 and (MNA) through (MNA)+8, respectively. The nutation
in right ascension is computed and stored in COMMON location NUTRA.
The nutations in longitude and obliquity are stored in locations NUTLON and
NUTOBL, respectively.

If CALL MNAMD1 is used then the contents of MNAET are used to determine
whether or not the .01 day test is to be used as criteria for recomputing the
matrices M and N. MNAET = 0 forces recomputation.

CODING INFORMATION

Length of subroutine (includes MNA, et. al., as a subset) is 1046(10) or 2026(8) words.

REFERENCE

Holdridge, D. B., Space Trajectories Program for the IBM 7090 Computer, Technical
Report No. 32-223, Revision No. 1, Jet Propulsion Laboratory, Pasadena, California,
September 1, 1962.
IDENTIFICATION

PATH/DIST
Peter S. Fisher, JPL
IBM 7094 Fap
December 2, 1964

PURPOSE
To compute the path (arc) length of a trajectory.

RESTRICTIONS
a. PATH should be called every end of step.
b. The subroutine PROD is called.
c. The current values of time and inertial velocity are expected in T, T + 1 and CX. to CX. + 2 respectively.
d. The arc length will be computed geocentrically when either the Earth or the Moon is the target, and heliocentrically for all other target bodies.

METHOD
\[ S = \int_{t_{\text{inj}}}^{t_{\text{end}}} v \, dt \]
is approximated by \[ \sum \bar{v} \Delta t \]
Where \( \Delta t \) is the stepsize and \( \bar{v} \) is the average velocity over a step \[ \bar{v} = \frac{v_i + v_{i+1}}{2} \]

USE
Calling sequence:
CALL PATH
return

The path length in km is stored in DIST.

CODING INFORMATION
Length of subroutine is 51(10) or 63(8) words.
IDENTIFICATION

PLL TT/PLTSET/PLOTFQ/FILENO/RECNUM/CANCLK

JPL Staff

IBM 7094 Fap

December 2, 1964

PURPOSE

To control the SAVE tape option.

RESTRICTIONS

a. Subroutines REWIND and READB are used to position the tape.
b. Subroutine SAVEIT is used to write the SAVE tape.
c. Subroutines FLOTT, ADD, CW1, CHANGE, SIN and COS are used to compute the SAVE tape parameters.
d. STABCD, PAGBCD, BLATZ, LAUNCH and GCE are referenced indirectly.
e. ABORT is called if there is an error return from SAVEIT.
f. Entry CANCLK is provided so three clock angles can be stored internally in this subroutine.
g. Entries FILENO and RECNUM are provided so the file number and record number are available for output.
h. Entry PLOTFQ is provided for the five input parameters needed to define the request to use the SAVE tape option.

METHOD

This subroutine is the driver subroutine that effects the generation of the SAVE tape.
The initialization entry PLTSET does the following:

a. Checks PLOTFQ to see if the SAVE tape option is requested. If zero, the subroutine gives an exit.
b. Positions the SAVE tape on the basis of the file number.
c. Fetches the station subtable names and puts them in an internal buffer.
d. Sets up the initialization calling sequence to SAVEIT.
e. Calls SAVEIT.
f. Initializes the record number to 0 and converts launch epoch to seconds past 1950 if it is input non-zero.

The execution entry PLL LT does the following:

a. Checks PLOTFQ to see if the SAVE tape option is requested. If zero, the subroutine gives an exit.
b. Checks PLOTFQ for the frequency of writing the SAVE tape. If PLOTFQ = N and this entry to PLL LT is not the first one or is not a multiple of N, or if the current epoch is the same as it was on the previous entry, then the subroutine gives an exit.
c. Computes time past injection (TTT).
d. Computes time from launch (TFL) and days past 0 hr of launch day (DM) if launch epoch was input non-zero.

e. Sets flags for LOOP and PRINTD.

e. Calls CHANGE, which eventually calls LOOP and PRINTD.

g. Resets flags used by LOOP and PRINTD.

h. Computes two angles not computed by LOOP or PRINTD: SI) and CO).

i. Moves the data to the data buffer, increments the record number and calls SAVEIT.

USE

Calling sequences:

a. Initialization entry: CALL PLTSET

b. Execution entry: CALL PLLLT

The control (input) parameters must be in PLOTFQ to PLOTFQ + 4 as follows:

PLOTFQ frequency of writing tape 0 = none
PLOTFQ+1 physical file number
PLOTFQ+2 time added to seconds past injection
PLOTFQ+3 stations to put on save tape (maximum of 5)
PLOTFQ+4 stations to put on save tape

The format and definition of the I.D. and data records on the SAVE tape are found in Section VA.

CODING INFORMATION

Length of subroutine is 515(10) or 1003(8) words.
IDENTIFICATION

PRINTD/PRNTD1/CONIC
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

a. PRINTD sets up and prints groups of output quantities whenever certain output control words are set.
b. PRNTD1 sets flags that override the output control words and then goes to PRINTD. The effect is to force computation and printing of the output quantities.
c. CONIC sets up and prints conic parameters.

RESTRICTIONS

a. It is assumed that the subroutine SPRAY has previously been called.
b. COMMON through COMMON +100 are used for temporary storage.
c. The following subroutines are called: SPRAY, EFFECT, ROT, PRSET, RESET, TIME1, DAYS, ARTAN, PROD, ARSIN, GETTER, SIN, SPACE, RVOUT, GEDLAT, ECLIP, GRUPPE, PROUT, UNIT, ARCOS, CROSS, MNA, MNAMDI, MATRIX, MARSM, MARSPC, MARFIX, NUTATE, ERPRT, ABORT, COS, JERYL, CLASS, SPECL, ADD, TIME3, BCDNO, SQRT, LN, and LOOP.
d. The following entries are referenced indirectly: HC, CANCLK, CLUCK, GRAV, CG, MHA, INJFLG, GROP, CAN50, CASE, INJBCD and INJTY.

METHOD

Each FLAG at GROPS to GROPS +3 and GROPS +5 to GROPS +6 is examined; if any cell is zero the corresponding group is not printed. If the cell has the value of two, the output is in ecliptic coordinates; a value of four gives equatorial coordinates. The following groups may be printed:

- Geocentric
- Geocentric Conic
- Heliocentric
- Heliocentric Conic
- Target Centered
- Target Centered Conic

The conic output quantities are in two groups: those independent of the reference coordinate system and those dependent on the reference coordinate system. The possible coordinate systems are earth equatorial, ecliptic, orbit plane of target and target true equator.
USE

Calling sequences:

a. CALL PRINTD
   return

b. CALL PRNTDI
   return

c. CLA I
   CALL CONIC
   return

where I = 0 for geocentric conic
   I = 1 for heliocentric conic
   I = 2 for targetcentric conic

CODING INFORMATION

Length of subroutine is 2820(10) or 5404(8) words.
IDENTIFICATION

PROUT/FLUSH

JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To convert to specific output format from 1 to N lines of single or double precision information, convert the output data on one or several of the following output devices:

a. User Area Printer (SC 3070)
b. Peripheral Output Tape (SYSOU1)
   i. 1401 off-line printer or punch
   ii. SC 4020 off-line microfilm recorder.

RESTRICTIONS

a. Care must be exercised if single and double precision numbers are intermixed within a repeated line format, to ensure that the address modifier _g will give the correct location for data in lines subsequent to the first.
b. Requires the SFOF subroutine OUTUS, an output coordinator of SFOF subroutines that require disk write operations. OUTUS includes the necessary buffers to be shared.
c. Requires the SFOF subroutine TAPEIO for off-line output requests.

USE

a. Calling sequence:

   CALL PROUT
   BCI 1, XXXX
   P FLAG, T, PROGID
   ZZZ
   .
   .
   FVE CODE, T, 1000A+B
   ZZZ
   .
   .
   .
   FVE CODE, T, 1000A+B

   Conversion control pseudo instructions (see Conversion Parameters below)

   Conversion control pseudo instructions
ZZZ
.
.
.
.
FVE CODE, T, 1000A+B
FVE 0, 0, 0

where,

XXXX 4 BCD characters of identification (symbols may not start with Z)
P = PZE specifies SC 3070 output with or without peripheral output
= MZE peripheral output only
FLAG, T is the location of the flag word where the status of the request will be placed
PROGID is the beginning location of 12 BCD characters of program identification to be used as part of the SC 3070 page headings; if PROGID = 0, page headings, page numbers, and page ejects (upon 53-line count) will be omitted. The provision for page headings, page numbers, and blocked output is the responsibility of the user program

For User Area Printing (SC 3070),
CODE = 0 indicates user area printing
T = 0 indicates user area printing
A = 0 indicates no post-print control
B = 1 indicates 15 line pre-print paper advance
= 10 indicates single space
= 20 indicates double space

For Peripheral Output Tape (1401-Printing or Punching),
CODE is the location of the system tape address or logical tape number for printing or punching
T = 0 indicates printing,
= 7 indicates punching
A or B = 0 indicates suppress post-print spacing, pre-print spacing, respectively
= I where 1 ≤ I ≤ 9, indicates skip to Channel I,
= 10K indicates K spaces (K < 100)

For Peripheral Output Tape (SC 4020),
CODE is the location of a control word that has the following format:
PZE L(system tape address or logical tape number),
0, Line Count
T = 1 indicates SC 4020 printing
A or B = 0 indicates suppress post-print spacing, pre-print spacing, respectively
= I where 1 ≤ I ≤ 9, indicates skip to Channel I.
= 10K indicates K spaces (K < 100)
The calling sequence must be terminated by the "end" instructions:
FVE 0, 0, 0

b. Conversion parameters:

<table>
<thead>
<tr>
<th>Function</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLOATING TO FIXED</td>
<td>SVN L, T, 1000D+PP</td>
</tr>
<tr>
<td>FLOATING TO FLOATING</td>
<td>SIX L, T, 1000D+PP</td>
</tr>
<tr>
<td>FIXED TO FIXED</td>
<td>FOR L, T, 1000D+PP</td>
</tr>
<tr>
<td>BCD TO HOLLERITH</td>
<td>PTH L, T, 1000N+PP</td>
</tr>
<tr>
<td>FULL WORD OCTAL</td>
<td>PTW L, T, PP</td>
</tr>
<tr>
<td>ADDRESS TO OCTAL</td>
<td>PTW L, T, 1000+PP</td>
</tr>
<tr>
<td>DECREMENT TO OCTAL</td>
<td>PTW L, T, 2000+PP</td>
</tr>
<tr>
<td>REPEAT LINE FORMAT</td>
<td>PTW ΔL, 0, 3000+K</td>
</tr>
<tr>
<td>TTY BINARY CODE</td>
<td>PTW L, T, 4000+N</td>
</tr>
<tr>
<td>SET BINARY POINT</td>
<td>PZE BP, 0, I</td>
</tr>
<tr>
<td>NO-OPERATION</td>
<td>PZE 0, 0, 0</td>
</tr>
<tr>
<td>REPEAT FIELD FORMAT</td>
<td>PZE ΔL, 0, 1000N+ΔP</td>
</tr>
<tr>
<td>INDIRECT ADDRESS</td>
<td>PON L, T, E</td>
</tr>
<tr>
<td>END</td>
<td>FVE 0, 0, 0</td>
</tr>
</tbody>
</table>

In these pseudo-instructions, PP represents the rightmost print position which will be used. PP may not exceed 132 for the off-line printer, 128 for the SC 4020, 120 for the SC 3070, and 72 for the off-line punch and teletypewriter. Characters before print position 2 will be lost, except for a teletypewriter line. Characters after limiting print position will result in an error indication. If fields should overlap, the later word will take precedence.

