A NUMERICAL EVALUATION OF PRELIMINARY ORBIT DETERMINATION METHODS

by William F. Huseonica

John F. Kennedy Space Center
Kennedy Space Center, Fla.

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# Abstract

This Technical Note presents a general FORTRAN Code and computer program flowcharts for twelve different Preliminary Orbit Determination Methods (PODM). A number of solutions were obtained from each PODM using input data from a predetermined reference orbit. A comparison of these PODMs in their ability to converge, error propagation, computation time, and total computer core requirements is presented.

## Keywords

- Orbit Calculations

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A NUMERICAL EVALUATION OF
PRELIMINARY ORBIT DETERMINATION METHODS

By William F. Huseonica
John F. Kennedy Space Center

SUMMARY

Solutions from twelve different Preliminary Orbit Determination Methods using data from two well defined orbits are presented. A number of different solutions were obtained from each method when the angular difference (true anomaly) between observation data was varied from several degrees to one complete revolution. The failure to converge and the numerical error propagation are indicated. The computation time and total computer core required for each PODM is tabulated. A computational algorithm was used to adapt inertial position, velocity, and time input data to angular, range, range rate, and time input data from several different observation stations. A general FORTRAN code and a computer program flowchart are documented and can be utilized with computers other than the Scientific Data Systems 930 used in these solutions.

INTRODUCTION

In preliminary orbit determination (the first approximation of the orbit) it is difficult to select a method which could be considered the best Preliminary Orbit Determination Method (PODM). The best method can be determined by considering several factors of interest to the particular analyst selecting an orbit determination method. These factors are:

Which method is the fastest from a computational point of view?

Which method has the least numerical error propagation?

Which method experiences the least convergence difficulties?

Which method will function most effectively with the observation data available (position, angles, range, range rate, and time)?

Which method can give the best numerical results from orbits of varying eccentricity and semimajor axis?

Which method gives the best results from observation data having small and large true anomaly angular differences?
Data presented in this report form the solutions of twelve different PODMs and will help in determining the best method for a given application. The twelve different PODMs encompass classical methods used in determining the motion of heavenly bodies and present day methods used in artificial satellite PODMs. These PODMs are found in computational algorithm form (Escobal, reference 1). The algorithms were programmed in a FORTRAN II code and the calculations were accomplished on a Scientific Data Systems (SDS) 930 computer.

The PODM input data were derived from two well defined orbits (with perturbations and differential corrections) of common occurrence for artificial earth satellites. One orbit has low eccentricity with a small semimajor axis; the second orbit has a higher eccentricity and a larger semimajor axis.

DISCUSSION

Symbols and Abbreviations

Because the nomenclature used within the field of PODM is so extensive and non-uniform from text to text, a list of symbols and abbreviations is included (appendix A). In addition, the unit vectors and orientation angles of the orbital plane are illustrated in appendix A, figure 1.

PODM Computational Algorithms

The twelve PODMs computed in this evaluation use various types of observation data necessary for a solution or preliminary determination of the orbit. Lambert-Euler, F and G series, Iteration of Semiparameter, Gaussian (time and position), and Iteration of the True Anomaly PODMs use inertial position vectors \((x_1, y_1, z_1)\) and \((x_2, y_2, z_2)\) and their corresponding universal times \(t_1\) and \(t_2\) as the input data. Method of Gauss (angles), Laplace, and Double R-Iteration PODMs require right ascension \(\alpha\) and declination \(\delta\) from three different stations and their corresponding universal times. Observation station data such as longitude, latitude, and elevation are also required. The remaining PODMs (Modified Laplacian, R-Iteration, Trilateration, and Herrick-Gibbs) require mixed data inputs. The mixed data inputs are selected from right ascension, declination, range and range rate along with the observation station data. Further discussion of these PODMs can be found in references 1 and 3. The computational algorithms for these PODMs are given in equations (1) through (439) in appendixes B through M.
Special considerations that must be given in the computational algorithms for retrograde orbits have been deleted. All orbits to be determined in this evaluation are those involving direct motion.

In nine of the PODMs an iteration of equations is involved which produces an iterative function that must be driven to zero or a lesser specified tolerance, i.e., epsilon. For this evaluation, a number of $10^{-10}$ was selected and is in line with the significant figures involved with the input data as well as the PODM solutions. This value for epsilon eliminated the need for extended range accuracy in the computer solutions.

Input data for these nine PODMs were derived from two National Aeronautics and Space Administration (NASA) earth-orbited satellites, OSO-III and Relay-II. These satellite orbits will be used as the bases for evaluation of the PODMs. The OSO-III orbit has an eccentricity of 0.00216 and a semimajor axis of 4,306.81 miles; Relay-II orbit eccentricity is 0.24115 and semimajor axis is 6,915.52 miles. The inclination angles are 32.863 degrees and 46.323 degrees for OSO-III and Relay-II respectively. Additional orbital elements for these satellites are specified in appendixes N and O. Orbital data were furnished by the NASA Goddard Space Flight Center (GSFC), Greenbelt, Maryland. Observation data were received from the various NASA tracking stations (references 5 and 6), and the resultant inertial position and velocity vector data for each minute of two complete revolutions for both orbits were generated from GSFC R083 Orbit Generator Routine-3 (references 7 and 8). The tracking stations and coordinates are listed in appendix P.

The inertial position vector data and corresponding universal time obtained from OSO-III and Relay-II orbits can be used as input data for the five PODMs using position and time inputs. However, these data must be modified to define range, range rate, and angular data to be used as an input for the remaining seven PODMs and to maintain a well defined orbit on which to base an evaluation of all PODMs. A computational algorithm developed to find $\rho$, $\phi$, $\alpha$, and $\delta$ is detailed in appendix Q, equations (440) through (459). Results from this computational algorithm can be selected and applied to the seven PODMs requiring angles only and mixed data.

The PODM computational algorithms terminate when the inertial position and velocity vector for a corresponding observation point is determined; the orbit is then considered determined. In many cases, the classical orbital elements may serve to better illustrate the significant changes in the evaluation of the PODM. Therefore, a computational algorithm that solves for the classical elements (semimajor axis, $a$; eccentricity, $e$; inclination, $i$; longitude of the ascending node, $\Omega$; argument of perigee, $\omega$; and time of perifocal passage, $T$) from the position and velocity vector is detailed in appendix R, equations (460) through (480). This algorithm is computed subsequent to the determination of the inertial position and velocity vector of each PODM.
Computer Program Language

To facilitate this evaluation, the most obvious tool is the digital computer. The computational algorithms discussed in the previous paragraphs are readily translatable into a program language for communicating with digital computers. The FORTRAN II language was used because it is not really a single computer language. Rather, it is a family of similar languages, or dialects, with one or more being developed for each class of digital computer. A later generation of FORTRAN (FORTRAN IV) will further minimize the difference in this language for each class of computer (reference 2). The FORTRAN language provides engineers and scientists with an efficient and easily understood means of writing programs for computers.

Computer Program Flowcharts

In preparation for the programming of each computational algorithm, a program flowchart was constructed. The flowchart describes the code sequences that accomplish the processing of information to obtain the desirable result. In programs involving a great number of statements, it becomes cumbersome to follow the sequence of written statements. Since written statements can be stated or can proceed in a variety of ways, flowcharts are excellent for conveying procedural concepts.

The value of flowcharts is further enhanced by consistency in the graphical conventions used. The conventions used in this paper are found in appendix S and were primarily adopted from reference 4.

Flowcharts describe the code sequences as written from the computational algorithms (appendixes B through M). The information within the flowchart symbols is the FORTRAN II code description of the expressions in the algorithm and in the program listings. Only statements conveying procedural concepts are presented in the flowcharts.

Computer Program Listing

For each PODM computed there is a computer program listing (appendixes B through M). The program listing is a sequence of FORTRAN language statements used in computation of the PODM. The program listing is a copy of the source language translated to machine code by the computer processor. The program listing serves as an indicator for the diagnostic report from the computer during the program debugging procedure. The algorithms are programmed in FORTRAN II for use with SDS Series 930 computer (references 9 and 10), but the output of the millisecond (run-time) clock on the SDS 930 was programmed in SDS Meta-Symbol language. The run-time clock tallied and obtained the total time necessary to compute the PODM programs by a program subroutine identified as ITIME. This subroutine used the programmed statements indicated on the program listing by S (SDS Meta-Symbol language). The millisecond clock was initialized by ITIME = 0 and incremented
each millisecond by the ITIME subroutine and would subsequently be printed out upon command at the conclusion of a block of computed programmed statements. This procedure was accomplished several times during the computation of each PODM program in order to obtain only computation time and not time required for READ and PRINT statements.

Discussion Summary

The PODMs used for evaluation were found basically in reference 1, Escobal. They were programmed in FORTRAN II and SDS Meta-Symbol for use in the SDS 930 computer. Prior to programming, the procedural concept was established with flowcharts. The two reference orbit data were obtained from GSFC. The data were adapted to input data for angles only and mixed data PODM by a computational algorithm that was programmed and computed prior to the PODM computations. All PODM computations were accomplished on the SDS 930 computer. However, selected programs were successfully compiled and computed on an IBM 1800 and an IBM 360 with only slight modifications. The compilation of algorithms, flowcharts, and computer program listings used to conduct this evaluation of twelve PODMs are detailed in appendixes B through M.

RESULTS AND CONCLUSIONS

The inertial position and velocity orbit data with their corresponding times from epoch used in this PODM evaluation are listed in tables 1 and 2 for OSO-III and Relay-II satellites, respectively. Also contained within these tables is the change in true anomaly angle of each data point referenced to data point 1. Data points contained in these tables are the data points used for the inertial position and time PODM inputs. The same data points were used in the generation of data inputs by the computational algorithm for range, range rate, and angular data for the angles only and mixed data PODMs (appendix Q). The evaluation will consider the inertial position and time PODMs separately from the angles only and mixed data PODMs because sufficient differences exist in the computational algorithms and the practical usage of these PODMs.

Position and Time PODMs

The PODMs which use inertial position vectors and their corresponding times are found in appendixes B through F. These algorithms were applied using all data points referenced from data point 1 in tables 1 and 2. The computational algorithms for inertial position and time PODMs conclude by computing an inertial velocity vector corresponding to one of the times for which an input of inertial position is known. This inertial position and velocity vector and the corresponding time are sufficient to consider the orbit determined.
Subsequent to determination of the inertial velocity vector, the classical orbital elements are computed by using the computational algorithm contained in appendix R. The results of these computations are detailed in figures 2 through 11 and tables 3 through 17.

Figures 2 through 11 are detailed plots of the computed inertial velocity vectors in the $\hat{x}$, $\hat{y}$, $\hat{z}$ components versus the true anomaly angular difference between input data components from tables 1 and 2. The true anomaly angular difference, of position and time PODM, is the angular difference between two inertial position vectors (figure 12). The true anomaly angular difference was varied from 3.8 to 360 degrees for OSO-III orbit and from 2.5 to 360 degrees for Relay-II orbit for convenience in adapting the same data to the angles only and mixed data PODM with consideration to station locations. A plot of the number of iterations required for the iteration loop within the PODM computational algorithm for each set of data input used is also contained in figures 2 through 11. Tables 3 through 12 are the tabulated results which are plotted in figures 2 through 11.

For example, in figure 2, results of Lambert-Euler PODM for OSO-III, at 10 degrees difference in true anomaly the inertial velocity vectors are as follows: $\hat{x}$ is $-0.67100$ CUL/CUT; $\hat{y}$ is $0.45242$ CUL/CUT; and $\hat{z}$ is $-0.51970$ CUL/CUT and the predicted number of iterations is seven. The nominal values are indicated for each component. Also denoted is the true anomaly angular difference beyond which the program fails to compute and yield satisfactory results.

A comparison in each case of the computed resultant classical orbital elements, with respect to the nominal values obtained from appendixes N and O, is listed in tables 13 through 17. Both the computed results and the nominal values from the reference orbit are referenced to the same time of epoch as denoted in tables 1 and 2.

Each PODM program listing as found in appendixes B through F requires a definite number of words available in the computer core before a successful computation can be accomplished. Table 18 lists the number of 24-bit words required in the computer core of the SDS 930 computer for variables, statements, and subprograms necessary for computation of each PODM. The number of core words required can vary and may depend on the programming efficiency of the programmer. One programmer may be able to accomplish the same task with fewer core words than another programmer.

Another factor which can vary the computer core requirements is the efficiency of the computer manufacturer’s library of translations of FORTRAN to machine language. In comparing the position and time PODMs, the core requirements for each PODM vary little except for the F and G Series (4649 words) requirement.
The time necessary to compute the computer coded program listing of each PODM was evaluated by printing time from the computer clock (ITIME) at the conclusion of a block of computations, ignoring the time necessary for READ and PRINT statements. The method used can be found in the computer program listing. The computation time required for each PODM is listed in table 19. The total time required for computation of each program with only one iteration ranges from 16 to 21 milliseconds, with F and G series being slowest and Lambert-Euler being fastest. The F and G series is slowest and Lambert-Euler and Gaussian PODMs fastest when comparing the time required for each additional iteration computation loop. However, the total time for computation during practical application of these PODMs is a function also of the rate of convergence. The average number of iterations required for the PODM iterative loop to converge is listed in table 20. Although the F and G series is slowest when computing for all portions of the algorithm, it is fastest in its ability to converge. The averages in table 20 considered only the data points for which the PODM yielded satisfactory results; i.e., the averages were computed from results of the PODM over true anomaly angular ranges which yielded acceptable solutions. The radius vector spread of the data input must be considered when choosing a PODM for a minimum computation time for a particular orbit because the convergence of the iteration loop is a function of the true anomaly difference.

Ease of convergence. - The ease of convergence of each PODM is indicated in table 20. The shape of the orbit appears to have some effect on the ability of the PODM to converge. Lambert-Euler, F and G series, and Iteration of True Anomaly PODMs decrease in ability to converge for an orbit with a larger semimajor axis and higher eccentricity while Gaussian and Iteration of Semiparameter PODMs increase.

The radius vector spread (true anomaly angular difference) over which these PODMs are likely to yield best results is concluded in table 21. The best result is a function of ease of convergence and accuracy.

Error propagation. - The position and time PODM that has the least error propagation is not readily distinguishable. There are relatively small differences in the propagation of error as indicated by the graph of inertial velocity versus true anomaly angular difference in figures 2 through 11. The profile of error in computing the inertial velocity in all PODMs appears the same until the radius vector spread becomes excessive for acceptable PODM results. The data also indicate that an optimum in radius vector spread for the most accurate computed velocity vector for these PODMs is 20 to 30 degrees.

Discussion of results. - In comparing the five PODMs using position and time input data, the results indicate that the optimum PODM is the Lambert-Euler followed by Iteration of Semiparameter, Iteration of True Anomaly, Gaussian, and F and G series. The optimum was a compromise between computation time, ease of convergence, and best overall accuracy considering radius vector spreads up to 360 degrees. These comparisons were made from the results of two different orbits; OSO-III and Relay-III. Table 22 indicates the standing of each PODM for consideration for determining the optimum.
Angles Only and Mixed Data PODMs

The PODMs using angles only and mixed data are found in appendixes G through M. These algorithms require a combination of three station observations of right ascension, declination, range or range rate, and their corresponding times from epoch in a topocentric coordinate system for a solution. The station location data is also required and is found in appendix P. From each data point in tables 1 and 2, values for range, range rate, declination, and right ascension were computed for several different stations using the computational algorithm found in appendix Q. These data are detailed in tables 23 and 24 for OSO-III and Relay-II, respectively. Tables 23 and 24 constitute the required input data to the angles only and mixed data PODMs being evaluated.

These PODMs require three observation data inputs for a solution and the observation station location data. There is also a requirement that the station observation data be from either three separate stations at three different times, or one station at three different times from epoch, or three stations with data input resolved to a common time from epoch. The number of stations required is determined in the computation algorithm by the input data necessary before a solution can be obtained from the PODM. The data points and observation stations combination used in computing results for evaluation of these PODMs are specified in tables 25 and 26.

The inertial velocity component results of these computations are specified in tables 27 through 39. These tables present the inertial velocity vector components $\hat{x}$, $\hat{y}$, and $\hat{z}$ with reference to inertial velocity vector of the nominal orbit from tables 1 and 2. A comparison in each case of the resultant classical orbital elements, with respect to the nominal values of the elements from appendixes N and O, is specified in tables 40 through 44.

Both the computed results and the nominal values from the reference orbit are referenced to the same time of epoch as denoted in tables 1 and 2.

Table 18 indicates the computer core requirements for the program listings contained in appendixes G through M and Q. The requirements range from 3525 words for Herrick-Gibbs to 5254 words for Method of Gauss.

Computation time. - The computation time required for each PODM is specified in table 19. Two of the PODMs in this table, one under mixed data and the other under angles only, differ from the others. Herrick-Gibbs PODM has no iteration loop and is fastest from the computation time; Gauss PODM has two iteration loops and is the slowest. The total computing time required ranges from 13 to 26 milliseconds when only one pass through the iteration loop is present. Time for each additional pass through the iteration loop ranges from 5 to 9 milliseconds.
The average number of iterations of each PODM, using both OSO-III and Relay-II orbits, is specified in table 45. Herrick-Gibbs and Trilateration PODM do not have an iteration loop. However, Trilateration does have a branch which is computed twice to determine best approximation for the inertial position vector. Neither has an iteration loop computation time which can be compared with the other PODMs. Of the remaining PODMs which have iteration loops, Laplace and Modified Laplacian are the fastest at 5 milliseconds for each iteration loop while the Double R-Iteration PODM is slowest at 9 milliseconds.

Ease of convergence. - The radius vector spread between $r_1$ to $r_2$ and $r_3$ for data inputs to the PODM was 3.8 to 360 degrees for OSO-III and 2.5 to 360 degrees for Relay-II. Considering the data points which yielded satisfactory results to define the orbit, table 45 indicates the difficulty in convergence. Double R-Iteration and Laplace (angles only) iteration loops did not converge in the allotted number indexed in the program (maximum number of iterations allowable is 25). It becomes apparent that changes are required in refining the iteration loop from either a mathematical or programming viewpoint or that observation station geometry is critical. From these two PODMs (Double R-Iteration and Laplace) only one set of results from each came close to resembling OSO-III or Relay-II orbits. As presented, these PODMs have difficulty in converging and require additional information.

The three remaining PODMs which have iteration loops (Method of Gauss, Modified Laplacian, and R-Iteration) have a greater ease of convergence with data from OSO-III orbit, having a lower eccentricity and semimajor axis, than with the data from Relay-II orbit.

The convergence question does not arise in Herrick-Gibbs or Trilateration PODMs since no iteration loops exist.

Error propagation. - Error propagation in the angles only and mixed data PODMs have no characteristic profile as in the case of the position and time PODMs. Many factors may contribute to the inconsistency of error propagation and overall accuracy of results.

One factor is that station observation data was generated by a scheme from inertial position and velocity data and not by direct station observations. The geometry established between the observing station and the orbiting body may also be a critical factor. The limited number of data points available and used may yield results not completely representative of the PODM error propagation. However, after such considerations, all PODMs used the same input data for the results being discussed. If an error propagation profile can be established sufficiently it would appear to be similar in the Herrick-Gibbs, Method of Gauss, Modified Laplacian, and R-Iteration PODMs. The Double R-Iteration and Laplace PODMs have no distinguishable error profile.
A more accurate and complete set of results exist from the Relay-II orbit input data to PODM than exists from the inputs used from the OSO-III orbit. It appears that an orbit with larger semimajor axis and eccentricity is more readily computable for acceptable results over a greater radius vector spread than an orbit of lesser semimajor axis and eccentricity (Relay-II versus OSO-III). The PODM with the best overall accuracy with a radius vector spread (υ) to 360 degrees is specified in table 46.

Discussion of results. - In comparing each PODM using angles only and mixed data, the optimum PODM was determined to be Herrick-Gibbs followed by Modified Laplacian, Method of Gauss, R-Iteration, Double R-Iteration, and Laplace. The optimum was a compromise between the computing time, ease of convergence, and best overall accuracy considering radius vector spreads up to 360 degrees. These comparisons were made using the results of OSO-III and Relay-II orbits. Table 47 indicates the rank of each PODM under several classifications.

A contrasting difference is apparent when comparing the angles only and mixed data PODMs in that the schemes converge more easily with an OSO-III type of orbit. However, acceptable results are more readily attainable over a greater radius vector spread with the Relay-II type orbit.

Trilateration

Trilateration PODM is unique in that it requires three different station observations at the same time. The geometry of the three stations is very critical for obtaining accurate results. A computed set of results for OSO-III and Relay-II orbits are detailed in table 39. The results of Relay-II are more accurate than those of OSO-III. This follows the same trend as the other PODMs using angles only or mixed data. Also, Trilateration does not have an iteration loop and, with the requirement of simultaneous observations, it makes this PODM sufficiently different to refrain from comparing it directly with other PODMs. Total computation time for Trilateration PODM was 17 milliseconds.

Conclusion

Solutions from twelve different PODMs using data from two well defined orbits are presented. A number of solutions were obtained from each PODM when the angular difference (true anomaly difference) between observation data was varied from several degrees to one complete revolution. The PODMs evaluated use combinations of inertial position, angels, range and range rate, and corresponding universal times as input data. The computation time required for each PODM is tabulated for a nearly circular orbit with a small semimajor axis and one of higher eccentricity and a larger semimajor axis.
In comparing the five PODMs using position and time input data, the results indicate that the optimum PODM is the Lambert-Euler. Herrick-Gibbs is the optimum of the seven PODMs using angles only and mixed data.

A computational algorithm was used to adapt inertial position, velocity, and time input data to angular, range, range rate, and time input data from several different observation stations. A general FORTRAN code with program listings and computer program flowcharts is documented and can be utilized with computers other than the SDS 930 used in these solutions with only slight modifications. The computer core requirements for each program listing presented is tabulated.

The PODMs using inertial position and universal time input data yield solutions to the intercept, rendezvous, and interplanetary transfer problems of trajectory analysis. The angles only PODMs are the more classical PODMs which solve for fundamental orbital elements using the observer as main participant. Standing on a given location on the central planet of the orbiting body, an observer can measure the angular coordinates and determine the orbit. With the introduction of radar, the mixed data techniques are attractive to the trajectory analyst. The slant range from the observer to the satellite is obtainable as well as the rate at which this range is changing. The modern trajectory analyst uses the mixed data PODMs more frequently because of the excellent range and range rate data available.

The twelve PODMs may be used in any number of different problems confronting the trajectory analyst. The data presented can be used to predetermine a set of conditions which must exist in order to use the PODM which will yield the best determination of the orbit. Various combinations of observation stations and satellite observation data can be used effectively for orbit determination. With the computer programs available to each PODM, they may be used as computer program options which can be called on command to yield the best orbital results. This would be an efficient and accurate method for determining orbits of unknown space objects. The PODM results can be used to determine look angles for observation stations at later dates.
APPENDIX A
SYMBOLS AND ABBREVIATIONS

English Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Azimuth angle. Miscellaneous constants. Area.</td>
</tr>
<tr>
<td>A</td>
<td>Auxiliary vector used in the method of Gauss. Unit vector pointing due east.</td>
</tr>
<tr>
<td>a</td>
<td>Semimajor axis of a conic section. Matrix coefficient.</td>
</tr>
<tr>
<td>a_e</td>
<td>Equatorial radius of Earth.</td>
</tr>
<tr>
<td>B</td>
<td>Miscellaneous constants.</td>
</tr>
<tr>
<td>B</td>
<td>Auxiliary vector used in the method of Gauss. Semiminor axis of a conic section.</td>
</tr>
<tr>
<td>C_ψ</td>
<td>The dot product of (-R • L).</td>
</tr>
<tr>
<td>C_e</td>
<td>Element (= e cos E_0).</td>
</tr>
<tr>
<td>C_h</td>
<td>Element (= e cosh F_0).</td>
</tr>
<tr>
<td>C_v</td>
<td>Element (= e cos v_0).</td>
</tr>
<tr>
<td>c</td>
<td>Ratio of sector to triangle in the method of Gauss.</td>
</tr>
<tr>
<td>E</td>
<td>Eccentric anomaly. Miscellaneous constants.</td>
</tr>
<tr>
<td>e</td>
<td>Orbital eccentricity. Mathematical constant.</td>
</tr>
<tr>
<td>f</td>
<td>Geometrical flattening of reference spheroid adopted for central planet. Functional notation. Coefficient of f and g series.</td>
</tr>
<tr>
<td>G</td>
<td>Station location and shape coefficients. Universal gravitational constant. Miscellaneous constants.</td>
</tr>
<tr>
<td>g</td>
<td>Coefficient of f and g series. Gravitational acceleration.</td>
</tr>
<tr>
<td>H</td>
<td>Station elevation measured normal to adopted ellipsoid.</td>
</tr>
</tbody>
</table>
h  Elevation angle.

A  Angular momentum vector.

i  Unit vector along the principal axis of a given coordinate system.

I  Orbital inclination. The imaginary (= $\sqrt{-1}$).

J  Harmonic coefficients of the Earth's potential function.