A tag (T) can be used for address modification in any pseudo-instruction except those with a prefix of FVE or PZE. A tag entry in the FVE code is interpreted as a flag only. The tag may be any number of the set 0, 1, 2, 3, 5, 6, 7. Index register 4 may not be used for address modification.

c. Parameter specifications:
Floating to Fixed    SVN L, T, 1000D+PP
The floating binary word in L, T will be rounded to D decimal places and converted to fixed decimal. If D is zero, there will be no decimal point. If the absolute value of the number is greater than \(2^{35} - 1\), it will be printed in floating decimal as described below. D must be less than or equal to 8. An error indication occurs when D > 8 unless \(n > 2^{35} - 1\) (floating point) or n = integer.
Floating to Floating SIX L, T, 1000D+PP

The floating binary word at L, T will be rounded to D decimal digits and converted to floating decimal. If D is less than or equal to 8, the number is taken as a single-precision number. If D is greater than 8 and less than or equal to 16, the number is considered to be in double-precision, floating-point form: the high-order part in L, T and the low order part in L+1, T. Any number less than 10^{-32} in absolute value will print as a single-precision zero. D must not be zero.

Fixed to Fixed FOR L, T, 1000D+PP

The fixed-point word used in L, T will be rounded to D decimal places and converted to fixed decimal. The location of the binary point is set by the last prior pseudo-instruction "SET BINARY POINT" (see below). If D is zero, there will be no decimal point. D must not exceed 8.

BCD to Hollerith PTH L, T, 1000N+PP

The N BCD words starting in L, T will be set for printing such that the last character will be in print position PP. N must be in the range permissible for the output device to be used.

Full Word Logical Octal PTW L, T, PP

The word in L, T will be converted to 12 logical octal digits.

Address in Octal PTW L, T, 1000+PP

The address portion of the word in L, T will be converted to octal.

Decrement in Octal PTW L, T, 2000+PP

The decrement portion of the word in L, T will be converted to octal.

Repeat Line Format PTW ΔL, 0, 3000+K

The string of data pseudo-instructions immediately following this instruction, defining a line image and terminating with one or more FVE code instructions, will produce K lines of output. After each line is formed the address fields of each data pseudo-instruction will be effectively incremented by ΔL for the next memory references.

Teletype Binary Code PTW L, T, 4000+N

The N six-bit characters starting in L, T will be placed on disk without conversion. This instruction cannot be indirectly addressed. Neither repeat command can be used in conjunction with this instruction. N must not exceed 999. No FVE code is used with this instruction since no line image is set up.

Set Binary Point PZE BP, 0, 1

The binary point for the following "FIXED TO FIXED" pseudo-instructions will be set at BP. Entry to the subroutine automatically performs PZE 35,, 1.

No-Operation PZE 0, 0, 0

This instruction is provided to facilitate modifying the calling sequence.
Repeat Field Format  PZE AL, 0, 1000N+ΔP

If the immediately preceding effective pseudo-instruction is "SET BINARY POINT" or either "REPEAT" instruction, error action is taken. Otherwise, the immediately preceding effective pseudo-instruction will be repeated with L + n (ΔL) and PP + n (ΔP) for n = 1, 2, ..., N. In the case of indirect addressing, the word repeated is the effective pseudo-instruction. FVE codes will not be repeated. N must not be zero.

Indirect Addressing  PON L, T, E

The word at L, T will be used at this point in the calling sequence as a pseudo-instruction. If E is not equal to zero, it will be used as the decrement in place of the decrement in L, T.

End  FVE 0, 0, 0

This pseudo-instruction signals the end of the calling sequence. Control is returned to the user program at the next instruction.

d. Coding information:

1. The user area printer (SC 3070) output is formatted as follows: a 15 line skip; a page header containing the 12 BCD characters of program identification beginning at PROGID, the 4 BCD characters of identification, date and page number; 2 blank lines; 50 lines, including spacing, specified by the user program. Each line image will be formatted, 5 BCD characters per word, with all necessary control indicators for the 7288 output subchannel.

2. Line images for peripheral output devices will be formed in standard format for off-line processing.

3. The BCD name specified in the calling sequence identifies a print output file which is to be placed on the disk. The user area is notified of the availability of the print output file when the file is closed. The size of the file should be arranged so that the print output is made available to the user area at frequent intervals, but not so frequent that the user area would have to make a request through the message composer for every few lines of output; this should be controlled by the frequency of closing the print output file. When the BCD name changes, the previous output file is closed and made available at the user area. When the user program has operated its minimum time and OFFSYS initiates a program interchange, all print output files are closed.

When ENDSYS or FINSYS are called, the print output files are also closed. If it is desired to close a print output file at a specific time other than those above, it may be accomplished by giving the following instruction:

```
CALL   ENDOUT
```

```
PZE   N
```
where,

\[
\begin{align*}
N = 1 & \quad \text{means to close print files} \\
= 2 & \quad \text{means to close plot files} \\
= 3 & \quad \text{means to close print and plot files} \\
= 4 & \quad \text{means to close teletype files} \\
= 5 & \quad \text{means to close teletype and print files} \\
= 6 & \quad \text{means to close teletype and plot files} \\
= 7 & \quad \text{means to close teletype, print, and plot files}
\end{align*}
\]

4. Before the subroutine FLUSH (described later) has been called, the completion flag of the last PROUT request must be checked to ensure that the file remains open until the output has been completed.

5. A page eject occurs and a new heading is printed (unless PROGID = 0) when any one of the following occurs:
   (a) Change of data name.
   (b) Change of ID heading (page numbers are not reset).
   (c) Calling ENDOUT.

6. When an MZE prefix, denoting off-line output only, is used, FVE codes specifying 3070 output cannot be contained in the calling sequence.

7. All off-line output is to be labeled. The label will consist of the 4-character user program name.

8. In MODE IV all PROUT 3070 output will be printed on the on-line printer under sense switch control:

   SSW No. 6 UP = no 3070 output
   DOWN = 3070 output printed on the on-line printer

9. User areas for which PROUT output is intended are not specified in the PROUT calling sequence. When data has been placed on disk, a message is sent to the appropriate used area(s) that this specific type of data is available. The user area can request the data when it is desirable. User areas receive only those data availability messages they designate at 7094 initialization.

10. All peripheral output processed by PROUT will be placed on the same output tape (SYSOU1). The BCD data name normally designated in the PROUT calling sequence is ignored.

11. FGDOUT option: Three types of floating to floating output are available in PROUT depending upon the contents of location FGDOUT:
   (a) \(c(\text{FGDOUT}) = 0\) indicates no leading +, and no + in the exponent field.
       \(= 1\) indicates leading +, and + in the exponent field.
       \(> 1\) indicates leading +, and E+ in the exponent field.
   (b) \(c(\text{FGDOUT})\) is initially >1.
e. Suggestions for output efficiency:

1. Use buffering techniques wherever possible.
2. Organize and group output so that the number of output requests is minimized.
3. Organize output formats to print full lines or as full as possible under format requirements.
4. Arrange user program to continue computations during output processing if it becomes necessary to wait for a free output buffer within OUTUS.
5. Care should be taken not to modify a calling sequence or loop through a calling sequence until the flag word has been tested to determine the status of the previous request.

f. Operational description:

The type of request is determined and processed in one of the following ways:

1. **User Area Printer Request**
   
The request is queued, and control is given to an output coordinating routine (OUTUS) which coordinates printing, plotting, and teletype requests, and their usage of output buffers, the calling of conversion routines, and making the necessary disk write requests. When OUTUS obtains a print (or plot or teletype) request from the queue, if an output buffer is available, OUTUS calls the proper conversion routine, and the converted output is placed in the output buffer. When the buffer is filled, or the data completed, a disk write request is then made by OUTUS to the disk control program (DCP), and control is returned to the user program. When the data has been written on disk, an interrupt occurs and control is routed to OUTUS to continue output of the request or initiate a new request. Then control is returned to the point of interruption. In this way, the print output (or plot output or teletype output) to be converted and placed on disk can be processed to make optimum usage of buffers and efficient requests of disk write operations. During the operation, if a buffer is filled or the queue is emptied or OUTUS has processed output requests as far as possible, control is returned to the user program.

2. **IBM 1401 Off-Line Printer or Punch Request**
   
The proper conversion routine is initiated and output is written on the 1401 output tape. The tape operation will be asynchronous under the supervision of IOEX. When the request has been initiated, control is returned to the user program.

3. **SC 4020 Off-Line Microfilm Recorder Request**
   
The proper conversion routine is initiated and output is written on the 4020 output tape. The tape operation will be asynchronous under the supervision of IOEX. When the request has been initiated, control is returned to the user program. In each option listed above, the results of the output request can be found in the flag word specified by the calling sequence.
g. Output:

1. Output Data:
   (a) 1401 - Print:
       Print lines may contain up to 132 characters.
   (b) 1401 - Punch:
       Card images may contain up to 72 characters.
   (c) SC 4020:
       Line images may contain up to 128 characters.
   (d) SC 3070:
       An integral number of lines of up to 120 characters each will be packed in each 128 word disk output buffer. The printed output is then available to the actual printer in the user area upon request.

2. Flags:
   (a) Upon entry, PROUT sets the user program flag word to zero. The user program can determine if the request has been completed by testing the flag word for zero or non-zero.
   (b) Upon completion of the request, the user program flag word is set with the results of the output operation as follows:
      (1) Sign Bit = 0: No unusual conditions occurred.
          = 1: At least one unusual condition occurred. The address will indicate the condition.
          Bit 32 = 1: A pseudo-instruction specifies too many (>132) characters for one line of output.
          Bit 31 = 1: There is an error in the repeat data pseudo-instruction.
          Bit 30 = 1: The binary point exceeds bit position 35.
      (2) Decrement = 1: Processing has been successfully completed.
      (3) When the address contains a flag bit; the decrement will contain the complement of the address of the pseudo-instruction in question.