K  Unit vector advanced to I by a right angle in the fundamental plane.

K  A constant.

K  Unit vector defined by I X J = K.

k_e  Gravitational constant.

L  Unit vector from observational station to satellite.

M  Mean anomaly $[= n(t - T)]$.

m  General symbol for mass. Meters.

N  Number of revolutions.

n  Mean motion $[= k\sqrt{\mu/a^2}]$. Number of revolutions.

P  Orbital period (time from perigee crossing to perigee crossing).

P_h  Perifocus.

P  Unit vector pointing toward perifocus.

p  Orbital semiparameter $[= a(1 - e^2)]$.

Q  Unit vector advanced to P by a right angle in the direction and plane of motion.

q  Generalized element. Perifocal distance $[= a(1 - e)]$. Parameter of f and g series expansions.

R  Perturbative function $[= \phi - V]$. Magnitude of station coordinate vector.
\( \mathbf{R} \)  
Station coordinate vector.  
Alternate notation for \( \mathbf{U} \).

\( r \)  
Magnitude of satellite radius vector.

\( \mathbf{r} \)  
Satellite radius vector.

\( S \)  
Satellite symbol.

\( S_e \)  
Element \( ( = e \sin E) \).

\( S_h \)  
Element \( ( = e \sinh F) \).

\( S_v \)  
Element \( ( = e \sin \nu) \).

\( s \)  
A parameter taking the value 1 or -1.

\( T \)  
Time of perifocal passage.

\( t \)  
Universal or ephemeris time.

\( \mathbf{U} \)  
Unit vector pointing toward given satellite.

\( u \)  
Argument of latitude.  
Parameter of \( f \) and \( g \) series expansions.

\( V \)  
General symbol for velocity vector magnitude.  
Spherical potential of planet.

\( \mathbf{v} \)  
Unit vector advanced to \( \mathbf{U} \) by a right angle in the direction and plane of motion.

\( \mathbf{w} \)  
Unit vector perpendicular to orbit plane.

\( X, Y, Z \)  
Rectangular coordinates of station coordinate vector.

\( x, y, z \)  
Rectangular coordinates of an object.

\( z \)  
Unit vector in the zenith direction.
Special Symbols

=  Identically equal to.
   Equal to by definition.

\equiv  Replace left side of equation with right side of equation.

\approx  Approximately equal to.

\varphi  Vernal equinox (sign of the Ram's Horns).

\infty  Infinity.

\angle x, y  Angle between x and y.

\rightarrow  Yields.

|x|  Absolute value of x.

Superscript Symbols

\cdot  Relating to modified time differentiation. Also ('').

\,\cdot\,  Relating to general differentiation.
   Relating to geocentric latitude.
   Minutes of arc.

\,\prime\,  Seconds of arc.

\ast  Particular parameter or special form of an analytical expression.

\sim  Particular parameter or special form of an analytical expression.

\bar  Used to denote average or special form of an analytical expression
   or parameter.

\circ  Degrees.

hr  Hours.

min  Minutes.

sec  Seconds.
Greek Alphabet

A α Alpha.  
B β Beta.  
Γ γ Gamma.  
Δ δ Delta.  
Ε ε Epsilon.  
Ζ ζ Zeta.  
Η η Eta.  
Θ θ Theta.  
Ι i Iota.  
Κ κ Kappa.  
Λ λ Lambda.  
Μ μ Mu.  
N ν Nu.  
Ξ ξ Xi.  
Ο o Omicron.  
Π π Pi.  
Ρ ρ Rho.  
Σ σ Sigma.  
Τ τ Tau.  
Τυ Upsilon.  
Φ φ Phi.  
Χ χ Chi.  
Ψ ψ Psi.  
Ω ω Omega.

Greek Symbols

α Right ascension.  
Δ Increment or difference.  
∇ Gradient operator.  

\[ \nabla = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} \]

ε Obliquity of the ecliptic.  
Specified tolerance.  
ζ Coefficient.  
θ Sidereal time.  
λ Longitude.  
μ Sum of masses or mass.  
ν True anomaly.  
ρ Slant range vector.
Greek Symbols (Cont'd)

- $\phi$  Geodetic latitude.
- $\phi$  Geocentric latitude.
- $\phi_a$  Astronomical latitude.
- $\Omega$  Longitude of ascending node.
- $\omega$  Longitude of descending node.
- $\omega$  Argument of perigee.

Abbreviations

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.u.</td>
<td>Astronomical units.</td>
</tr>
<tr>
<td>cm</td>
<td>Centimeters.</td>
</tr>
<tr>
<td>c.m.</td>
<td>Central masses.</td>
</tr>
<tr>
<td>c.s.u.</td>
<td>Circular satellite units (also g.c.s.u.; geocentric circular satellite units)</td>
</tr>
<tr>
<td>c.u.</td>
<td>Characteristic units.</td>
</tr>
<tr>
<td>CUL</td>
<td>Canonical unit of length.</td>
</tr>
<tr>
<td>CUT</td>
<td>Canonical unit of time.</td>
</tr>
<tr>
<td>deg</td>
<td>Degrees.</td>
</tr>
<tr>
<td>e.m.</td>
<td>Earth masses.</td>
</tr>
<tr>
<td>e.r.</td>
<td>Earth radii.</td>
</tr>
<tr>
<td>ft</td>
<td>Feet.</td>
</tr>
<tr>
<td>gm</td>
<td>Grams.</td>
</tr>
<tr>
<td>hr</td>
<td>Hours.</td>
</tr>
<tr>
<td>h.c.s.u.</td>
<td>Heliocentric circular satellite units.</td>
</tr>
<tr>
<td>J.D.</td>
<td>Julian date.</td>
</tr>
<tr>
<td>km</td>
<td>Kilometers.</td>
</tr>
<tr>
<td>m</td>
<td>Meters.</td>
</tr>
<tr>
<td>min</td>
<td>Minutes.</td>
</tr>
<tr>
<td>sec</td>
<td>Seconds.</td>
</tr>
<tr>
<td>s.m.</td>
<td>Solar masses.</td>
</tr>
</tbody>
</table>
Figure 1. Orbit Plane Coordinate System Showing Unit Vectors and Orientation Angles
APPENDIX B
LAMBERT-EULER PODM, POSITION AND TIME

Given $r_1 (x_1, y_1, z_1)$, $r_2 (x_2, y_2, z_2)$ and their corresponding universal times, $t_1$ and $t_2$, proceed as follows:

$$\tau = k_e (t_2 - t_1)$$  \hspace{1cm} (1)

$$r_1 = \frac{1}{\sqrt{r_1 \cdot \overline{r}_1}}$$  \hspace{1cm} (2)

$$r_2 = \frac{1}{\sqrt{r_2 \cdot \overline{r}_2}}$$  \hspace{1cm} (3)

$$u_1 = \frac{r_1}{r_1}$$  \hspace{1cm} (4)

$$u_2 = \frac{r_2}{r_2}$$  \hspace{1cm} (5)

$$\cos (v_2 - v_1) = u_1 \cdot u_2$$  \hspace{1cm} (6)

$$\sin (v_2 - v_1) = \frac{x_1 y_2 - x_2 y_1}{|x_1 y_2 - x_2 y_1|} \sqrt{1 - \cos^2 (v_2 - v_1)}$$  \hspace{1cm} (7)

As a first approximation, if no better estimate is available, set

$$a = \frac{(r_1 + r_2)}{2}$$  \hspace{1cm} (8)
and continue calculating with

$$c = + \left[ r_2^2 + r_1^2 - 2(x_1x_2 + y_1y_2 + z_1z_2) \right]^{1/2} \ 	ag{9}$$

$$\sin \frac{1}{2} \varepsilon = + \sqrt{\frac{1}{4a} \left( r_2 + r_1 + c \right)} \ 	ag{10}$$

$$\sin \frac{1}{2} \delta = + \frac{\sqrt{r_2r_1} \cos \left( \frac{\nu_2 - \nu_1}{2} \right)}{2a \sin \frac{1}{2} \varepsilon} \ 	ag{11}$$

$$\cos \frac{1}{2} \delta = + \sqrt{1 - \frac{1}{4a} \left( r_2 + r_1 - c \right)} \ 	ag{12}$$

Set

$$s = 1 \ 	ag{13}$$

Later the analysis will be repeated for

$$s = -1 \ 	ag{14}$$

Continue with

$$\cos \frac{1}{2} \varepsilon = s \sqrt{1 - \sin^2 \frac{1}{2} \varepsilon} \ 	ag{15}$$

$$F = \tau - \frac{3a}{\sqrt{\mu}} \left[ (\varepsilon - \sin \varepsilon) - (\delta - \sin \delta) \right] \ 	ag{16}$$

If

$$|F| < \Delta \ 	ag{17}$$
where $\Delta$ is a given tolerance, i.e., $10^{-10}$, proceed to equation (22); if it is not, save $F(a)$ and increment $a$, by 5 percent, that is, $\Delta a$, to obtain:

$$a + \Delta a$$  \hspace{2cm} (18)

Repeat equational loop (10) through (16), obtaining $F(a + \Delta a)$, and form

$$F'(a) = \frac{F(a + \Delta a) - F(a)}{\Delta a}$$  \hspace{2cm} (19)

Improve the value of $a$ by

$$a_{j+1} = a_j - \frac{F(a_j)}{F'(a_j)}, \quad j = 1, 2, 3, ..., q$$  \hspace{2cm} (20)

If

$$|a_{j+1} - a_j| < \Delta$$  \hspace{2cm} (21)

Proceed to equation (22); if not return to equation (10), replacing $a_j$ with $a_{j+1}$.

$$E_2 - E_1 = \epsilon - \delta$$  \hspace{2cm} (22)

$$f = 1 - \frac{a}{r_1} \left[ 1 - \cos (E_2 - E_1) \right]$$  \hspace{2cm} (23)

$$g = \tau - \frac{a^2}{\mu} \left[ E_2 - E_1 - \sin (E_2 - E_1) \right]$$  \hspace{2cm} (24)

$$r_1 = \frac{r_2 - f r_1}{g}$$  \hspace{2cm} (25)

Continue by calculating for the classical elements.
LAMBERT-EULER FLOWCHART

START

XLC (1), YLC (1), 2L (1), XLC (2), YLC (2), T (1), T (2), XMU, XK

ECHO CHECK

TIME = 0

DO 6
I = 1, 2

DO 31
I = 1, 25

F (I), 1

A

F (I) < 10^-10

T

B

F

1 <= 1

T

DELA = 0.05

DEL A

C

F

[ F (I) - DELA ] < 10^-10

T

B

F

I = 25

T

C

32

D

PAGE 24
LAMBERT-EULER FLOWCHART (CONT'D)

D

XLCV (1), YLCV (1), ZLCV (1)

SOLUTION FOR CLASSICAL ELEMENTS

JTIME, ALC, ELC, TE, OMEGA, OMICL, W

STOP
LAMBERT-EULER PRELIMINARY ORBIT DETERMINATION
POSITION AND TIME (FSRENAL PAGE 25)

DIMENSION F(P), X(P), Y(P), Z(P), RLC(P), YLC(P),
CYLC(P), ZLC(P), T(P), XLCV(1), YLCV(1), ZLCV(1), RLCV(1)

data 40. h = 1.6

READ TWO INERTIAL POSITION VECTORS AND THEIR CORRESPONDING TIMES

READ 101, YLC(1), YLC(1), ZLC(1), T(1), XLC(2)
READ 101, YLC(2), ZLC(2), T(2), X'U', X'

FORMAT(5F16.9)

END CHECK

PRINT 104, XLC(1), YLC(1), ZLC(1), T(1), XLC(2), YLC(2), ZLC(2), T(2), X'U', X'

FORMAT(10E16.9, 10X)

BEGIN COMPUTATIONS

ALL META SYMBOLS IS ITIME SUBROUTINE

ITIME = 0

LDA 2058
STA 2058
SRT 2058
SPL 2058
SPL20 2058
SPL30 2058
SPL40 2058

FIR

TAU = YV * (T(1) - T(1))

2 DO 6 I=1, P

RLC(I) = SQRT(YLC(I)**2 + YLC(I)**2 + ZLC(I)**2)

JX(I) = XLC(I) / RLC(I)

JY(I) = YLC(I) / RLC(I)

6 uz(I) = ZLC(I) / RLC(I)

VCS = (JX(I) * YV(2) + JY(I) * UY(2) + UZ(I) * UZ(2))

COS = XLC(I) / RLC(2) * YLC(1)

VSIV = C0V / ASIV(C0V) * SQRT(1.0 - VCS**2)

C = SQRT(RLC(2)**2 + RLC(1)**2 - 2.0 * (YLC(1) * XLC(2) + YLC(2) * YLC(1))