3. The Entry Point FLUSH:
   PROUT, being a buffered output routine, must have some means of emptying its buffer when desired, even though it may be only partially filled. For this purpose an entry to PROUT has been provided whose calling sequence is simply
   CALL FLUSH
   return
   If the buffer in use by PROUT is empty, return is immediate to the next sequential instruction. If there are any words waiting to be written, the buffer is emptied. At the completion of the I/O, return is made to the location after the call.

CODING INFORMATION

Length of subroutine is 1484(10) or 2714(8) words
IDENTIFICATION

READN/READ1/READC/SPAM
Peter S. Fisher, JPL
IBM 7094, Fap
December 2, 1964

PURPOSE

To allow appropriate data communication between the spacecraft ephemeris tape and SPASM's HBANK. To help SPASM find discontinuity points in the ephemeris.

RESTRICTIONS

a. S/C ephemeris data is sprayed into cells with certain names expected to be entry points elsewhere in core.
b. TAPIO and PROUT are used for input-output.

METHOD

a. SPAM sets up an independent variable trigger using the two cells following the calling sequence in order to find discontinuity points in the S/C ephemeris.
b. READ1 finds the correct ID record corresponding to the (RUNID) given and reads said record. This record contains the injection conditions, constants, and option flags used in the corresponding SPACE run.
c. READN reads the data record of the tape. This record has two formats depending on whether or not the variational equations were integrated in SPACE. This condition is relayed to READN through the ID record.
d. READC repositions the S/C ephemeris tape after the processor has finished using it. It is important that this is done so that there is no possibility of SPACE writing over the unused portion.

USE

Calling sequences:
CALL READI
return
CALL READN
return
CALL READC
return

CODING INFORMATION

Length of subroutine is 224 (10) or 340 (8) words.
IDENTIFICATION

ROTEQ/DELTJD
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To rotate mean Earth equator and equinox of-date coordinates to mean Earth equator and equinox of 1950.0 and vice versa.

RESTRICTIONS

a. The matrix is stored in the COMMON locations AA through AA+8.
b. The subroutine uses COMMON through COMMON+2.
c. The option of recomputing the matrix only if time has changed by at least 1/64 day is controlled by the contents of the external quantity MNAET. Nominally MNAET is zero which turns off the 1/64 day test which forces a recomputation of the matrix.
d. An entry has been provided for access to DELTJD, the difference between the J.D. of 1950.0 and the J.D. of 0 hr January 1, 1950, in days.

METHOD

The general precession of the Earth's equator and the consequent retrograde motion of the equinox on the ecliptic may be represented by the rotation matrix:

\[
\begin{pmatrix}
X' \\
Y' \\
Z'
\end{pmatrix} =
\begin{pmatrix}
a_{11} & a_{12} & a_{13} \\
a_{21} & a_{22} & a_{23} \\
a_{31} & a_{32} & a_{33}
\end{pmatrix}
\begin{pmatrix}
X \\
Y \\
Z
\end{pmatrix}
\]

where \(X, Y,\) and \(Z\) are expressed in the mean equator and equinox of 1950.0 and \(X', Y',\) \(Z'\) are the coordinates in the mean equator and equinox of date. The geometry of the precession has been represented by the three small parameters \(\xi_0, z,\) and \(\theta\) in the following sketch.
where $\tau_{1950.0}$ is the mean equinox of 1950.0; $\epsilon_{1950.0}$ is the mean obliquity of 1950.0; $\tau$ is the mean equinox of date; $\epsilon$ is the mean obliquity of date. Measured in the mean equator of 1950.0 from the mean equinox of 1950.0, 90 deg - $\xi_0$ is the right ascension of the ascending node of the mean equator of date on the mean equator of 1950.0. 90 deg + $z$ is the right ascension of the node measured in the mean equator of date from the mean equinox of date. $\theta$ is the inclination of the mean equator of date to the mean equator of 1950.0.

In terms of $\xi_0$, $z$, and $\theta$, $(a_{ij})$ is given by

$$
\begin{align*}
  a_{11} &= -\sin \xi_0 \sin z + \cos \xi_0 \cos z \cos \theta \\
  a_{12} &= -\cos \xi_0 \sin z - \sin \xi_0 \cos z \cos \theta \\
  a_{13} &= -\cos z \sin \theta \\
  a_{21} &= \sin \xi_0 \cos z + \cos \xi_0 \sin z \cos \theta \\
  a_{22} &= \cos \xi_0 \cos z - \sin \xi_0 \sin z \cos \theta \\
  a_{23} &= -\sin z \sin \theta \\
  a_{31} &= \cos \xi_0 \sin \theta \\
  a_{32} &= -\sin \xi_0 \sin \theta \\
  a_{33} &= \cos \theta
\end{align*}
$$

$$
\begin{align*}
  \xi_0 &= 2304.'997T + 0.'302T^2 + 0.'0179T^3 \\
  z &= 2304.'997T + 1.'093T^2 + 0.'0192T^3 \\
  \theta &= 2004.'298T - 0.'426T^2 - 0.'0416T^3
\end{align*}
$$

with $T$ the number of Julian centuries of 36,525 days past the epoch 1950.0.

The actual computational form of $(a_{ij})$ is obtained by expanding the $a_{ij}$ in power series in $\xi_0$, $z$, $\theta$ and replacing the arguments by the above time series. The results are

$$
\begin{align*}
  a_{11} &= 1 - 0.00029697T^2 - 0.00000013T^3 \\
  a_{12} &= a_{21} = -0.02234988T - 0.00000676T^2 + 0.00000221T^3 \\
  a_{13} &= a_{31} = -0.00971711T + 0.00000207T^2 + 0.00000096T^3 \\
  a_{22} &= 1 - 0.00024976T^2 - 0.00000015T^3 \\
  a_{23} &= a_{32} = -0.00010859T^2 - 0.00000003T^3 \\
  a_{33} &= 1 - 0.00004721T^2 + 0.0000002T^3
\end{align*}
$$
USE

Calling sequence:

Enter with days past 0 hr January 1, 1950 E.T. in the AC-MQ.

CALL ROTEQ
PFX X, Y
return

where

X-3, X-2, X-1 contain the input vector.
Y-3, Y-2, Y-1 contain the output vector.
PFX = PZE assumes mean 1950.0 input and rotates to mean of-date.
PFX = MZE assumes mean of-date input and rotates to mean 1950.0.
X = Y is permitted.

CODING INFORMATION

Length of subroutine is 107(10) or 153(8) words.

REFERENCE

IDENTIFICATION

RVIN/RVOUT

JPL Staff

IBM 7094 Fap

December 2, 1964

PURPOSE

a. RVIN transforms a set of input spherical coordinates R, \( \Phi \), \( \theta \), \( V \), \( \Gamma \), \( \Sigma \), to a set of cartesian coordinates \( X \), \( Y \), \( Z \), \( \dot{X} \), \( \dot{Y} \), \( \dot{Z} \).

b. RVOUT transforms a set of input cartesian coordinates \( X \), \( Y \), \( Z \), \( \dot{X} \), \( \dot{Y} \), \( \dot{Z} \), to a set of spherical coordinates \( R \), \( \Phi \), \( \theta \), \( V \), \( \Gamma \), \( \Sigma \).

RESTRICTIONS

a. Subroutines called are \( \text{SIN} \), \( \text{COS} \), \( \text{MATRIX} \), \( \text{PROD} \), \( \text{ARTAN} \), \( \text{UNIT} \), and \( \text{ARSIN} \).

b. All angles are assumed to be in degrees.

METHOD

a. RVIN computes the cartesian components of the vector \( \vec{R} \) by

\[
\begin{pmatrix}
X \\
Y \\
Z
\end{pmatrix} =
\begin{pmatrix}
R \cos \Phi \cos \theta \\
R \cos \Phi \sin \theta \\
R \sin \Phi
\end{pmatrix}
\]

where \( \theta \) is the longitude measured clockwise in the \( X \) - \( Y \) plane from the \( X \)-axis and \( \Phi \) is the latitude measured positive above the \( X \) - \( Y \) plane. The quantities \( \Gamma \), the path angle, and \( \Sigma \), the azimuth angle determine the orientation of the velocity vector with respect to the plane of the local horizontal, that is, perpendicular to the \( \vec{R} \) vector. \( \vec{V} \) is expressed in the local horizontal system as

\[
\begin{pmatrix}
\dot{X}' \\
\dot{Y}' \\
\dot{Z}'
\end{pmatrix} =
\begin{pmatrix}
V \sin \Gamma \\
V \cos \Gamma \sin \Sigma \\
V \cos \Gamma \cos \Sigma
\end{pmatrix}
\]
and finally the results in the original system are

\[
\begin{pmatrix}
X \\
Y \\
Z
\end{pmatrix}
= \begin{pmatrix}
\cos \theta & -\sin \theta & 0 \\
\sin \theta & \cos \theta & 0 \\
0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
\cos \phi & 0 & -\sin \phi \\
0 & 1 & 0 \\
\sin \phi & 0 & \cos \phi
\end{pmatrix}
\begin{pmatrix}
\dot{X}' \\
\dot{Y}' \\
\dot{Z}'
\end{pmatrix}
\]

b. RVOUT performs the computations which follow:

\[
R = \sqrt{x^2 + y^2 + z^2}
\]

\[
\phi = \arcsin \frac{z}{R}, \quad -90 \text{ deg} \leq \phi \leq 90 \text{ deg}
\]

\[
\theta = \arctan \frac{y}{x}, \quad 0 \text{ deg} \leq \theta < 360 \text{ deg}
\]

which gives \( R \), the magnitude of \( \vec{R} \), the latitude \( \phi \) and longitude \( \theta \). The cartesian velocity components \((X, Y, Z)\) are rotated to the local horizontal system where the components are called \((\dot{X}, \dot{Y}, \dot{Z})\) by

\[
\begin{pmatrix}
\dot{X}' \\
\dot{Y}' \\
\dot{Z}'
\end{pmatrix}
= \begin{pmatrix}
\cos \phi & 0 & \sin \phi \\
0 & 1 & 0 \\
-\sin \phi & 0 & \cos \phi
\end{pmatrix}
\begin{pmatrix}
\dot{X} \\
\dot{Y} \\
\dot{Z}
\end{pmatrix}
\]

the spherical set may then be obtained as follows:

\[
V = \sqrt{\dot{x}'^2 + \dot{y}'^2 + \dot{z}'^2}
\]

\[
\Gamma = \arcsin \frac{\dot{Y}'}{V}, \quad -90 \text{ deg} \leq \Gamma \leq 90 \text{ deg}
\]

\[
\Sigma = \arctan \frac{\dot{Y}'}{\dot{Z}'}, \quad 0 \text{ deg} \leq \Sigma < 360 \text{ deg}
\]
USE

Calling sequences:

a. Spherical to cartesian:

\[
\text{CALL RVIN}
\]
\[
PZE \ldots A
\]
\[
PZE \ldots B
\]
\[
PZE \ldots C
\]

where A, \ldots, A + 5 contain the input R, \phi, \theta, \psi, \gamma; the output variables X, Y, Z are placed in B, B + 1, B + 2 and \dot{X}, \dot{Y}, \dot{Z} are placed in C, C + 1, C + 2.

b. Cartesian to spherical:

\[
\text{CALL RVOUT}
\]
\[
PZE 1, A
\]
\[
PZE 1, B
\]
\[
PZE 1, C
\]

where A, A + 1, A + 2 contain the input X, Y, Z and B, B + 1, B + 2 contain the input \dot{X}, \dot{Y}, \dot{Z}. The output variables R, \phi, \theta, \psi, \gamma, \delta are placed in C, \ldots, C + 5.

CODING INFORMATION

Length of subroutine is 200(10) or 310(8) words.

REFERENCE

IDENTIFICATION

SAVEIT
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To write labeled binary tapes with information for reading contained in the label. These tapes will be used by the subroutine READIT.

RESTRICTIONS

Subroutines WRITEB, ENDFIL, BSREC are called.

METHOD

This subroutine is designed to be a companion to the subroutine READIT. It is designed to write "SAVE" tapes which normally contain trajectory information only at discrete time points along the S/C path. These tapes will be used for input to plotting programs or other programs requiring trajectory information only at discrete time points. It is felt that by correct usage of this program, other needs for retaining the information on magnetic tapes can be serviced. TAPIO is used by this subroutine to obtain asynchronous operation. The burden of supplying a buffer area is left to the user. The tape written is labeled with BCD information supplied by the user via tables. Data record lengths are always equal within one file. The length of the data records is defined by initializing information. A binary record is the first record made for each file of information and is of a fixed length. Following this is a BCD record containing labeling information for the file and for each of the data words in the data records. These two records are written on the tape upon successful execution of the initialization calling sequence. Data records are written on the tape by successful execution of the execution calling sequence.

USE

Initialization calling sequence:

CALL SAVEIT
PZE FLC
PZE L(F)
PZE L(HEAD)
PZE L(N2)
PZE L(MAIN)
PZE L(N3)
PZE L(NAME)
FLC is the logical tape number or unit control block communication cell.

F is the file number (fixed point) for identification.

HEAD is the name of a BCD table of labeling information for the file.

N2 is the number of words in the table HEAD (fixed point).

MAIN is the name of a BCD table containing one word labels in the main data table in each data record.

N3 is the number of words in the table MAIN and therefore the number of words in each main table in the data records (fixed point).

NAME is the name of a BCD table containing the names of each subtable within a data record. (Each data record contains the same number of subtables and all corresponding subtables in each data record have the same name.) The names are placed in the table name in the same order that their subtable appears in the data record. Each subtable name entry consists of 4 BCD words.

N4 is the number of subtables found in each data record. The length of the table name is therefore (N4x4).

TABLE is a BCD table containing the labels of the entries in a subtable, one word for each data word in a subtable (it is assumed that the names of corresponding data words in two or more subtables are the same).

N5 is the number of words in the table TABLE and therefore the number of words in each subtable (fixed point).

TABLE1 is the name of a binary table containing N3 words of main table data words (This table is filled some time prior to the execution of each execution entry).

TABLE2 is the name of a binary table containing N4xN5 words of subtable data words, the first N5 words representing the first subtable, the next N5 words, the second subtable, etc. (This table is filled some time prior to the execution of each execution entry.)

1. The length of the BCD record which is the second record written on the tape is N1 words where

146
2. The first record written is always 8 words long and contains in order:
   \[ N_1 = N_2 + N_3 + (N_4 \cdot 4) + N_5 + 1 \]

   \[ F \]
   \[ N_1 \]
   \[ N_2 \]
   \[ N_3 \]
   \[ N_4 \]
   \[ N_5 \]

   Format type 0 = FAP
   Check sum

   3. The third record written and all succeeding records written in the file are
      \[ N_3 + (N_4 \cdot N_5) + 1. \]

   Upon return an integer will be placed in the accumulator, as follows:
   \[ K \]
   \[ 1 = \text{normal return.} \]
   \[ 2 = \text{physical end of tape has been encountered while attempting to write.} \]

   The subroutine assumes all tables in the user's FAP program have been defined as blocks
   starting with symbols (BSS).

   Execution calling sequence:
   \[ \text{CALL SAVEIT} \]
   \[ \text{TSX L(ERROR)} \]
   \[ \text{RETURN} \]

   where \text{ERROR} is the name of an error return subroutine supplied by the user.

   End-of-file calling sequence:
   \[ \text{CALL FILE} \]
   \[ \text{TSX L(ERROR)} \]
   \[ \text{RETURN} \]

   Return indicators are the same as those for the execution entry.
   \[ 1 = \text{normal return. All buffers will have been dumped to tape and an end of file placed} \]
   \[ \text{after the last recorded data record. An eight word trailer record will have been} \]
   \[ \text{written identical to the binary record initially recorded on tape with one exception:} \]
   \[ \text{F will have the value} -3777777777. \] A subsequent entry into \text{SAVEIT} initialization
   \[ \text{routine for another file will replace the dummy record with the binary} \]
   \[ \text{identification record of the next. When searching for a specific file, \text{READIT} will} \]
   \[ \text{distinguish the logical files by the tape marks and the end of recorded data by the} \]
   \[ \text{dummy record placed on tape by the last Call File entry.} \]
This routine assumes that each file to be written will always contain the complete tabular structure; i.e., HEADING, MAIN items and SUBTABLE items.

CODING INFORMATION

Length of subroutine is 110 (10) or 156 (8) words.
IDENTIFICATION

SEITE/CASE/EJECT/EJECT1/LINES/PAGBCD

JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To eject the page, set up and print the first three lines (heading) of each page.

RESTRICTIONS

a. Subroutine PROUT is called. DATCEL is referenced indirectly and contains the BCD date of loading of the program.
b. Entries are provided for locations CASE, EJECT, EJECT1, LINES and PAGBCD, where
   C(CASE) = case number
   C(EJECT) = page count
   C(EJECT1) = line count
   C(LINES) = 63: number of lines to be put on a page
   C(PAGBCD through PAGBCD+39) = page heading.

METHOD

a. The page number, N, is incremented by 1.
b. The case number, C, is computed.
c. A page eject is given.
d. "Case C IBSYS-JPTRAJ-SFPRO C(DATCEL) N" is printed.
e. The 40 BCD words at PAGBCD are printed on two lines.
f. The line count is set to 3.

USE

Calling sequence:

CALL SEITE
return

CODING INFORMATION

Length of subroutine is 129(10) or 201(8) words.
IDENTIFICATION

SPASM
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To sum sixth-order backward differences to obtain the values of the n-dependent variable of the differential equations and their derivatives, and then to interpolate for some epoch in the range of the difference array.

REstrictions

a. An external buffer, HBank, is required.

b. The error exit is taken whenever an independent variable trigger epoch is equal to a time earlier than the left end of the step being taken.

c. Entries HC, NI, TGLO, Y, YDOT, Y(2), Y0, Y0(Z), BABBTB, DELX, J, HD, ND, SET, and JJ are provided for communication with other subroutines.

METHOD

This subroutine is a modification of the subroutine MARK (see Reference). Nominally the order of differences is 6, \( t_\beta \) is the epoch at the left end of the interval and \( t_{\beta+1} \) is the epoch at the right end of the interval. \( \nabla^0, \ n = 1, \ldots, 6 \) designates the \( n \)th backward differences. \( \nabla^0 \) designates the \( n \) derivatives at \( t_{\beta+1} \). The following sketch relates these parameters:

```
   \nabla^6     \nabla^5     \nabla^4     \nabla^3     \nabla^2     \nabla^1     \nabla^0

H   H   H   H   H   H   H
1   2   3   4   5   6   7

^t_\beta

^t_{\beta+1}
```
SPASM sums the equally spaced backward differences to obtain the values of the n-dependent variables of the differential equations from \( t_\beta \) to \( t_{\beta+1} \) at each stepsize interval, \( H \). By differentiation, an interpolation formula may be derived for obtaining derivatives as well. Thus, given the \( \nabla^0, \cdots, \nabla^6 \) and the values of the n-dependent variables of the differential equations at \( t_{\beta+1} \), both the dependent variables and their derivatives may be obtained by interpolation for any epoch between \( t_\beta \) and \( t_{\beta+1} \).

USE

Same as for MARK (see Reference, page 6.31).

CODING INFORMATION

Length of subroutine is 1366(10) or 2526(8) words.

REFERENCE

White, R. J. et al., SPACE--Single Precision Cowell Trajectory Program, Technical Memorandum 33-198, Jet Propulsion Laboratory, Pasadena, California, January 15, 1965.
IDENTIFICATION

SPRAY
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To decode the input quantity GROP into twelve flags and to store the flags into GROPS to GROPS +11 before and after transformation by EFFECT.

RESTRICTIONS

a. It is assumed that parameter GROP contains 12 octal group output option flags, each octal digit being a flag.
b. GROPS to GROPS +11, in COMMON, are used. GROP is referenced indirectly.

METHOD

Each of the twelve octal digits in GROP is placed in bits 33 - 35 in an otherwise zero accumulator. These twelve words are stored sequentially into GROPS to GROPS +11.

USE

Calling sequence:

CALL SPRAY
return

CODING INFORMATION

Length of subroutine is 10(10) or 12(8) words.
IDENTIFICATION

SQRT
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To compute $\sqrt{x}$ for a normalized floating point, single precision $x$.

RESTRICTIONS

a. An error return will occur if the argument is negative, in which case the accumulator will contain $\sqrt{|x|}$.
b. Uses COMMON to COMMON +3.

METHOD

The Newton Raphson method is used to compute the square root of $x$ where $0 \leq x \leq 2^{128}$.

Accuracy: The result is accurate to 8 decimal digits.

USE

Enter with the argument in the accumulator. Exit with the result in the accumulator.

Calling sequence:

<table>
<thead>
<tr>
<th>CALL</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLA</td>
<td></td>
</tr>
<tr>
<td>CALL</td>
<td>SQRT</td>
</tr>
</tbody>
</table>

error return
normal return

CODING INFORMATION

Length of subroutine is 41(10) or 51(8) words.
IDENTIFICATION

TIME1/TIME2/TIME3/LAUNCH
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To compute and print the calendar date, the Julian date and the trajectory time, given
the double precision seconds past 0h January 1, 1950.