+ ZLC(1) * ZLC(2))

S = 1.0

14 A = (RLC(1) + RLC(2)) / 2.0

BEGIN LAMBERT-EULER ITERATION

15 DO 31 I = 1, P

SHFRS = SQRT((RLC(2) + RLC(1) + C) / (4.0 * A))

AMSV = ATAN(VSIV, VCS)

SHEL = SQRT(RLC(1) * RLC(2)) / COS(ASIV / SHFRS) / (2.0 * ASIV / SHFRS)
CHDEL = SCRT((1.0) - (RLC(2) + RLC(1) - C)/(4.0*A1))
CHEPS = SCRT((1.0) - SHFPS**2)
EPSL = 2.0*ATAN(SHPS, CHEPS)
DELTA = 2.0*ATAN(SHDEL, CHDEL)
F(I) = TAN(SCRT(A**3/X**U)) (((EPSL' = SIN(EPSL')) - (DELTA - SIN(''))))
CT1 = ITIMF
PRINT 120, CT1
PRINT 120, F(I)_D
FORMAT(1X, 1D20.14, 1X, 'I', 1X, 1D20.14, 1X, 'I')
ITIMF = 0
24 IF (ABS(F(I)) <= COCOCOCOCO1) $24, 25, 26
25 IF (I = 1) GO TO 26
26 FPA = (F(I) = F(I-1))/DELTA
27 IF (ABS(F(I) / FPA = DELTA - COCOCOCOCO1) $28, 29, 28
28 DELTA = F(I) / FPA
29 GO TO 31
30 DELTA = FPA
31 A = ABS(A + DELTA)
C
SOLVE FOR INITIAL VELOCITY VECTORS XDOT, YDOT, ZDOT.
C
32 DIFF = DELTA * DELTA
33 FLC = X**3-(X**3*(X**3) + (X**3+C))
34 SLC = TAN((A**3/X**U) + (X**3) - SIN(''))
XLCV(1) = (XLC(2) - FLC*XLC(1))/SLC
YLCV(1) = (YLC(2) - FLC*YLC(1))/SLC
ZLCV(1) = (ZLC(2) - FLC*ZLC(1))/SLC
CT1 = ITIMF
PRINT 120, CT1
PRINT 120, XLCV(1), YLCV(1), ZLCV(1)
FORMAT(1X, 1F16.5, 1X, 1F16.5, 1X, 1F16.5, 1X, 1F16.5)
C
SOLVE FOR CLASSICAL ELEMENTS
C
ITIMF = 0
RLC(1) = X**3*(X**3) + YLC(1)*X**3 + ZLC(1)*X**3
RLC(1) = X**3*(X**3) + YLC(1)*X**3 + ZLC(1)*X**3
RLCV(1) = X**3*(X**3) + YLCV(1)*X**3 + ZLCV(1)*X**3
V = SRT((XLCV(1)**3) + YLCV(1)**3 + ZLCV(1)**3)
ALC = (SLC(1)**3) + (XLCV(1)**3) + (YLCV(1)**3) + (ZLCV(1)**3)
CS = (ALC**3) + (XLCV(1)**3) + (YLCV(1)**3) + (ZLCV(1)**3)
SS = (CS**3) + (XLCV(1)**3) + (YLCV(1)**3) + (ZLCV(1)**3)
FLC = CS**3 + XLCV(1)**3 + YLCV(1)**3 + ZLCV(1)**3
XSCV = ALC**3*(X**3*FLC)
YSCV = ALC**3*(Y**3*FLC)
ZSCV = ALC**3*(Z**3*FLC)
SINV = SRT((X**3) + (Y**3) + (Z**3))
SINV = SRT((X**3) + (Y**3) + (Z**3))
F = A**3 + CS
T = T**3*(X**3*FLC) + (Y**3*FLC) + (Z**3*FLC)
X = (T**3) + (T**3) + (T**3)
Y = (T**3) + (T**3) + (T**3)
Z = (T**3) + (T**3) + (T**3)
V = A**3 + CS
26
APPENDIX C
F AND G SERIES PODM, POSITION AND TIME

Given \( r_1 (x_1, y_1, z_1) \), \( r_2 (x_2, y_2, z_2) \) and their corresponding universal times, \( t_1 \) and \( t_2 \), proceed as follows:

\[
\begin{align*}
\text{r}_1 &= \mp \sqrt{r_1 \cdot r_1} \\
\text{r}_2 &= \pm \sqrt{r_2 \cdot r_2} \\
\text{u}_1 &= \frac{r_1}{r_1} \\
\text{u}_2 &= \frac{r_2}{r_2} \\
\cos (v_2 - v_1) &= \text{u}_1 \cdot \text{u}_2 \\
\sin (v_2 - v_1) &= \frac{x_1y_2 - x_2y_1}{|x_1y_2 - x_2y_1|} \sqrt{1 - \cos^2 (v_2 - v_1)} \\
\end{align*}
\]

\[
\begin{align*}
t_0 &= \frac{t_2 + t_1}{2} \\
\tau_1 &= k_e (t_1 - t_0) \\
\tau_2 &= k_e (t_2 - t_0)
\end{align*}
\]
\[ r_0 = \frac{r_2 + r_1}{2} \]  
\[ A = 1 - \frac{\mu\tau_1^2}{2r_0^3} \]  
\[ B = 1 - \frac{\mu\tau_2^2}{2r_0^3} \]  
\[ \Delta = A \tau_2 - B \tau_1 \]  
\[ \dot{r}_0 = \left( \frac{\tau_2}{\Delta} \right) r_1 - \left( \frac{\tau_1}{\Delta} \right) r_2 \]  
\[ \ddot{r}_0 = \left( \frac{A}{\Delta} \right) r_2 - \left( \frac{B}{\Delta} \right) r_1 \]  
\[ r_0 = \sqrt{r_0 \cdot \ddot{r}_0} \]  
\[ v_0 = \sqrt{\dot{r}_0 \cdot \ddot{r}_0} \]  
\[ \ddot{r}_0 = \frac{r_0 \cdot \ddot{r}_0}{r_0} \]  
\[ \frac{1}{a} = \frac{2}{r_0} - \frac{v_0^2}{\mu} \]
\[ U_0 = \frac{\mu}{r_0^3} \]  

(45)

\[ P_0 = \frac{r_0 \dot{r}_0}{r_0^2} \]  

(46)

\[ q_0 = \frac{v_0^2 - r_0^2 u_0}{r_0^2} \]  

(47)

Utilize the \( f \) and \( g \) functions:

\[ f_1 = f (V_0, r_0, \dot{r}_0, \tau_1) \]  

(48)

\[ f_2 = f (V_0, r_0, \dot{r}_0, \tau_2) \]  

(49)

\[ g_1 = g (V_0, r_0, \dot{r}_0, \tau_1) \]  

(50)

\[ g_2 = g (V_0, r_0, \dot{r}_0, \tau_2) \]  

(51)

and form

\[ D = f_1 g_2 - f_2 g_1 \]  

(52)

\[ C_1 = \frac{g_2}{D} \]  

(53)
\[ c_2 = \frac{-g_1}{D} \]  \hfill (54)
\[ \dot{c}_1 = \frac{-f_2}{D} \]  \hfill (55)
\[ \dot{c}_2 = \frac{f_1}{D} \]  \hfill (56)

Hence, a better approximation to \( \hat{r}_0, \hat{r}_0 \) is given by

\[ \hat{r}_0 = c_1 \hat{r}_1 + c_2 \hat{r}_2 \]  \hfill (57)
\[ \ddot{r}_0 = \dot{c}_1 \hat{r}_1 + \dot{c}_2 \hat{r}_2 \]  \hfill (58)

Return to equation (41) and repeat the equational loop to equation (58); continue until \( r_0, \hat{r}_0, V_0 \) from equations (41), (42), and (43) do not vary, that is,

\[ |(r_0)_{n+1} - (r_0)_n| < \varepsilon_1 \]  \hfill (59)
\[ |(\hat{r}_0)_{n+1} - (\hat{r}_0)_n| < \varepsilon_2 \]  \hfill (60)
\[ |(V_0)_{n+1} - (V_0)_n| < \varepsilon_3, \ n = 1, 2, \ldots, q \]  \hfill (61)

Where \( \varepsilon_1, \varepsilon_2, \) and \( \varepsilon_3 \) are tolerances, i.e., \( 10^{-10} \). Having \( r, \dot{r}, \text{ and } V \), utilize the derivatives of the \( f \) and \( g \) functions, that is,

\[ \dot{f}_1 = \dot{f} (V_0, r_0, \dot{r}_0, \tau_1) \]  \hfill (62)
\[ \dot{g}_1 = \dot{g} (V_0, r_0, \dot{r}_0, \tau_1) \]  \hfill (63)
to obtain

\[ \dot{r}_1 = \dot{f}_1 r_0 + \dot{g}_1 \dot{r}_0 \]  \hspace{1cm} (64)

Continue by calculating for classical elements
F AND G SERIES FLOWCHART

START

XLC(1), YLC(1), ZLC(1), XLC(2), YLC(2), ZLC(2), T(1), T(2), XMU, XK

ECHO CHECK

ITIME = 0

DO 5
J = 1, 2

D

DO 53
I = 1, 25

A

32
L = 1, 2

RLCN(1), VN(1), RLCNV(1), T

ABS \[ \frac{RLCN(h+1)}{RLCN(h)} \] \( < 10^{-10} \)

F

T

ABS \[ \frac{VN(i+1) - VN(i)}{VN(i)} \] \( < 10^{-10} \)

F

T

ABS \[ \frac{RLCNV(i+1)}{RLCNV(i)} \] \( < 10^{-10} \)

T

51

B

C

PAGE 34

PAGE 34
F AND G SERIES FLOWCHART (CONT'D)

B

C

T

I = 25

F

D

54

XLCV (1), YLCV (1), ZLCV (1)

SOLUTION FOR CLASSICAL ELEMENTS

ITIME, ALC, ELC, TE, OMEGA, OINCL, W

STOP

PAGE 33
F AND G SERIES PRELIMINARY ORBIT DETERMINATION METHOD
POSITION AND TIME (FSCORBAL, PAGE 22)

DIMENSION RLC(3), UX(2), UY(2), UZ(2), XLC(P), YLC(P), T(3),
CTAU(P), XLCV(1), YLCV(1), 7LCV(1), RLCN(25), C(2), CV(2), G(2), F(L)
C
CVN(25), PLCN(25), XLCN(25), YLCN(25), ZLCN(25), XLCV(25), YLCV(25), ZLCV(25)
C
DB 90 K=1,6

READ TWO INERTIAL POSITION VECTORS AND THEIR CORRESPONDING TIMES

READ 101, XLC(1), YLC(1), ZLC(1), T(1), XLC(2)
READ 101, YLC(2), ZLC(2), T(2), X, Y, Z

FORMAT(5F16.8)

ECH3 CHECK

PRINT 104, XLC(1), YLC(1), ZLC(1), T(1), XLC(2), YLC(2), ZLC(2), T(2),
CXMUX

104 FORMAT(14H0, 5X, XLC(1) = F16.8, YLC(1) = F16.8, ZLC(1) = F16.8,
1H+T(1) = F16.8, XLC(2) = F16.8, YLC(2) = F16.8, ZLC(2) = F16.8,
1H+T(2) = F16.8, XMUX = F16.8, XK = F16.8)

BEGIN COMPUTATIONS

ALL META SYMBOLS IS TIME SUBROUTINE

ITIM='0
1 DO 5 J=1, P
RLC(J) = RCT(1, XLC(J), YLC(J), ZLC(J), T(J))
UX(J) = XLC(J)/RLC(J)
UY(J) = YLC(J)/RLC(J)
UZ(J) = ZLC(J)/RLC(J)
VCOS = UX(1)*UX(J) + UY(1)*UY(J) + UZ(1)*UZ(J)
COS = XLC(1) - XLC(J) - YLC(1) - YLC(J) - ZLC(1) - ZLC(J)
T(3) = T(J) + T(1) / P
TAU(1) = Y* (T(1) - T(3))
TAU(2) = Y* (T(2) - T(3))
RX = (PLC(J) - PLC(P)) / P
A=1*Y* Y* TAU(1)* P / P* C
B=1*Y* Y* TAU(2)* P / P* C
DELTA = A*TAU(J) - B*TAU(1)
XLC(J) = (TAU(2)/DELTA))*XLC(J) - (T(J)/DELTA)*XLC(1)
YLC(J) = (TAU(2)/DELTA))*YLC(J) - (T(J)/DELTA)*YLC(1)
ZLC(J) = (TAU(2)/DELTA))*ZLC(J) - (T(J)/DELTA)*ZLC(1)