RESTRICTIONS

a. DAYS, FIXT, ADD, FIX, FLOAT, GRUPPE and PROUT are called.
b. OPRFLG, EQUNX1, TARBCD and INJEQX are used.
c. A double precision number is assumed to be two floating point words.
d. The entry LAUNCH is provided to allow access to the launch epoch if it is input.

METHOD

a. Subroutine DAYS is used to obtain the integral days and residual seconds past 0h
January 1, 1950. The Julian date (JD) is then computed as a one word floating
point integer and a one word floating point fraction using the following relations:
   integral JD = integral days from 0h January 1, 1950, to date
               +2433282, the Julian date of 12h January 0, 1950 +I
   fractional JD = residual days -0.5 + (1-I)
where
   I = 0 if residual days < 0.5
   = 1 if residual days ≥ 0.5
b. The calendar date is computed by calling subroutine FIXT.
c. The trajectory time is computed using the following relation:
   trajectory time = current epoch minus injection epoch.
d. If LAUNCH is non-zero, then an additional line is printed in the TIME1 entry, giving
   TFL the trajectory time from launch using the following relation:
   TFL = current epoch minus launch epoch.

USE

Enter with the time in double precision seconds past 0h January 1, 1950,
in the AC and MQ.
The three entries provide for three output formats as follows:
TIME1: X DAYS X HRS. X MIN. X.XXX SEC., C(EQUNX1), Octal sec past 50,
        JD, calendar date
TIME2: INJECTION CONDITIONS, C(INJEQX), C(TARBCD),
        Octal sec past 50, JD, calendar date

154
TIME3: EPOCH OF PERICENTER PASSAGE, Octal sec past 50,
        JD, calendar date
Calling sequence:
CLA     L(SECONDS A)
LDQ     L(SECONDS B)
CALL    TIME1 (or TIME2 or TIME3)
return

CODING INFORMATION

Length of subroutine is 235(10) or 353(8) words.
IDENTIFICATION

TRAJ
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To provide the control and closed subroutines needed to drive the subroutine SPASM.

RESTRICTIONS

Since TRAJ is the driver subroutine for SFPFR, numerous entries and transfer vectors are used for communication and control.

METHOD

TRAJ performs the following tasks:

a. Initializes triggers on the basis of input parameters.

b. Converts BCD input to integers via subroutine BCDNO.

c. Converts sexagesimal input to seconds past 0 hr January 1, 1950 via subroutines FLOT or FLOTT.

d. Obtains injection conditions, physical constants and other data defining the trajectory from the identification record of the spacecraft ephemeris tape.

e. Initializes the n-body ephemerides by calling EPHSET and INTR1.

f. Sets control flags and branches on the basis of input parameters.

g. Obtains the proper set of phase parameters and initializes triggers on the basis of those parameters.

h. Calls SPASM.

i. Supplies SPASM with derivative, end-of-step, step-size control and trigger subroutines as required.

j. Terminates a phase (and repeats starting at g above) or terminates the run and returns to JPTRAJ via JEXIT or ABORT.

USE

Calling sequence:

    CALL   TRAJ

    return

CODING INFORMATION

Length of subroutine is 1943(10) or 3627(8) words.
IDENTIFICATION

FLOTT
JPL Staff
IBM 7094 Fap
December 2, 1964

PURPOSE

To convert a sexagesimal date or an interval past the initial epoch, to seconds past 0 hr January 1, 1950.

RESTRICTIONS

a. FLOTT is a subset of the driver, TRAJ.
b. Subroutine FLOT is called to make the time conversion.
c. T(0) in COMMON is used.

METHOD

Subroutine FLOT is called to get the time in seconds past 0 hr January 1, 1950. However, if this number is less than $1 \times 10^8$ then the assumption is made that the input time was a time interval past the initial epoch. In this case the input interval, converted to seconds, is added to T(0), the initial epoch.

USE

Calling sequence:

```plaintext
CALL FLOTT
PPP A, N, B
```

where

- A, N and A+1, N contain the input time
- B, PPP and B+1, PPP contain the output seconds past 0 hr January 1, 1950

and PPP is the FAP code for 0, 1, ..., 7 designating the index register to use to locate the output storage cell.

CODING INFORMATION

Length of subroutine (includes FLOTT as a subset) is 1943(10) or 3627(8) words.
IDENTIFICATION

WOLF/TIM/MACH
Peter S. Fisher, JPL
IBM 7094 Fap
December 2, 1964

PURPOSE

To print an explanatory comment at injection and at each phase change.

RESTRICTIONS

a. Subroutines PRSET, TIME1, PROUT, GRUPPE and TIME are called.
b. OPRFLG is set non-zero to signify that if on-line print has been requested then the line generated by this subroutine is also to be printed on-line. KERN1 is referenced to obtain the BCD name of the central body for integration.
c. Entries TIM and MACH have been provided to allow access to the time of day and computer I.D. character.
d. It is assumed that the date has been provided by the system at SYSDAT, octal location 101.

METHOD

A test is made to see if the current epoch, T, is injection epoch. If so, then subroutine TIME is called to obtain the time of day and computer I.D. character. Then the following comments are printed on one line:

DATE OF RUN MMDDYYC TTTT RR S BBBBBB IS THE CENTRAL BODY FOR INTEGRATION COWELL EQUATIONS OF MOTION

Where MM is the month, DD is the day, YY is the year, C is the computer I.D. character, TTT is the hour of day, RR is minutes, and S is the tens of seconds. BBBBBBB is the name of the body currently used as the central body for integration.

If the current epoch is not injection epoch then TIME1 is called to print the time line and then the following comments are printed on one line:

CHANGE OF PHASE OCCURS AT THIS POINT BBBBBB IS THE CENTRAL BODY FOR INTEGRATION COWELL EQUATIONS OF MOTION

Where BBBBBBBBB is the name of the body currently used as the central body for integration.

USE

Calling sequence: CALL WOLF

CODING INFORMATION

Length of subroutine is 77(10) or 115(8) words.
VII. CHECK CASES

Four check cases have been used for several years by JPL trajectory engineers to confirm that the version of the trajectory program being released for use is computationally correct. In addition, other trajectories are run which check the options not used by the four standard cases.
A. Check case 1 is an Earth-Moon trajectory with a fine print. The spacecraft injects near the Earth on January 13, 1963 and impacts the Moon after a 66.08-hour flight time.
CASE 1

18337-JP84-4 SPCC 041795

GATE CARTESIAN
GEOCENTRIC S/C EPHEMERIS WRITTEN OT626BG 041765 RUNID=ITRAJOLI
OUTBLF PR_BISIPN EPHEMERIS TAPE - EPHE I
EARTH_CCN FINE PRINT CHECK I
CASE | INJECTION _C_DITIC_S I450.0 0ON
BTO -0.10_OJe_ Ot RAP
SMA COL 10/57921 OUT .350_0000 g2 .Dr .31219413 00 SHA -.65653256 04 GEO -.6341445_ 0I
EGM -.667099g_-I_A
SMA INC ._l?_h¢Io 02 tAN .7_1I_8_9 oz
INC . -.J61U_lb4 0(' _Y .T_72.L36 00
VH .92250_68-01 C_ -.lO1231bl
ORM -.30270318 O_ 0 hRS. 0

GEOCENTRIC RS .0000 SEC.

GEOCENTRIC EPOCH OF PERMISSION PASSAGE
JAN. 13,1963 18 42 2.971
SMA 1847979 G 0 0 0000 SEC.
TA 13024413 40.00000000 0.0 0.0 0.0 0.0 0.0 0.0

GEOCENTRIC EPHEMERIS

GEOCENTRIC EQUATORIAL COORDINATES
JAN. 13,1963 18 42 2.971
ALL VECTORS REFERENCED TO EARTH EQUIATOR PLANE
PER... EQUATORIAL COORDINATES

CASE 2

18337-JP84-4 SPCC 041795

GATE CARTESIAN
GEOCENTRIC S/C EPHEMERIS WRITTEN OT626BG 041765 RUNID=ITRAJOLI
OUTBLF PR_BISIPN EPHEMERIS TAPE - EPHE I
EARTH_CCN FINE PRINT CHECK I
CASE | INJECTION _C_DITIC_S I450.0 0ON
BTO -0.10_OJe_ Ot RAP
SMA COL 10/57921 OUT .350_0000 g2 .Dr .31219413 00 SHA -.65653256 04 GEO -.6341445_ 0I
EGM -.667099g_-I_A
SMA INC ._l?_h¢Io 02 tAN .7_1I_8_9 oz
INC . -.J61U_lb4 0(' _Y .T_72.L36 00
VH .92250_68-01 C_ -.lO1231bl
ORM -.30270318 O_ 0 hRS. 0

GEOCENTRIC RS .0000 SEC.

GEOCENTRIC EPOCH OF PERMISSION PASSAGE
JAN. 13,1963 18 42 2.971
SMA 1847979 G 0 0 0000 SEC.
TA 13024413 40.00000000 0.0 0.0 0.0 0.0 0.0 0.0

GEOCENTRIC EPHEMERIS

GEOCENTRIC EQUATORIAL COORDINATES
JAN. 13,1963 18 42 2.971
ALL VECTORS REFERENCED TO EARTH EQUIATOR PLANE
PER... EQUATORIAL COORDINATES

JPL TECHNICAL MEMORANDUM NO. 33-199
<table>
<thead>
<tr>
<th>EPOCH OF PERICENTRE PASSAGE</th>
<th>GEOCENTRIC EQUATORIAL COORDINATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>2556120152636206732000000</td>
<td></td>
</tr>
<tr>
<td>J.D. = 248034.32</td>
<td></td>
</tr>
<tr>
<td>AD = 0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>RA = -0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>Dec = -0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>SMA = 317162405</td>
<td></td>
</tr>
<tr>
<td>1271059525</td>
<td></td>
</tr>
<tr>
<td>3581066005</td>
<td></td>
</tr>
<tr>
<td>G = 0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>H = 0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>k = 0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>2556120152636206732000000</td>
<td></td>
</tr>
<tr>
<td>J.D. = 248034.32</td>
<td></td>
</tr>
<tr>
<td>AD = 0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>RA = -0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>Dec = -0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>SMA = 317162405</td>
<td></td>
</tr>
<tr>
<td>1271059525</td>
<td></td>
</tr>
<tr>
<td>3581066005</td>
<td></td>
</tr>
<tr>
<td>G = 0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>H = 0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>k = 0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>2556120152636206732000000</td>
<td></td>
</tr>
<tr>
<td>J.D. = 248034.32</td>
<td></td>
</tr>
<tr>
<td>AD = 0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>RA = -0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>Dec = -0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>SMA = 317162405</td>
<td></td>
</tr>
<tr>
<td>1271059525</td>
<td></td>
</tr>
<tr>
<td>3581066005</td>
<td></td>
</tr>
<tr>
<td>G = 0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>H = 0.0000000 D</td>
<td></td>
</tr>
<tr>
<td>k = 0.0000000 D</td>
<td></td>
</tr>
</tbody>
</table>

**EARTH-PCE FIRE POINT CHECK 1**

<table>
<thead>
<tr>
<th>GEOCENTRIC EQUATORIAL COORDINATES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**EARTH-PCE FIRE POINT CHECK 2**

<table>
<thead>
<tr>
<th>GEOCENTRIC EQUATORIAL COORDINATES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**EARTH-PCE FIRE POINT CHECK 3**

<table>
<thead>
<tr>
<th>GEOCENTRIC EQUATORIAL COORDINATES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**EARTH-PCE FIRE POINT CHECK 4**

<table>
<thead>
<tr>
<th>GEOCENTRIC EQUATORIAL COORDINATES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
**JPL TECHNICAL MEMORANDUM NO. 33-199**

**EARTH-MCN FIN CHART CHECK 1**

<table>
<thead>
<tr>
<th>GEODETIC</th>
<th>EQUATORIAL COORDINATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>X = -26.347373 06</td>
<td>F = -3.942789 09</td>
</tr>
<tr>
<td>Z = -26.347373 06</td>
<td>F = -3.942789 09</td>
</tr>
</tbody>
</table>

**EPOCH OF PRINCIPAL PASSAGE**

<table>
<thead>
<tr>
<th>GEODETIC COORDINATE</th>
<th>EQUATORIAL COORDINATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>X = -26.347373 06</td>
<td>F = -3.942789 09</td>
</tr>
</tbody>
</table>

**ALL VECTORS REFERENCED TO EARTH EQUATOR PLANE**

<table>
<thead>
<tr>
<th>ALL VECTORS REFERENCED TO EARTH EQUATOR PLANE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL VECTORS REFERENCED TO EARTH EQUATOR PLANE</td>
</tr>
</tbody>
</table>

**GEOCENTRIC**

<table>
<thead>
<tr>
<th>GEODETIC</th>
<th>EQUATORIAL COORDINATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>X = -26.347373 06</td>
<td>F = -3.942789 09</td>
</tr>
</tbody>
</table>

**EPOCH OF PASSAGE**

<table>
<thead>
<tr>
<th>GEODETIC COORDINATE</th>
<th>EQUATORIAL COORDINATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>X = -26.347373 06</td>
<td>F = -3.942789 09</td>
</tr>
</tbody>
</table>

**ALL VECTORS REFERENCED TO EARTH EQUATOR PLANE**

<table>
<thead>
<tr>
<th>ALL VECTORS REFERENCED TO EARTH EQUATOR PLANE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALL VECTORS REFERENCED TO EARTH EQUATOR PLANE</td>
</tr>
</tbody>
</table>

**EARTH-MCN FIN PRINT CHECK 1**

<table>
<thead>
<tr>
<th>GEODETIC</th>
<th>EQUATORIAL COORDINATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>X = -26.347373 06</td>
<td>F = -3.942789 09</td>
</tr>
</tbody>
</table>

**EQUATORIAL COORDINATE**

<table>
<thead>
<tr>
<th>EQUATORIAL COORDINATE</th>
<th>EQUATORIAL COORDINATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>X = -26.347373 06</td>
<td>F = -3.942789 09</td>
</tr>
</tbody>
</table>

**GEOCENTRIC**

<table>
<thead>
<tr>
<th>GEODETIC</th>
<th>EQUATORIAL COORDINATES</th>
</tr>
</thead>
<tbody>
<tr>
<td>X = -26.347373 06</td>
<td>F = -3.942789 09</td>
</tr>
</tbody>
</table>

**EQUATORIAL COORDINATE**

<table>
<thead>
<tr>
<th>EQUATORIAL COORDINATE</th>
<th>EQUATORIAL COORDINATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>X = -26.347373 06</td>
<td>F = -3.942789 09</td>
</tr>
</tbody>
</table>
JPL TECHNICAL MEMORANDUM NO. 33-199

CASE 1

EARTH-MCC FINE PRINT CHECK

ETE .11297247 03 ETS .48829334 01 ETC .29530194 03

BTO .98393429 03 BTO .20056297 02 B .81665910 03

THA .1767693 03 I VECTOR IN ORBIT PLANE OF TARGET

ALL VECTORS REFERENCED TO TRUE TARGET EQU. PLANE

X -.1070267 04 Y -.2383814 03 Z -.2276820 03

EA .16535403 03 LA .94553100 03 AP .0826868 02

MX -.24115491 00 MY -.15507303 00 MZ -.96214574 00

FX -.67727777 00 FY -.71765967 00 FZ -.18551723 00

WX -.08992316 00 WY -.80920279 00 WZ -.00000000 00

QX -.12817611 00 QY -.00647715 00 QZ -.00000000 00

BX -.49546502 03 BY -.10494266 00 BZ -.14864001 03

SM -.13406754 00 SU -.89194600 00 SZ -.14553100 00

TX -.86326645 00 TY -.47878840 00 TZ -.81971146 00

RX -.12567731 00 RY -.14659293 00 RZ -.99465338 00

TX .43845243 00 TY .10441625 00 TZ .00000000 00

QX -.18611107 00 QY -.10725871 02 QZ -.26040452 03

BX .17031493 02 BY -.14864007 02 BZ .26154479 03

ETE .09305602 03 EAT -.03099040 02 ETA .18903150 03

15966333220 21457346352 61259323929 62196294091 21442046560 603534774303 000000000000 000000000000 172

END TATTOGRAPH (SEP19) 014645 5
B. Check case 2 is an Earth-Venus trajectory made during the Mariner II mission. The spacecraft injects near Earth-Sun phase change on September 5, 1962 and encounters Venus 100.81 days later with a miss of 41,000 km. Radiation pressure was included as a perturbation on the spacecraft.
CASE 1

EARTH-VENUS, ECLIPTIC FRG, D

ECCENTRIC COORDINATES

X = -1.64232097 Y = -1.19494997 Z = 1.01857157

EROV = 3.90924727 ZNO = 2.74568297 RX = 3.18763293

CROSS = 3.30633293 SY = 0.43068717 TQ = 0.66207275

UAV = 0.272974227 VUV = 0.487431470 WUV = 0.442782017

EQUAL ARMS

X = -1.64232097 Y = -1.19494997 Z = 1.01857157

CASE 2

EARTH-VENUS, ECLIPTIC FRG, D

ECCENTRIC COORDINATES

X = -1.64232097 Y = -1.19494997 Z = 1.01857157

EROV = 3.90924727 ZNO = 2.74568297 RX = 3.18763293

CROSS = 3.30633293 SY = 0.43068717 TQ = 0.66207275

UAV = 0.272974227 VUV = 0.487431470 WUV = 0.442782017

EQUAL ARMS

X = -1.64232097 Y = -1.19494997 Z = 1.01857157

-174
**EARTH-VENUS RADIATIVE \ CASE**

**GEOCENTRIC EQUATORIAL COORDINATES**

<table>
<thead>
<tr>
<th>Epoch</th>
<th>Peri</th>
<th>True</th>
<th>L2</th>
<th>L3</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 days</td>
<td>|</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**HELIOCENTRIC ECLIPTIC COORDINATES**

<table>
<thead>
<tr>
<th>Sun</th>
<th>Earth</th>
<th>Venus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**ECLIPTIC COORDINATES**

<table>
<thead>
<tr>
<th>J0</th>
<th>J1</th>
<th>J2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200000000</td>
<td>1200000000</td>
<td>1200000000</td>
</tr>
</tbody>
</table>

**GEOCENTRIC CONIC EQUATION**

<table>
<thead>
<tr>
<th>SMA</th>
<th>E</th>
<th>i</th>
<th>e</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200000000</td>
<td>1200000000</td>
<td>1200000000</td>
<td>1200000000</td>
</tr>
</tbody>
</table>

**ECLIPTIC COORDINATES**

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200000000</td>
<td>1200000000</td>
<td>1200000000</td>
</tr>
</tbody>
</table>

**GEOCENTRIC CONIC EQUATION**

<table>
<thead>
<tr>
<th>SMA</th>
<th>E</th>
<th>i</th>
<th>e</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200000000</td>
<td>1200000000</td>
<td>1200000000</td>
<td>1200000000</td>
</tr>
</tbody>
</table>

**ECLIPTIC COORDINATES**

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200000000</td>
<td>1200000000</td>
<td>1200000000</td>
</tr>
</tbody>
</table>
### CASE 1

**Earth-Venus, Radiation Phas. On**

<table>
<thead>
<tr>
<th><strong>ECLIPSE COORDINATES</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>L</strong></td>
<td>-121.221277</td>
</tr>
<tr>
<td><strong>M</strong></td>
<td>-28.076305</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>-98.168723</td>
</tr>
<tr>
<td><strong>Q</strong></td>
<td>-140.216472</td>
</tr>
<tr>
<td><strong>R</strong></td>
<td>-172.072027</td>
</tr>
<tr>
<td><strong>S</strong></td>
<td>-204.027693</td>
</tr>
<tr>
<td><strong>T</strong></td>
<td>-236.083350</td>
</tr>
<tr>
<td><strong>U</strong></td>
<td>-268.139007</td>
</tr>
<tr>
<td><strong>V</strong></td>
<td>-299.194664</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td>-331.250321</td>
</tr>
<tr>
<td><strong>X</strong></td>
<td>-363.305978</td>
</tr>
<tr>
<td><strong>Y</strong></td>
<td>-395.361635</td>
</tr>
<tr>
<td><strong>Z</strong></td>
<td>-427.417292</td>
</tr>
</tbody>
</table>

### CASE 2

**Geocentric Coordinates**

<table>
<thead>
<tr>
<th><strong>ECLIPSE COORDINATES</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>L</strong></td>
<td>-121.221277</td>
</tr>
<tr>
<td><strong>M</strong></td>
<td>-28.076305</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>-98.168723</td>
</tr>
<tr>
<td><strong>Q</strong></td>
<td>-140.216472</td>
</tr>
<tr>
<td><strong>R</strong></td>
<td>-172.072027</td>
</tr>
<tr>
<td><strong>S</strong></td>
<td>-204.027693</td>
</tr>
<tr>
<td><strong>T</strong></td>
<td>-236.083350</td>
</tr>
<tr>
<td><strong>U</strong></td>
<td>-268.139007</td>
</tr>
<tr>
<td><strong>V</strong></td>
<td>-299.194664</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td>-331.250321</td>
</tr>
<tr>
<td><strong>X</strong></td>
<td>-363.305978</td>
</tr>
<tr>
<td><strong>Y</strong></td>
<td>-395.361635</td>
</tr>
<tr>
<td><strong>Z</strong></td>
<td>-427.417292</td>
</tr>
</tbody>
</table>