5 CONTINUE
BEGIN F AND G SERIES ITERATION

DF 35 J=1,2

AIV=N=0.*C(I)*C(L)*V(I)*V(L)

UN=X(I)*C(L)*C(I)

P=V(L)*I*RLC(I)*RLC(I)

V=V(I)*P*RLC(I)*RLC(I)

30 IF J=1,2

D(L)=1.*C(I)*C(L)*TAU(L)

C(N)=15.*C(I)*C(L)*TAU(L)

G(L)=TAU(L)*10.*C(I)*C(L)*TAU(L)

C(1)=C(I)*C(L)*C(I)*C(L)

C(N)=30.*C(I)*C(L)*C(I)*C(L)

D(G)=G(L)*G(L)

C(1)=C(I)*C(L)

C(N)=C(I)*C(L)

CV(I)=F(V(I))

F(V)=F(1)

XLC(I+1)=C(I)*XLC(I)+C(I)*XLC(I)

YLC(I+1)=C(I)*YLC(I)+C(I)*YLC(I)

ZLC(I+1)=C(I)*ZLC(I)+C(I)*ZLC(I)

RCLC(I+1)=C(I)*RCLC(I)+C(I)*RCLC(I)

RLC(I+1)=C(I)*RLC(I)+C(I)*RLC(I)

V(I+1)=SFT(XLC(I+1)*YLC(I+1)*ZLC(I+1))

C(I+1)=C(I)*C(I)+C(I)*C(I)

CT=CT

40 IF(ABS(RCLC(I+1)-RCLC(I))<E00000000000001)

50 IF(ABS(V(I+1)-V(I))<E00000000000001)

50 IF(ABS(ZLC(I+1)-ZLC(I))<E00000000000001)

CONTINUE

50 XLC=XL(I+1)

50 YLC=YL(I+1)

50 ZLC=ZL(I+1)
107 FORMAT(140, 1ALC=E16.8, 1CL=C=E16.8, 1TF=T15.8, 1MEGA=ME16.8, 0J=JCL=E16.8, 1J=16.8)
90 CONTINUE
GO TO 61
STOP PZE
S  MIN         ITIME
S  BRU         *STOP
61  END
APPENDIX D
ITERATION OF SEMIPARAMETER PODM, POSITION AND TIME

Given \( r_1 (x_1, y_1, z_1) \), \( r_2 (x_2, y_2, z_2) \) and their corresponding universal times, \( t_1 \) and \( t_2 \), proceed as follows:

\[
\tau = k_e (t_2 - t_1) \quad (65)
\]

\[
r_1 = + \sqrt{r_1 \cdot r_1} \quad (66)
\]

\[
r_2 = + \sqrt{r_2 \cdot r_2} \quad (67)
\]

\[
u_1 = \frac{r_1}{r_1} \quad (68)
\]

\[
u_2 = \frac{r_2}{r_2} \quad (69)
\]

\[
\cos (\nu_2 - \nu_1) = u_1 \cdot u_2 \quad (70)
\]

\[
\sin (\nu_2 - \nu_1) = \frac{x_1 y_2 - x_2 y_1}{|x_1 y_2 - x_2 y_1|} \sqrt{1 - \cos^2 (\nu_2 - \nu_1)} \quad (71)
\]

As a first estimate, let

\[
p_g = 0.4 (r_1 + r_2) \quad (72)
\]
\[ p = p_g \]  \hspace{1cm} (73)

and continue calculating with

\[ e \cos v_1 = \frac{p}{r_1} - 1 \]  \hspace{1cm} (74)

\[ e \cos v_2 = \frac{p}{r_2} - 1 \]  \hspace{1cm} (75)

\[ e \sin v_1 = \frac{\cos (v_2 - v_1)(e \cos v_1) - (e \cos v_2)}{\sin (v_2 - v_1)} \]  \hspace{1cm} (76)

\[ e \sin v_2 = \frac{-\cos (v_2 - v_1)(e \cos v_2) - (e \cos v_1)}{\sin (v_2 - v_1)} \]  \hspace{1cm} (77)

\[ e = \sqrt{(e \cos v_1)^2 + (e \sin v_1)^2} \]  \hspace{1cm} (78)

\[ a = \frac{p}{1 - e^2} \]  \hspace{1cm} (79)

\[ n = k \sqrt{\frac{\mu}{a^3}} \]  \hspace{1cm} (80)
If \( e \neq 0 \), proceed with equation (81); if \( e = 0 \) within a given tolerance, continue with equation (83).

\[
\cos E_i = \frac{r_i}{p} (\cos \nu_i + e), \quad i = 1, 2 \tag{81}
\]

\[
\sin E_i = \frac{r_i}{p} \sqrt{1 - e^2 \sin \nu_i}, \quad i = 1, 2 \tag{82}
\]

Continue calculating with equation (88).

\[
e = 0 \quad , \quad \nu_1 = 0 \tag{83}
\]

\[
\cos E_1 = 1 \tag{84}
\]

\[
\cos E_2 = \cos (\nu_2 - \nu_1) \tag{85}
\]

\[
\sin E_1 = 0 \tag{86}
\]

\[
\sin E_2 = \sin (\nu_2 - \nu_1) \tag{87}
\]

\[
M_i = E_i - e \sin E_i \quad , \quad i = 1, 2 \tag{88}
\]

\[
F = \tau - \left( \frac{M_2 - M_1}{n} \right) k_e \tag{89}
\]
If \( F = 0 \), proceed to equation (92); if not, increment \( p \) by 5 percent and, by repeating equational loop (74) through (89), obtain

\[
F'(p) = \frac{F(p + \Delta p) - F(p)}{\Delta p}
\]  
(90)

Hence, a better approximation to the semiparameter is

\[
p_{j+1} = p_j - \frac{F(p_j)}{F'(p_j)} , \quad j = 1, 2, \ldots, q
\]  
(91)

Repeat the above loop \( q \) times until \( p \) is constant within a given tolerance, i.e., \( 10^{-10} \). Finally, continue calculating with equation (92).

\[
f = 1 - \frac{a}{r_1} \left[ 1 - \cos (E_2 - E_1) \right]
\]  
(92)

\[
g = \tau - \sqrt{\frac{a^3}{\mu}} \left[ E_2 - E_1 - \sin (E_2 - E_1) \right]
\]  
(93)

\[
c_1 = \frac{r_2 - f r_1}{g}
\]  
(94)

Continue by calculating for classical elements.
ITERATION OF SEMIPARAMETER

START

XLC(1), YLC(1), zLC(1), T(1), XLC(2), YLC(2), zLC(2), T(2), XMV, XK

ECHO CHECK

ITIME = 0

DO 6
I = 1, 2

DO 48
I = 1, 25

ELC ≤ 10^-10

T

ELC = 0.0

F

A

B

DO 28
N = 1, 2

38

DO 39
M = 1, 2

F(I), 1

ABS[F(I)] < 10^-10

T

C

PAGE 44

F

I ≤ 1

T

F

D

DEL P = 0.05

PLC

PAGE 44

E
ITERATION OF SEMIPARAMETER (CONT'D)

ITERATION OF SEMIPARAMETER (CONT'D)

ITERATION OF SEMIPARAMETER (CONT'D)

ITERATION OF SEMIPARAMETER (CONT'D)

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ITERATION OF SEMIPARAMETER (CONT'D)

ITERATION OF SEMIPARAMETER (CONT'D)

ITERATION OF SEMIPARAMETER (CONT'D)
ITERATION OF SEMIPARAMETER COUPLING AT TIME AND POSITION (COMPUTATIONAL PAGE 91)

DIMENSION T(20),YLC(2),UX(J),UY(J),UZ(J),COS(J),S(J),
COSV(J),SIV(J),COSR(J),ST(J),DR(J),XLC(2),YLC(1),UX(J),UY(J),UZ(J),
ZLCV(1),ZLV(1),YLC(1),XLC(2),YLC(2),ZLC(1),1(J),

DO TC=1,4

READ TWO INITIAL POSITION VECTORS AND THEIR CORRESPONDING VELOCITIES
READ 101, YLC(1), YLC(2), ZLC(1), T(1), XLC(2)
READ 101, YLC(2), ZLC(2), T(2), XLC(2)
FORMAT(FF16.8)

END FILE

READ 104, XLC(1),YLC(1),ZLC(1),T(1),XLC(2),YLC(2),ZLC(2),T(2)
FORMAT(FF16.8)

BEGI COMPUTATIONS

ALL INITIAL VELOCITIES ARE SET TO ZERO

ITR = 0

LDA 2059
STA 2058
BNE 2060

S205 BNE 2060

S206 POT = 00000000

S207 EIP

TA=F*(T(2)-T(1))

DO 6 J=1,2

PLC(J)=COS(YLC(J))*UX(J)+YLC(J)*COS(1)*UX(J)

UX(J)=UX(J)/PLC(J)

UY(J)=UY(J)/PLC(J)

UZ(J)=UZ(J)/PLC(J)

6 VCONS=U(1)*UY(2)+U(2)*UY(1)+U(1)*UZ(2)+U(2)*UZ(1)

CVR=U(1)*YLC(J)+XLC(2)*YLC(1)

VS1=CVR/ABS(CVR)*SUV(1)/CVR*CVR

PC=0.5*(YLC(1)+ZLC(2))

PLC=PC

BEIG I ITERATION OF SEMIPARAMETER

DO 11 K=1,2

FCOSV(1)=PLC/RC(1)-1.0

FCOSV(2)=PLC/RC(2)-1.0

ESTLV(1)=FCOSV*FCSV(1)-FCSV(2)/VST1

ESTLV(2)=(FCOSV*FCSV(1)+FCSV(2))/VST1

11 CONTINUE
ELC=SORT(ABS(COSV(1)**2+ESINV(1)**2))
ALC=PLC/(1+ELC**2)
ETA=XX*SORT(ABS(XMU/ALC**2))
COSV(1)=PLC/(RLC(1)*ELC)-1.0/ELC
COSV(2)=PLC/(RLC(2)*ELC)-1.0/ELC
SINV(1)=VCAS+COSV(1)-COSV(2)/(VSIN*ELC)
SINV(2)=VCAS+COSV(2)+COSV(1)/(VSIN*ELC)

24 IF(ELC=0) GOTO 30
25 DO PR=1,2
26 CASE(1)=RLC(1)/PLC*(COSV(N)+FLC)
27 CASE(2)=RLC(2)/PLC*SORT(1.0+ELC*PR)*SINV(N)
28 ANGE(N)=ATAN(SINV(N),COSV(N))
29 STOP
30 ELC=0.0
31 VLC(1)=NO
32 CASE(1)=1.0
33 CASE(2)=VCPS
34 SINV(1)=0.0
35 SINV(2)=VLC(N)
36 ANGE(1)=0.0
37 ANGE(2)=ATAN(SINV(2),CASE(2))
38 DB 39 DM=1.0
39 XM=FAN(N)=ANGE(N)-FLC*SINV(N)
40 F(I)=TATAN((XMFAN(N)-XMFAN(1))/ETA)*XK
41 CT=ITIME+C
42 PRINT 130, CT
43 PRINT 130, F(I), 1
44 FORMAT(110, IF(I)=TET1,=***I=**12)
45 ITIME=0
46 IF(I=1) 47,48
47 IF(I-1) 49,50
48 IF(I=1,2) 47,48
49 IF(I=1) 51,52
50 IF(I=2) 53,54
51 IF(I=1,2) 50,52
52 IF(I=1,2) 51,53
53 IF(I=1,2) 52,54
54 IF(I=1) 55,56
55 IF(I=2) 57,58
56 IF(I=1) 53,54
57 CT=ITIME
58 PRINT 130, CT
59 PRINT 130, XLCV(1), YLCV(1), ZLCV(1)
60 FORMAT(*,YLCV(1)=F16.8,X/YLCV(1)=11.68.8/15.7LC(1))
61 SOLVE FOR INITIAL VELOCITY VECTORS X, Y, AND Z
62 SOLVE FOR CLAISON ELEMENTS
63 ITIME=0
64 RLC(1)=SORT(YLC(1)**2+YLC(1)**2+ZLC(1)**2)
APPENDIX E
GAUSSIAN POOM, POSITION AND TIME

Given $r_1 (x_1, y_1, z_1)$, $r_2 (x_2, y_2, z_2)$ and their corresponding universal times, $t_1$ and $t_2$, proceed as follows:

$$\tau = k_e (t_2 - t_1) \quad (95)$$

$$r_1 = +\sqrt{r_1 \cdot r_1} \quad (96)$$

$$r_2 = +\sqrt{r_2 \cdot r_2} \quad (97)$$

$$\cos (\nu_2 - \nu_1) = \frac{r_1 \cdot r_2}{r_1 r_2} \quad (98)$$

$$\sin (\nu_2 - \nu_1) = \frac{x_1 y_2 - x_2 y_1}{|x_1 y_2 - x_2 y_1|} \sqrt{1 - \cos^2 (\nu_2 - \nu_1)} \quad (99)$$

Obtain the constants

$$l = \frac{r_1 + r_2}{4 \sqrt{r_1 r_2} \cos \left(\frac{\nu_2 - \nu_1}{2}\right)} - \frac{1}{2} \quad (100)$$

$$m = \frac{\mu \tau^2}{\left[2 \sqrt{r_1 r_2} \cos \left(\frac{\nu_2 - \nu_1}{2}\right)\right]^3} \quad (101)$$
As a first approximation, set

\[ y = 1 \]  \hspace{1cm} (102)

and continue calculating with

\[ x = \frac{m}{y^2} - 1 \]  \hspace{1cm} (103)

\[ \cos \left( \frac{E_2 - E_1}{2} \right) = 1 - 2x \]  \hspace{1cm} (104)

\[ \sin \left( \frac{E_2 - E_1}{2} \right) = \sqrt{4x (1 - x)} \]  \hspace{1cm} (105)

\[ X = \frac{(E_2 - E_1) - \sin (E_2 - E_1)}{\sin^3 \left( \frac{E_2 - E_1}{2} \right)} \]  \hspace{1cm} (106)

\[ y = 1 + X (1 + x) \]  \hspace{1cm} (107)

If \( y \) is now equal to the assumed value within some tolerance, continue with equation (108); if it is not, place the value of \( y \) from equation (107) into equation (103) and repeat equational loop (103) through (107). Continue calculating with

\[ a = \left[ \frac{\pi \sqrt{\mu}}{2y \sqrt{r_2 r_1} \cos \left( \frac{\nu_2 - \nu_1}{2} \right) \sin \left( \frac{E_2 - E_1}{2} \right)} \right]^2 \]  \hspace{1cm} (108)
\[ f = 1 - \frac{a}{r_1} \left[ 1 - \cos (E_2 - E_1) \right] \quad (109) \]

\[ g = \sqrt[3]{\frac{a}{\mu}} \left[ (E_2 - E_1) - \sin (E_2 - E_1) \right] \quad (110) \]

\[ \dot{r}_1 = \frac{r_2 - f \cdot r_1}{g} \quad (111) \]

Continue to calculate for classical elements.
GAUSSIAN PRELIMINARY PAGE "DETERMINATION" "ETC."

POSITION AND TIME (ESCAPE, CASE 166)

DIMENSION XLC(2), YLC(2), ZLC(2), RLC(2), YLC(25), YLCV(1),
CZLCV(1), YLCV(1), T(2), RLCV(1)

DE 70, X = 1.6

READ THE VS/ANG WAVEFUNCTION AND THE LCP.

READ 101, XLC(1), YLC(1), ZLC(1), T(1), YLC(2)
READ 101, YLC(2), ZLC(2), T(2), X =, X

FORMAT (*.16, E)

END CHECK

PRINT 104, XLC(1), YLC(1), ZLC(1), T(1), XLC(2), YLC(2), ZLC(2), T(2), X =, X

FORMAT(*.16, E)

104 FORMAT(*.16, E)

BEGIN FORMATION'S

ALL METALS AND LCP'S

ITM #0

LDA 2005

STA 2006

BRJ 2006

BRV 2006

S205 2005

S206 2006

S207 2007

S208 2008

S209 2009

S210 2010

END #0

BEGIN GAUSSIAN, ITERATION

10 DO 10 I = 1, 25

XLC = * ./ YLC(1) * #2

ECV = *.1, 2, 3, 4 * XLC

FSV = FST(4, 1 * XLC, (1 + XLC))

ANG = ATAN(FSV, ECV)

X = (2 * ANGE - SIN(2 * ANGE) / (1 + SIN(ANGE) * 3))

YLC(I + 1) = 1.0 * X * (VL + XLCP)

52
SOLVE FOR INERTIAL VELOCITY VECTORS XVLV, YVLV, ZVLV.

\[
A = (\cos(\theta) \cdot \cos(\phi)) \cdot (\cos(\theta) \cdot \sin(\phi) \cdot \alpha + \cos(\phi))
\]

\[
F_{LC} = 1 \cdot \cos(\theta) \cdot \cos(\phi) \cdot \sin(\phi) \cdot \alpha \geq \sin^2(\theta) \cdot \cos(\phi)
\]

\[
V_{LCV} = (XLCV \cdot YLCV) \cdot \sin(\phi) \cdot \alpha \cdot \cos(\phi)
\]

\[
Y_{LCV} = (YLCV \cdot ZLCV) \cdot \sin(\phi) \cdot \alpha \cdot \cos(\phi)
\]

\[
Z_{LCV} = (ZLCV \cdot XLCV) \cdot \sin(\phi) \cdot \alpha \cdot \cos(\phi)
\]

SOLUTION FOR CLASSICAL ELEMENTS

\[
\text{TIME} = \text{TIME}
\]

\[
\text{PRINT} \quad 122, \quad \text{TIME}
\]

\[
\text{PRINT} \quad 102, \quad \text{YLCP}(I+1), \quad I
\]

\[
\text{FORMAT}(122) \quad I \cdot \text{YLCP}(I+1) = \text{YLCP}(I+1), \quad I
\]

\[
\text{TIME} = \text{TIME}
\]

\[
\text{IF} \quad \text{ABS}(\text{YLCP}(I+1) - \text{YLCP}(I+1)) < 1.0 \quad \text{THEN}
\]

\[
\text{CONTINUE}
\]

\[
\text{PRINT} \quad 102, \quad \text{TIME}
\]

\[
\text{PRINT} \quad 122, \quad \text{XLCV}(1), \quad \text{YLCV}(1), \quad \text{ZLCV}(1)
\]

\[
\text{PRINT} \quad 122, \quad \text{XLCV}(1), \quad \text{YLCV}(1), \quad \text{ZLCV}(1)
\]

\[
\text{PRINT} \quad 122, \quad \text{XLCV}(1), \quad \text{YLCV}(1), \quad \text{ZLCV}(1)
\]

\[
\text{PRINT} \quad 122, \quad \text{XLCV}(1), \quad \text{YLCV}(1), \quad \text{ZLCV}(1)
\]

\[
\text{PRINT} \quad 122, \quad \text{XLCV}(1), \quad \text{YLCV}(1), \quad \text{ZLCV}(1)
\]

\[
\text{PRINT} \quad 122, \quad \text{XLCV}(1), \quad \text{YLCV}(1), \quad \text{ZLCV}(1)
\]

53
CTR=ITIME
PRINT 100,CTR
100 FORMAT(*MILLSSEC=I8)
PRINT 107,A10,E10,T,E*MEGA,E*INCL
107 FORMAT(10D16.8,16.8,16.8,16.8,16.8)
70 CONTINUE
GO TO 41
S2050 P26
S MIN ITIME
S INJ *P2050
41 END
APPENDIX F
ITERATION OF TRUE ANOMALY PODM, POSITION AND TIME

Given \( r_1 (x_1, y_1, z_1), \ r_2 (x_2, y_2, z_2) \) and their corresponding universal times, \( t_1 \) and \( t_2 \), proceed as follows:

\[
\tau = k_e (t_2 - t_1)
\]

(112)

\[
r_1 = +\sqrt{r_1 \cdot r_1}
\]

(113)

\[
r_2 = +\sqrt{r_2 \cdot r_2}
\]

(114)

\[
U_1 = \frac{r_1}{r_1}
\]

(115)

\[
U_2 = \frac{r_2}{r_2}
\]

(116)

\[
\cos (\nu_2 - \nu_1) = U_1 \cdot U_2
\]

(117)

\[
\sin (\nu_2 - \nu_1) = \frac{x_1 y_2 - x_2 y_1}{|x_1 y_2 - x_2 y_1|} \sqrt{1 - \cos^2 (\nu_2 - \nu_1)}
\]

(118)

As a first approximation, set

\[
\nu_1 = 0^\circ
\]

(119)
\[ v_2 = v_1 + (v_2 - v_1) \quad (120) \]

\[ e = \frac{(r_2 - r_1)}{r_1 \cos v_1 - r_2 \cos v_2} \quad (121) \]

If \( e < 0 \), return to equation (119) and increment \( v_1 \) by \( \Delta v_1 \), 10 degrees; if \( e > 0 \), proceed with equation (122).

\[ a = \frac{r_1 (1 + e \cos v_1)}{(1 - e^2)} \quad (122) \]

If \( a < 0 \), return to equation (119) and increment \( v_1 \) by \( \Delta v_1 \), again 10 degrees; if \( a > 0 \), proceed with equation (123).

\[ \sin E_1 = \frac{\sqrt{1 - e^2 \sin v_1}}{1 + e \cos v_1} \quad (123) \]

\[ \cos E_1 = \frac{\cos v_1 + e}{1 + e \cos v_1} \quad (124) \]

\[ \sin E_2 = \frac{\sqrt{1 - e^2 \sin v_2}}{1 + e \cos v_2} \quad (125) \]

\[ \cos E_2 = \frac{\cos v_2 + e}{1 + e \cos v_2} \quad (126) \]

\[ M_2 - M_1 = E_2 - E_1 + e \left( \sin E_1 - \sin E_2 \right) \quad (127) \]

\[ n = k_e \sqrt{\frac{\mu}{a^3}} \quad (128) \]
\[ F = \tau - \left( \frac{M_2 - M_1}{n} \right) k_e \]  

(129)

If the iterative function is less than a specified tolerance \( \varepsilon_1 \), that is, \( 10^{-10} \),

\[ |F| < \varepsilon_1 \]  

(130)

proceed to equation (135); if not, save the numerical value of \( F \) and increment \( v_1 \) by a small amount, \( \Delta v \), to obtain

\[ v_1 + \Delta v \]  

(131)

Repeat equational loop (120) to (129) obtain \( F(v_1 + \Delta v) \) and form

\[ F'(v_1) = \frac{F(v_1 + \Delta v) - F(v_1)}{\Delta v} \]  

(132)

Improve the value of \( v_1 \) by

\[ (v_1)_{j+1} = (v_1)_j - \frac{F}{F'} (v_1)_j \quad , \quad j = 1, 2, 3, \ldots, q \]  

(133)

If

\[ |(v_1)_{j+1} - (v_1)_j| < \varepsilon_2 \]  

(134)

where \( \varepsilon_2 \) is another specified tolerance, i.e., \( 10^{-10} \), proceed to equation (135); if not, return to equation (120) with the improved value of \( v_1 \).
Continue calculating with:

\[
f = 1 - \frac{a}{r_2} \left[ 1 - \cos (E_2 - E_1) \right]
\]  \hspace{1cm} (135)

\[
g = \tau \sqrt{\frac{a^3}{\mu}} \left[ E_2 - E_1 - \sin (E_2 - E_1) \right]
\]  \hspace{1cm} (136)

\[
\dot{r}_1 = \frac{r_2 - f r_1}{g}
\]  \hspace{1cm} (137)

Continue by calculating for classical elements.
ITERATION OF TRUE ANOMALY
FLOWCHART

START

ECHO CHECK

\[ \text{ITIME} = 0 \]

DO 6 
\[ J = 1, 2 \]

DO 35 
\[ I = 1, 25 \]

B

E

A


A

ELC \geq 10^{-10}

T

B

ALC \geq 10^{-10}

F

B

19

F(I), I

ABS \left[ F(I) \right] < 10^{-10}

T

C

D

PAGE 60

PAGE 60
ITERATION OF TRUE ANOMALY FLOWCHART (CONT'D)

\( D \)

\( I \leq i \)

F

\( \text{ABS} \left( \frac{F(i)}{FPV} \right) \)

DELV \( < 10^{-10} \)

F

\( E \)

PAGE 59

\( \text{DELV} = 0.05 \times VLC(1) \)

C

\( I = 25 \)

F

E

PAGE 59

36

XLCV(1), YLCV(1), ZLCV(1)

SOLUTION FOR CLASSICAL ELEMENTS

F

ITIME, ALC, ELC, TE, OMEGA, QINCL, W

STOP

60
POSITION AND TIME (ESCAGAL, PAGE 21)

DIMENSION P(2), RLC(2), UX(2), UY(2), UZ(2), VLC(2), F[text]
CEOB(2), ANG(2), VLC(2), YLC(2), ZLC(2), YLCV(1), YLCV(2), T(J)
DO 30 N=1,6