---

### JPL TECHNICAL MEMORANDUM NO. 33-199

**Earth-Venus, Radiation Phas. On**

**Geocentric Coordinates**

<table>
<thead>
<tr>
<th><strong>ECLIPSE COORDINATES</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>L</strong></td>
<td>-121.221277</td>
</tr>
<tr>
<td><strong>M</strong></td>
<td>-28.076305</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>-98.168723</td>
</tr>
<tr>
<td><strong>Q</strong></td>
<td>-140.216472</td>
</tr>
<tr>
<td><strong>R</strong></td>
<td>-172.072027</td>
</tr>
<tr>
<td><strong>S</strong></td>
<td>-204.027693</td>
</tr>
<tr>
<td><strong>T</strong></td>
<td>-236.083350</td>
</tr>
<tr>
<td><strong>U</strong></td>
<td>-268.139007</td>
</tr>
<tr>
<td><strong>V</strong></td>
<td>-299.194664</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td>-331.250321</td>
</tr>
<tr>
<td><strong>X</strong></td>
<td>-363.305978</td>
</tr>
<tr>
<td><strong>Y</strong></td>
<td>-395.361635</td>
</tr>
<tr>
<td><strong>Z</strong></td>
<td>-427.417292</td>
</tr>
</tbody>
</table>

---

**Geodetic Coordinates**

<table>
<thead>
<tr>
<th><strong>ECLIPSE COORDINATES</strong></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>L</strong></td>
<td>-121.221277</td>
</tr>
<tr>
<td><strong>M</strong></td>
<td>-28.076305</td>
</tr>
<tr>
<td><strong>P</strong></td>
<td>-98.168723</td>
</tr>
<tr>
<td><strong>Q</strong></td>
<td>-140.216472</td>
</tr>
<tr>
<td><strong>R</strong></td>
<td>-172.072027</td>
</tr>
<tr>
<td><strong>S</strong></td>
<td>-204.027693</td>
</tr>
<tr>
<td><strong>T</strong></td>
<td>-236.083350</td>
</tr>
<tr>
<td><strong>U</strong></td>
<td>-268.139007</td>
</tr>
<tr>
<td><strong>V</strong></td>
<td>-299.194664</td>
</tr>
<tr>
<td><strong>W</strong></td>
<td>-331.250321</td>
</tr>
<tr>
<td><strong>X</strong></td>
<td>-363.305978</td>
</tr>
<tr>
<td><strong>Y</strong></td>
<td>-395.361635</td>
</tr>
<tr>
<td><strong>Z</strong></td>
<td>-427.417292</td>
</tr>
</tbody>
</table>
null
JPL TECHNICAL MEMORANDUM NO. 33-199

CASE 1

EARTH-VENUS, RADAR/TECH. PRES. ON

CHECK 1

HELIOCENTRIC

ECLIPTIC COORDINATES

APPROXIMATE

EPHEM ER

ECLIPTIC COORDINATES CONIC

DAY 19 MJD 4.9411446 00

19 DAYS 10 HRS 45 MIN 43.435 SEC

10683-JPT/31-SPRDC 04/76

15

19857-JPT/RAJ-SPRDC 04/1765

16
C. Check case 3 is an Earth-Mars trajectory made during the design phase of the Mariner C mission. The spacecraft injects near the Earth on November 11, 1964 and encounters Mars 258.97 days later with a miss of 236,205 km. A minimum print was requested. Earth and Mars oblateness perturbations were included.
<table>
<thead>
<tr>
<th>Case 1</th>
<th>1476.4.022/4.00404446923.352.0F 1976.4.022/4.00404446923.352.0F</th>
<th>1476.4.022/4.00404446923.352.0F</th>
</tr>
</thead>
<tbody>
<tr>
<td>EARTH - PAS</td>
<td>CHECK 3</td>
<td>CHECK 3</td>
</tr>
<tr>
<td>DOUBLE PRECISION SPHERICAL EARTH - EPHemeris</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CASE</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>EARTH - PAS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ORBIT CONDITIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 3,000,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DATE OF RUN</td>
<td>041764.001</td>
<td>041764.001</td>
</tr>
<tr>
<td>GME</td>
<td>02.56740/2.0E-05</td>
<td>02.56740/2.0E-05</td>
</tr>
<tr>
<td>REA</td>
<td>3.78564/3.0E-05</td>
<td>3.78564/3.0E-05</td>
</tr>
<tr>
<td>JUP</td>
<td>-0.07295/0.0E-05</td>
<td>-0.07295/0.0E-05</td>
</tr>
<tr>
<td>SAT</td>
<td>0.00000/0.0E-05</td>
<td>0.00000/0.0E-05</td>
</tr>
<tr>
<td>DATE OF RUN</td>
<td>041764.001</td>
<td>041764.001</td>
</tr>
<tr>
<td>GME</td>
<td>02.56740/2.0E-05</td>
<td>02.56740/2.0E-05</td>
</tr>
<tr>
<td>REA</td>
<td>3.78564/3.0E-05</td>
<td>3.78564/3.0E-05</td>
</tr>
<tr>
<td>JUP</td>
<td>-0.07295/0.0E-05</td>
<td>-0.07295/0.0E-05</td>
</tr>
<tr>
<td>SAT</td>
<td>0.00000/0.0E-05</td>
<td>0.00000/0.0E-05</td>
</tr>
<tr>
<td>INJECTION CONDITIONS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALT</td>
<td>196.40000</td>
<td>196.40000</td>
</tr>
<tr>
<td>VEL</td>
<td>262.40000</td>
<td>262.40000</td>
</tr>
<tr>
<td>INJ</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>INJ L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ENF</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>ENF L</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>DYN</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>DYN L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ALT</td>
<td>196.40000</td>
<td>196.40000</td>
</tr>
<tr>
<td>VEL</td>
<td>262.40000</td>
<td>262.40000</td>
</tr>
<tr>
<td>INJ</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>INJ L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ENF</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>ENF L</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>DYN</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>DYN L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ALT</td>
<td>196.40000</td>
<td>196.40000</td>
</tr>
<tr>
<td>VEL</td>
<td>262.40000</td>
<td>262.40000</td>
</tr>
<tr>
<td>INJ</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>INJ L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ENF</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>ENF L</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>DYN</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>DYN L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ALT</td>
<td>196.40000</td>
<td>196.40000</td>
</tr>
<tr>
<td>VEL</td>
<td>262.40000</td>
<td>262.40000</td>
</tr>
<tr>
<td>INJ</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>INJ L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ENF</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>ENF L</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>DYN</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>DYN L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ALT</td>
<td>196.40000</td>
<td>196.40000</td>
</tr>
<tr>
<td>VEL</td>
<td>262.40000</td>
<td>262.40000</td>
</tr>
<tr>
<td>INJ</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>INJ L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ENF</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>ENF L</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>DYN</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>DYN L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ALT</td>
<td>196.40000</td>
<td>196.40000</td>
</tr>
<tr>
<td>VEL</td>
<td>262.40000</td>
<td>262.40000</td>
</tr>
<tr>
<td>INJ</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>INJ L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ENF</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>ENF L</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>DYN</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>DYN L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ALT</td>
<td>196.40000</td>
<td>196.40000</td>
</tr>
<tr>
<td>VEL</td>
<td>262.40000</td>
<td>262.40000</td>
</tr>
<tr>
<td>INJ</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>INJ L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ENF</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>ENF L</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>DYN</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>DYN L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ALT</td>
<td>196.40000</td>
<td>196.40000</td>
</tr>
<tr>
<td>VEL</td>
<td>262.40000</td>
<td>262.40000</td>
</tr>
<tr>
<td>INJ</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>INJ L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>ENF</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>ENF L</td>
<td>307.40000</td>
<td>307.40000</td>
</tr>
<tr>
<td>DYN</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>DYN L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
<tr>
<td>TOT L</td>
<td>246.80000</td>
<td>246.80000</td>
</tr>
</tbody>
</table>
CASE 1