READ THE INERTIAL POSITION VECTORS AND THEIR CORRESPONDING TIMES

READ 101, XLC(1), YLC(1), ZLC(1), T(1), XLC(2)
READ 101, YLC(2), ZLC(2), T(2), XU, X

101 FORMAT(5F16.8)

C
C ECHO CHECK
C
PRINT 104, XLC(1), YLC(1), ZLC(1), T(1), YLC(2), ZLC(2), XU, X

104 FORMAT(15X, 2X, 2X, 2X, 2X, 2X, 2X, 2X, 2X, 2X, 2X, 2X, 2X)

BEGIN COMPUTATIONS

ALL MATH SYMBOLS IS ITIME SUBROUTINE

ITIME=0

LDA 2035
STA 2025
BRU 2025
S205 RSW 2025
S200 FCE=20200
S5 PRT = CCP3000
S6 FIN
TA=XT*(T(2)-T(1))
D#5 J=1,2
RLC(J)=SQR(T(1)*(RLC(J)**2+YLC(J)**2+ZLC(J)**2))
UX(J)=XLC(J)/RLC(J)
UY(J)=YLC(J)/RLC(J)
UZ(J)=ZLC(J)/RLC(J)

6 VCBS=UX(1)*UX(2)+UY(1)*UY(2)+UZ(1)*UZ(2)
C=XT=XT*XLC(1)*YLC(2)*ZLC(1)
VSIN=CPV/ABS(CM)*SRT(1-O-VCBS**2)
ANGY=ATAN(VSIN,VCBS)

VLC(1)=9.0

BEGIN ITERATION OF TRUE ANOMALY

11 20 35 I=1,5
12 VYC(2)=VLC(1)+ANG
FLC=(RLC(2)-FLC(1))/RLC(1)+CBS(VLC(1))=RLC(2)*CBS(VLC(1))
IF(FLC=2.0000000001) 17,17,15
15 ALCE=(RLC(1)**2*FLC+CBS(VLC(1)))/(1.0+FLC**2)
16 IF(ALCE=2.0000000001) 17,17,19
17 VLC(1) = VLC(1) + 0.1743295
18 GO TO 12
19 ESIN(1) = SORT(1.0 - FLC**2) * SIN(VLC(1)) / (1.0 + FLC * COS(VLC(1)))
   ECOS(1) = (COS(VLC(1)) + FLC) / (1.0 + FLC * COS(VLC(1)))
   ESIN(2) = (SORT(1.0 - FLC**2) * SIN(VLC(2))) / (1.0 + FLC * COS(VLC(2)))
   ECOS(2) = (COS(VLC(2)) + FLC) / (1.0 + FLC * COS(VLC(2)))
   ANGE(1) = ATAN(ESIN(1), ECOS(1))
   ANGE(2) = ATAN(ESIN(2), ECOS(2))
   DIF = ANGE(1) - ANGE(2) + FLC * (ESIN(1) - ESIN(2))
   ETA = X * SORT(XMU / XLC**3)
   F(1) = TAU * DIF / ETA * X
   CT = ITIM
   PRINT 100, CT
   PRINT 100, F(1), 1
   FORMAT(1H0, *F(I) =E16.8**I**I=E13.5)
   ITIM = 0
   IF(AHS(F(I)) = 0.0000000001) 36, 37, 39
   IF(I = 1) 34, 35, 39
   29 FPV = (F(I) - F(I - 1)) / DELV
   30 IF(AHS(F(I) / FPV = +1.00000000)) 36, 37, 39
   31 IF(AHS(F(I) / FPV = -1.00000000)) 36, 37, 39
   32 DELV = F(I) / FPV
   33 GO TO 35
   34 DELV = 0.15 * VLC(1)
   35 VLC(1) = VLC(1) - DELV
C
C SOLVE FOR INITIAL VELOCITY VECTORS XCV1, YCV1, ZCV1
C
36 FLC = 1.0 - ALC / XLC(1) / (1.0 - COS(ALC / XLC(1)) / XLC(1))
   GLC = TAU - SORT(ALC / XMU) * (ANGE(2) - ANGE(I) - SIN(ALC / XLC(1)))
   XLCV(1) = (XLC(1) - FLC * XLC(1)) / GLC
   YLCV(1) = (YLC(1) - FLC * YLC(1)) / GLC
   ZLCV(1) = (ZLC(1) - FLC * ZLC(1)) / GLC
   CT = ITIM
   PRINT 102, CT
   PRINT 102, XCV(1), YCV(1), ZCV(1)
   FORMAT(1H0, *XCV(I) =E16.8**I**I=YCV(1) =E16.8**I**I=ZCV(I) =E16.8**I**I)
C
C SOLUTION FOR CLASSICAL ELEMENTS
C
103 FORMAT(1H0, XCV(1) =E16.8**I**I=YCV(1) =E16.8**I**I=ZCV(1) =E16.8**I**I)
104 ITIM = 0
   RLC(1) = SORT(XCV(1)**2 + YCV(1)**2 + ZCV(1)**2)
   BLT = YCV(1) * XLCV(1) + YLCV(1) + ZLCV(1) / XLC(1)
   PLCV(1) = SORT / RLC(1)
   V = SORT / (XCV(1)**2 + YCV(1)**2 + ZCV(1)**2)
   ALC = (RLC(1) * XCV(1)) / (2.0 * YCV(1)**2 + ZCV(1)**2)
   CSULC = (1.0 - RLC(1) / ALC)
   SSULC = (RLC(1) / XCV(1)) / SORT(XCV(1) / ALC)
   ELC = SORT / (XCV(1)**2 + YCV(1)**2 + ZCV(1)**2)
   CPSULC = ALC / (ELC / ELC)
   XCV(1) = ALC / (CPSULC / XCV(1))
   YCV(1) = ALC / (CPSULC / YCV(1))
   ZCV(1) = ALC / (CPSULC / ZCV(1))
   ST = SORT / (XCV(1)**2 + YCV(1)**2 + ZCV(1)**2)
   SS = SORT / (XCV(1)**2 + YCV(1)**2 + ZCV(1)**2)
   E = ATAN(SIN(1) / COS(1))
   62
Given $\alpha_i, \delta_i, \phi_i, \lambda_{E_i}, H_i, t_i$ for $i = 1, 2, 3$, and the constants $d\phi/dt$, $f, a_e, \mu, k_e$, compute the following:

\[
\tau_1 = k_e (t_1 - t_2)
\]

\[
\tau_3 = k_e (t_3 - t_2)
\]

\[
\tau_{13} = \tau_3 - \tau_1
\]

\[
A_1 = \frac{\tau_3}{\tau_{13}}
\]

\[
B_1 = \left( \tau_{13}^2 - \tau_3^2 \right) \frac{A_1}{6}
\]

\[
A_3 = -\frac{\tau_1}{\tau_{13}}
\]

\[
B_3 = \left( \tau_{13}^2 - \tau_1^2 \right) \frac{A_3}{6}
\]

\[
Tu = \frac{J.D. - 2415020}{36525}
\]

\[
\theta_{90} = 99^\circ 6909833 + 36000^\circ 7689 Tu + 0^\circ 00038708 Tu^2
\]

For $i = 1, 2, 3$, compute

\[
L_{X_i} = \cos \delta_i \cos \alpha_i
\]

\[
L_{Y_i} = \cos \delta_i \sin \alpha_i
\]
\[ L_{zi} = \sin \delta_i \]  

(147)

\[ \theta_i = \theta_0 + \frac{d\theta}{dt} (t_i - t_0) + \gamma_E \]  

(148)

\[ G_{1i} = \frac{ae}{\sqrt{1 - (2f \cdot f^2) \sin^2 \phi_i}} + H_i \]  

(149)

\[ G_{2i} = \frac{(1 - f)^2 a e}{\sqrt{1 - (2f \cdot f^2) \sin^2 \phi_i}} + H_i \]  

(150)

\[ X_i = - G_{1i} \cos \phi_i \cos \theta_i \]  

(151)

\[ Y_i = G_{1i} \cos \phi_i \sin \theta_i \]  

(152)

\[ Z_i = - G_{2i} \sin \phi_i \]  

(153)

Compute the following:

\[ D = L_{x1} (L_y2^Lz3 - L_z2^Ly3) - L_{x2} (L_y1^Lz3 - L_z1^Ly3) + L_{x3} (L_y1^Lz2 - L_z1^Ly2) \]  

(154)

\[ a_{11} = \frac{L_y2^Lz3 - L_y3^Lz2}{D} \]  

(155)
\[
\begin{align*}
a_{12} &= -\frac{(L_{x2}L_{z3} - L_{x3}L_{z2})}{D} \\
a_{13} &= \frac{L_{x2}L_{y3} - L_{x3}L_{y2}}{D} \\
a_{21} &= -\frac{(L_{y1}L_{z3} - L_{y3}L_{z1})}{D} \\
a_{22} &= \frac{L_{x1}L_{z3} - L_{x3}L_{z1}}{D} \\
a_{23} &= -\frac{(L_{x1}L_{y3} - L_{x3}L_{y1})}{D} \\
a_{31} &= \frac{L_{y1}L_{z2} - L_{y2}L_{z1}}{D} \\
a_{32} &= -\frac{(L_{x1}L_{z2} - L_{x2}L_{z1})}{D} \\
a_{33} &= \frac{L_{x1}L_{y2} - L_{x2}L_{y1}}{D}
\end{align*}
\]
and form the vectors

\[ \mathbf{A} = \begin{bmatrix} A_1, & -1, & A_3 \end{bmatrix} \quad (164) \]

\[ \mathbf{B} = \begin{bmatrix} B_1, & 0, & B_3 \end{bmatrix} \quad (165) \]

\[ \mathbf{X} = \begin{bmatrix} X_1, & X_2, & X_3 \end{bmatrix} \quad (166) \]

\[ \mathbf{Y} = \begin{bmatrix} Y_1, & Y_2, & Y_3 \end{bmatrix} \quad (167) \]

\[ \mathbf{Z} = \begin{bmatrix} Z_1, & Z_2, & Z_3 \end{bmatrix} \quad (168) \]

Evaluate the coefficients:

\[ A_2^* = - \left( a_{21} \mathbf{A} \cdot \mathbf{X} + a_{22} \mathbf{A} \cdot \mathbf{Y} + a_{23} \mathbf{A} \cdot \mathbf{Z} \right) \quad (169) \]

\[ B_2^* = - \left( a_{21} \mathbf{B} \cdot \mathbf{X} + a_{22} \mathbf{B} \cdot \mathbf{Y} + a_{23} \mathbf{B} \cdot \mathbf{Z} \right) \quad (170) \]

\[ C_\psi = - 2 \left( X_2 L_x + Y_2 L_y + Z_2 L_z \right) \quad (171) \]
\[ R_2^2 = X_2^2 + Y_2^2 + Z_2^2 \]  

(172)

\[ a = - (c \psi A_2^* + A_2^* + R_2^2) \]  

(173)

\[ b = - \mu (c \psi B_2^* + 2A_2^* B_2^*) \]  

(174)

\[ c = - \mu^2 B_2^* \]  

(175)

Solve

\[ r_2^8 + ar_2^6 + br_2^3 + c = 0 \]  

(176)

to obtain the applicable real root \( r_2 \), and continue calculating with

\[ u_2 = \frac{\mu}{r_2^3} \]  

(177)

\[ D_1 = A_1 + B_1 u_2 \]  

(178)

\[ D_3 = A_3 + B_3 u_2 \]  

(179)

\[ A_1^* = a_{11} A \cdot X + a_{12} A \cdot Y + a_{13} A \cdot Z \]  

(180)

68
\[ B_{1*} = a_{11} \mathbf{B} \cdot \mathbf{X} + a_{12} \mathbf{B} \cdot \mathbf{Y} + a_{13} \mathbf{B} \cdot \mathbf{Z} \]  
(181)

\[ A_{3*} = a_{31} \mathbf{A} \cdot \mathbf{X} + a_{32} \mathbf{A} \cdot \mathbf{Y} + a_{33} \mathbf{A} \cdot \mathbf{Z} \]  
(182)

\[ B_{3*} = a_{31} \mathbf{B} \cdot \mathbf{X} + a_{32} \mathbf{B} \cdot \mathbf{Y} + a_{33} \mathbf{B} \cdot \mathbf{Z} \]  
(183)

\[ \rho_1 = \frac{A_{1*} + B_{1*} u_2}{D_1} \]  
(184)

\[ \rho_2 = A_{2*} + B_{2*} u_2 \]  
(185)

\[ \rho_3 = \frac{A_{3*} + B_{3*} u_2}{D_3} \]  
(186)

\[ \Upsilon_i = \rho_i \xi_i - \frac{R_i}{\tau} \]  
for \( i = 1, 2, 3 \)  
(187)