Earth - Mars

39 WOPERA

HACER

R. .24970726 O 0

MIN .80679570 0 0

MCA .35326610 0 0

U1 .11331637 O 0

R1 .63706049 0 0

R2 .68077612 O 0

D1 .32846015 0 0

0 DAYS 1 HR. 51 MIN. 34.505 SEC.

CASE 2

Earth - Mars

39 WOPERA

HACER

R. .24970726 O 0

MIN .80679570 0 0

MCA .35326610 0 0

U1 .11331637 O 0

R1 .63706049 0 0

R2 .68077612 O 0

D1 .32846015 0 0

0 DAYS 1 HR. 51 MIN. 34.505 SEC.

JPL TECHNICAL MEMORANDUM No. 33-199

MEMORANDUM NO. 33-199

OF

ELEVATION

CASE 1

Earth - Mars

41 WOPERA

HACER

R. .24970726 O 0

MIN .80679570 0 0

MCA .35326610 0 0

U1 .11331637 O 0

R1 .63706049 0 0

R2 .68077612 O 0

D1 .32846015 0 0

0 DAYS 1 HR. 51 MIN. 34.505 SEC.

EXTREME ELEVATION

CASE 1

Earth - Mars

41 WOPERA

HACER

R. .24970726 O 0

MIN .80679570 0 0

MCA .35326610 0 0

U1 .11331637 O 0

R1 .63706049 0 0

R2 .68077612 O 0

D1 .32846015 0 0

0 DAYS 1 HR. 51 MIN. 34.505 SEC.

END OF VIEW PERIOD

CASE 1

Earth - Mars

41 WOPERA

HACER

R. .24970726 O 0

MIN .80679570 0 0

MCA .35326610 0 0

U1 .11331637 O 0

R1 .63706049 0 0

R2 .68077612 O 0

D1 .32846015 0 0

0 DAYS 1 HR. 51 MIN. 34.505 SEC.

START OF VIEW PERIOD

CASE 1

Earth - Mars

41 WOPERA

HACER

R. .24970726 O 0

MIN .80679570 0 0

MCA .35326610 0 0

U1 .11331637 O 0

R1 .63706049 0 0

R2 .68077612 O 0

D1 .32846015 0 0

0 DAYS 1 HR. 51 MIN. 34.505 SEC.

EXTREME ELEVATION

CASE 1

Earth - Mars

41 WOPERA

HACER

R. .24970726 O 0

MIN .80679570 0 0

MCA .35326610 0 0

U1 .11331637 O 0

R1 .63706049 0 0

R2 .68077612 O 0

D1 .32846015 0 0

0 DAYS 1 HR. 51 MIN. 34.505 SEC.

START OF VIEW PERIOD

CASE 1

Earth - Mars

41 WOPERA

HACER

R. .24970726 O 0

MIN .80679570 0 0

MCA .35326610 0 0

U1 .11331637 O 0

R1 .63706049 0 0

R2 .68077612 O 0

D1 .32846015 0 0

0 DAYS 1 HR. 51 MIN. 34.505 SEC.

EXTREME ELEVATION

CASE 1

Earth - Mars

41 WOPERA

HACER

R. .24970726 O 0

MIN .80679570 0 0

MCA .35326610 0 0

U1 .11331637 O 0

R1 .63706049 0 0

R2 .68077612 O 0

D1 .32846015 0 0

0 DAYS 1 HR. 51 MIN. 34.505 SEC.

START OF VIEW PERIOD

CASE 1

Earth - Mars

41 WOPERA

HACER

R. .24970726 O 0

MIN .80679570 0 0

MCA .35326610 0 0

U1 .11331637 O 0

R1 .63706049 0 0

R2 .68077612 O 0

D1 .32846015 0 0

0 DAYS 1 HR. 51 MIN. 34.505 SEC.
### Case 1

#### EQUATORIAL COORDINATES

**EPOCH OF PREDICTED PASSAGE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPL 1055-4FHAF-SPKNO 04.425</td>
<td></td>
</tr>
</tbody>
</table>

**EARTL = ❅**

#### GEOCENTRIC CONICAL

**EPOCH OF PREDICTED PASSAGE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPL 1055-4FHAF-SPKNO 04.425</td>
<td></td>
</tr>
</tbody>
</table>

**EARTL = ❅**

---

### Case 2

#### EQUATORIAL COORDINATES

**EPOCH OF PREDICTED PASSAGE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPL 1055-4FHAF-SPKNO 04.425</td>
<td></td>
</tr>
</tbody>
</table>

**EARTL = ❅**

#### GEOCENTRIC CONICAL

**EPOCH OF PREDICTED PASSAGE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPL 1055-4FHAF-SPKNO 04.425</td>
<td></td>
</tr>
</tbody>
</table>

**EARTL = ❅**

---

### Case 3

#### EQUATORIAL COORDINATES

**EPOCH OF PREDICTED PASSAGE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPL 1055-4FHAF-SPKNO 04.425</td>
<td></td>
</tr>
</tbody>
</table>

**EARTL = ❅**

#### GEOCENTRIC CONICAL

**EPOCH OF PREDICTED PASSAGE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPL 1055-4FHAF-SPKNO 04.425</td>
<td></td>
</tr>
</tbody>
</table>

**EARTL = ❅**

---

### Case 4

#### EQUATORIAL COORDINATES

**EPOCH OF PREDICTED PASSAGE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPL 1055-4FHAF-SPKNO 04.425</td>
<td></td>
</tr>
</tbody>
</table>

**EARTL = ❅**

#### GEOCENTRIC CONICAL

**EPOCH OF PREDICTED PASSAGE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPL 1055-4FHAF-SPKNO 04.425</td>
<td></td>
</tr>
</tbody>
</table>

**EARTL = ❅**

---

### Case 5

#### EQUATORIAL COORDINATES

**EPOCH OF PREDICTED PASSAGE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPL 1055-4FHAF-SPKNO 04.425</td>
<td></td>
</tr>
</tbody>
</table>

**EARTL = ❅**

#### GEOCENTRIC CONICAL

**EPOCH OF PREDICTED PASSAGE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPL 1055-4FHAF-SPKNO 04.425</td>
<td></td>
</tr>
</tbody>
</table>

**EARTL = ❅**

---

### Case 6

#### EQUATORIAL COORDINATES

**EPOCH OF PREDICTED PASSAGE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPL 1055-4FHAF-SPKNO 04.425</td>
<td></td>
</tr>
</tbody>
</table>

**EARTL = ❅**

#### GEOCENTRIC CONICAL

**EPOCH OF PREDICTED PASSAGE**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>JPL 1055-4FHAF-SPKNO 04.425</td>
<td></td>
</tr>
</tbody>
</table>

**EARTL = ❅**

## 194
### JPL Technical Memorandum No. 33-199

**Case 1**

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Check 3</th>
<th>X Ry</th>
<th>Y Ry</th>
<th>Xz</th>
<th>Yz</th>
<th>Zz</th>
<th>Lm</th>
<th>Qm</th>
<th>Rm</th>
<th>Xar</th>
<th>Yar</th>
<th>Zar</th>
<th>Xsar</th>
<th>Ysar</th>
<th>Zsar</th>
</tr>
</thead>
<tbody>
<tr>
<td>257 Days 10 Hrs 3 Min. 16.208 Sec.</td>
<td>2357244201222704120000 J.G.C. = 2439946.7378485</td>
<td>JULY 27, 1965 05 42 33.251</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Case 2

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Check 3</th>
<th>X Ry</th>
<th>Y Ry</th>
<th>Xz</th>
<th>Yz</th>
<th>Zz</th>
<th>Lm</th>
<th>Qm</th>
<th>Rm</th>
<th>Xar</th>
<th>Yar</th>
<th>Zar</th>
<th>Xsar</th>
<th>Ysar</th>
<th>Zsar</th>
</tr>
</thead>
<tbody>
<tr>
<td>257 Days 14 Hrs 50 Min. 31.915 Sec.</td>
<td>2357242232425124000000 J.G.C. = 2439946.8124794</td>
<td>JULY 27, 1965 07 29 54.339</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Case 3

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Check 3</th>
<th>X Ry</th>
<th>Y Ry</th>
<th>Xz</th>
<th>Yz</th>
<th>Zz</th>
<th>Lm</th>
<th>Qm</th>
<th>Rm</th>
<th>Xar</th>
<th>Yar</th>
<th>Zar</th>
<th>Xsar</th>
<th>Ysar</th>
<th>Zsar</th>
</tr>
</thead>
<tbody>
<tr>
<td>258 Days 1 Hrs 27 Min. 15.688 Sec.</td>
<td>23572442015723557577 J.G.C. = 2439946.2036716</td>
<td>JULY 27, 1965 19 08 38.731</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Case 4

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Check 3</th>
<th>X Ry</th>
<th>Y Ry</th>
<th>Xz</th>
<th>Yz</th>
<th>Zz</th>
<th>Lm</th>
<th>Qm</th>
<th>Rm</th>
<th>Xar</th>
<th>Yar</th>
<th>Zar</th>
<th>Xsar</th>
<th>Ysar</th>
<th>Zsar</th>
</tr>
</thead>
<tbody>
<tr>
<td>258 Days 2 Hrs 43 Min. 31.614 Sec.</td>
<td>235724420167333333 J.G.C. = 2439946.5121310</td>
<td>JULY 27, 1965 20 23 22.104</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Case 5

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Check 3</th>
<th>X Ry</th>
<th>Y Ry</th>
<th>Xz</th>
<th>Yz</th>
<th>Zz</th>
<th>Lm</th>
<th>Qm</th>
<th>Rm</th>
<th>Xar</th>
<th>Yar</th>
<th>Zar</th>
<th>Xsar</th>
<th>Ysar</th>
<th>Zsar</th>
</tr>
</thead>
<tbody>
<tr>
<td>258 Days 8 Hrs 57 Min. 3.516 Sec.</td>
<td>235724420199999999 J.G.C. = 2439946.0000000</td>
<td>JULY 28, 1965 01 36 28.579</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**200**
JPL TECHNICAL MEMORANDUM NO. 33-199

CASE 1

EARTH ↔ MARS

CHECK 3

11 GOLDEN: HAEC

CASE 1

EARTH ↔ MARS

CHECK 3

11 GOLDEN: HAEC

CASE 1

EARTH ↔ MARS

CHECK 3

12 GOLDEN: HAEC

CASE 1

EARTH ↔ MARS

CHECK 3

10 GOLDEN: HAEC

CASE 1

EARTH ↔ MARS

CHECK 3

10 GOLDEN: HAEC

JPL TECHNICAL MEMORANDUM NO. 33-199

11 GOLDEN: HAEC

CASE 1

EARTH ↔ MARS

CHECK 3

11 GOLDEN: HAEC

CASE 1

EARTH ↔ MARS

CHECK 3

11 GOLDEN: HAEC

CASE 1

EARTH ↔ MARS

CHECK 3
JPL TECHNICAL MEMORANDUM NO. 33-199

CASE I

1807-JPLR12-SFPRO 04/765

EARTh - MARS

AECENTRIC EQUATORIAL COORDINATES

A. EPOCH OF PERIGEE PASSAGE

B. ALL VECTORS REFERENCED TO EARTH EQUATOR PLANE

C. ALL VECTORS REFERENCED TO AREOCENTRIC EQUATORIAL PLANE

D. ALL VECTORS REFERENCED TO EARTH EQUATOR PLANE

E. AECENTRIC EQUATORIAL COORDINATES
D. Check case 4 is an Earth-Moon trajectory with a minimum print requested. The spacecraft injects near the Earth on August 6, 1963 and impacts the Moon after a 66.37-hour flight time.
ALL VECTORS REFERENCED TO EARTH EQUATOR PLANE

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1.120136</td>
<td>0.811996</td>
<td>0.4</td>
</tr>
<tr>
<td>0.404287</td>
<td>0.9762</td>
<td>0.05</td>
</tr>
</tbody>
</table>

ALL VECTORS REFERENCED TO TRUE TARGET EQU. PLANE

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.604724</td>
<td>0.794896</td>
<td>0.4</td>
</tr>
<tr>
<td>0.502765</td>
<td>0.498839</td>
<td>0.0</td>
</tr>
</tbody>
</table>

CASE 1

EARTH-MOON CHECK 4

END TRAJECORY (STP/A)

026162

G

206
REFERENCES


ACKNOWLEDGEMENT

The authors gratefully acknowledge the support of personnel at JPL which contributed to the analysis contained in both TM 33-198 and this Report. Significant contributions were made by V. C. Clarke, Jr., F. M. Sturms, D. A. Tito, W. E. Kirhofer, R. A. Winneberger, R. J. Richard, and N. R. Haynes.

We also wish to acknowledge the programming and analysis done by D. B. Holdridge, A. L. Laxdal and D. E. Richardson which form the basis of the current program. The authors regret that the above list is incomplete and extend their appreciation to all other contributors.