Then, utilizing the Herrick-Gibbs formulas, calculate

\[ d_1 = \tau_3 \left( \frac{\mu}{12r_1^3} - \frac{1}{\tau_1 \tau_3} \right) \]  
(188)

\[ d_2 = (\tau_1 + \tau_3) \left( \frac{\mu}{12r_3^3} - \frac{1}{\tau_1 \tau_3} \right) \]  
(189)

\[ d_3 = -\tau_1 \left( \frac{\mu}{12r_3^3} + \frac{1}{\tau_3 \tau_1} \right) \]  
(190)
\[
\dot{r}_2 = - d_1 r_1 + d_2 r_2 + d_3 r_3
\]  
(191)

\[
r_2 = \sqrt{\dot{r}_2 \cdot \dot{r}_2}
\]  
(192)

\[
\ddot{r}_2 = \frac{\dot{r}_2 \cdot \dot{r}_2}{r_2}
\]  
(193)

\[
V_2 = \sqrt{\ddot{r}_2 \cdot \dot{r}_2}
\]  
(194)

\[
\frac{1}{a} = 2 \frac{r_2}{r_2^2} - \frac{V_2^2}{\mu}
\]  
(195)

From the \(f\) and \(g\) functions, calculate

\[
f_1 = f(V_2, r_2, \dot{r}_2, \tau_1)
\]  
(196)

\[
f_3 = f(V_2, r_2, \dot{r}_2, \tau_3)
\]  
(197)

\[
g_1 = g(V_2, r_2, \dot{r}_2, \tau_1)
\]  
(198)

\[
g_3 = g(V_2, r_2, \dot{r}_2, \tau_3)
\]  
(199)

Continue calculating with

\[
D^* = f_1 g_3 - f_3 g_1
\]  
(200)
\[ c_1 = \frac{g_3}{D^2} \]  

(201)

\[ c_2 = -1.0 \]  

(202)

\[ c_3 = -\frac{g_1}{D^2} \]  

(203)

\[ G = c_1 R_1 + c_2 R_2 + c_3 R_3 \]  

(204)

\[ (\rho_1)_n = \frac{1}{c_1} \left( a_{11}G_x + a_{12}G_y + a_{13}G_z \right) \]  

(205)

\[ (\rho_2)_n = -\left( a_{21}G_x + a_{22}G_y + a_{23}G_z \right) \]  

(206)

\[ (\rho_3)_n = \frac{1}{c_3} \left( a_{31}G_x + a_{32}G_y + a_{33}G_z \right) \]  

(207)

The first time through, test to see if
\[ |(\rho_1)_n - \rho_1| < \epsilon_1 \]  

(208)

\[ |(\rho_2)_n - \rho_2| < \epsilon_2 \]  

(209)

\[ |(\rho_3)_n - \rho_3| < \epsilon_3 \]  

(210)
where $\varepsilon_1$, $\varepsilon_2$, $\varepsilon_3$ are tolerances, i.e., $10^{-10}$. If so, proceed to equation (214); if not, return to equation (187) using $(\rho_n)$ and repeat equational loop (188) to (207); however, from this point on, test to see if

$$|(\rho_1)_{n+1} - (\rho_1)_n| < \varepsilon_1$$

(211)

$$|(\rho_2)_{n+1} - (\rho_2)_n| < \varepsilon_2$$

(212)

$$|(\rho_3)_{n+1} - (\rho_3)_n| < \varepsilon_3$$

(213)

And repeat equational loop (188) to (207) until test is successful. Continue by calculating

$$\rho_2 = \rho_2 L_2 - R_2$$

(214)

$$\dot{\rho}_2 = -d_1 \dot{\tau}_1 + d_2 \dot{\rho}_2 + d_3 \dot{\tau}_3$$

(215)

Continue by calculating the classical elements.
ALPHA(1), DELTA(1), YAME(1), PHI(1), H(1), T(1), FOR I = 1, 2, 3; XMU, DTHETA, FLAT, AE, XK, TJD, T(4)

ECHO CHECK

ITIME = 0

DO 19 J = 1, 3

DO 47 I = 1, 25

REX(I), RLC(2), I

ABS \left[ \frac{RLC}{CLC} \right] < 10^{-10}

I ≤ 1

ABS \left[ \frac{REX(I) - EPR}{DELR} \right] < 10^{-10}

I = 25

DELR = 0.05 RLC(2)
IF (ABS(X*Y) > RPR * DELR) = 0.000000001

DELR = RPR

DEL = 47

DEL = 0.5 * PLC(2)

RLC(2) = APS(RLC(2) + DELR)

ULC(2) = Y / U * RLC(2) * * 3

D1 = A(1) * B(1) * JLC(2)

D3 = A(1) * F(3) * JLC(2)

AS(1) = A(1) * A1(2) * AY + A1(3) * AZ

BS(1) = B(1) * B1(2) * BY + A1(3) * BZ

AS(3) = A1(1) * F(3) * AY + A3(3) * AZ

BS(3) = A1(1) * B1(2) * BY + A3(3) * BZ

P(1) = (A1(1) + BS(1) * ULC(2)) / B(1)

P(2) = AS(2) + BS(2) * ULC(2)

P(3) + TS(3) * ULC(2) / B(3)

C

ITERATIVE LOOP FOR DETERMINING SCALAR OF THE RANGE VECTOR

---

DB 75 = T(1) + 25

DB 63 = J = 3

XLC(J) = Y(J) * YL(J) + X(J)

YLC(J) = Y(J) * YL(J) + Y(J)

ZLC(J) = J = 3

RLC(J) = C + 7 * (XLC(J) + 1) * YLC(J) + 2 * ZLC(J)

DLG(3) = (TAU(3) * (1 * X / RLC(1)) + 1 * Y / TAU(3) * DTAU(1))

DLG(2) = (TAU(1) + TAU(3)) * (1 * X / RLC(2) + 1 * Y / TAU(3) * DTAU(1))

DLG(2) = (TAU(1) + TAU(3)) * (1 * X / RLC(3) + 1 * Y / TAU(3) * DTAU(1))

XLCV(2) = XLC(2) + DLA(2) + DLA(2) + DLA(2) + DLA(2)

YLCV(2) = YLC(2) + DLA(2) + DLA(2) + DLA(2) + DLA(2)

ZLCV(2) = ZLC(2) + DLA(2) + DLA(2) + DLA(2) + DLA(2)

RLCV(2) = (XLCV(2) + YLCV(2) + ZLCV(2)) / RLC(2)

A1 = 2 + 2 * RLC(2) / RLC(2)

ULC(2) = Y / U * RLC(2) * * 3

PLC(2) = PLC(2) * RLC(2) / RLC(2)

QLC(2) = (1 + 2) * RLC(2) / RLC(2)

---

DB 78 = J = 3

F(J) = 1.0 + 5 * ULC(2) * TAU(J) * * 3 + 4 * ULC(2) * PLC(2) * TAU(J)

C1 = 1 + 2 * 4 * (3 + ULC(2) * PLG(2) = 15 * ULC(2) * PLC(2) * * 2 + ULC(2) * * 2)

CTAU(J) = 4 + 1 + 8 + 5 * ULC(2) * PLC(2) * * 3 + 3 * ULC(2) * PLC(2) * PLC(2) =

CULC(2) * * 2 + PLC(2) * TAU(J)

FT(J) = 1.0 + 2 * ULC(2) * PLC(2) * * 2 + ULC(2) * PLC(2) = 24 * ULC(2) * PLC(2) * * 2

COLC(2) = 1.0 + 2 * 4 + 5 * ULC(2) * PLC(2) * * 2 + 945 * ULC(2) * PLC(2) * * 4 +

C210 * ULC(2) * * 2 + PLC(2) * * 2 + TAU(J)

F(J) = F(J) + F(T)

G(J) = TAU(J) * 1.0 + 4 * ULC(2) * TAU(J) * * 3 + 1.0 + 4 * ULC(2) * PLC(2)

CTAU(J) = 4 + 1 + 120 + 5 * ULC(2) * PLC(2) = 45.0 * ULC(2) * PLC(2) * * 2 +

CULC(2) * * 2 + TAU(J)

G(J) = G(J) + G(T)

DS = F(1) * G(3) + F(3) * G(1)

C(1) * G(3) + DS
C(2) = 1.0
C(3) = 6.1 /DS
GX = C(1) * Y(1) + C(2) * X(2) + C(3) * X(3)
GY = C(1) * Y(1) + C(2) * Y(2) + C(3) * Y(3)
GZ = C(1) * Y(1) + C(2) * Z(2) + C(3) * Z(3)
P1(1) = (1.0 / C(1)) * (A(1, 1) * GX + A(1, 2) * GY + A(1, 3) * GZ)
P2(1) = (A(2, 1) * GX + A(2, 2) * GY + A(2, 3) * GZ)
P3(1) = (1.0 / C(3)) * (A(3, 1) * GX + A(3, 2) * GY + A(3, 3) * GZ)
CT(1) = 1.0 /F
PRINT 100, CT
PRINT 103, P1(1), 1, P2(1), 1, P3(1), 1
FOR IATT = 1 TO 2, 1
IF (ABS(PI(1)) > 6.0) GOTO 120
IF (ABS(PI(1)) > 0.1) GOTO 120
IF (ABS(PI(1)) > 0.001) GOTO 120
PI(1) = PI(1)
P(1) = P1(1)
P(2) = P2(1)
P(3) = P3(1)
SOLVE FOR INERTIAL POSITION AND VELOCITY VECTORS
XLC(2) = P(2) * YL(2) - X(2)
YL(2) = P(2) * YL(2) - Y(2)
ZLC(2) = P(2) * ZL(2) - Z(2)
XLCV(2) = - XLC(1) * YLC(1) + XLC(2) * YLC(2) + XLC(3) * YLC(3)
YLCV(2) = - YLC(1) * YLC(1) + YLC(2) * YLC(2) + YLC(3) * YLC(3)
ZLCV(2) = - ZLC(1) * ZLC(1) + ZLC(2) * ZLC(2) + ZLC(3) * ZLC(3)
CT(1) = 1.0 /F
PRINT 100, CT
PRINT 103, XLCV(2), YLCV(2), ZLCV(2)
FOR IATT = 1 TO 2, 1
SOLVE FOR CLASSICAL ELEMENTS
XLC(2) = SQRT(XLC(2)**2 + YLC(2)**2 + ZLC(2)**2)
RR987 = XLC(2) * XLCV(2) + YLC(2) * YLCV(2) + ZLC(2) * ZLCV(2)
RRCV(2) = RR987 / XLC(2)
VS = SQRT(XLCV(2)**2 + YLCV(2)**2 + ZLCV(2)**2)
ALC = (RRCV(2) * XMU) / (2.0 * VS * VE)**2 * RLC(2)
CSUBx = (1.0 - RLC(2) / ALC)
SSUBx = (RLCV(2) * RLC(2)) / SQRT(XMU * ALC)
ELC = SQRT(SSUBx**2 + CSUBx**2)
CASE = (ALC * RLC(2)) / (4 * ELC * ELC)
XSUBx = ALC * (CASE - ELC)
CBSV = XSUBx / RLC(2)
SINV = SQRT(RLC(2)**2 - XSUBx**2) / RLC(2)
SINC = SQRT(1.0 - ELC**2) * SINV / (1.0 + ELC * SINV)
ETA = SINC / SINV
TEX = (1.0 - (1.0 - ELC**2 - SINC**2) / XSUBx) * SQRT(ALC**2)
HX = YLC(2) * ZLCV(2) - ZLC(2) * YLCV(2)
HY = (XLC(3) * YLCV(3) + YLC(2) * XLCV(2))
HZ = XLC(2) * YLCV(2) - YLC(2) * XLCV(2)
VANGF = ATAN2(SINHVCOSV)
SINH = HX
COSH = HY
BMGDP = ATAN2(SINHX, C0S-HY)
EXP = SQR ((HX * X + HY * HY))
B1INC = ATAN2 (EXP, Z1)
U1(LC) = XLC(3) * SINH + YLCV(3) * COSH + YLC(2) * COSB1INC + ZLCV(3) * S1B1INC
DE = XLC(2) * COSB2INC + YLCV(2) * SINB2INC
U = ATAN2 (U, DE1)
W = U - VANGF
CT4 = ITIT
PRINT 108, CT4
PRINT 107, ALG, ECF, TF, BMEGAP, SINC, W
107 FORMAT (10.0, 1LC=1E16.8, //, TELC=S1E16.8, //, TE=S1E16.8, //)
108 FORMAT (10.0, ///, BMEGAP=S1E16.8, //, SL=S1E16.8, //)
109 FORMAT (10.0, ///, BMEGAP=S1E16.8, //, SL=S1E16.8, //)
CF = TIT1LC
GO TO 98
97 CF = T1LC
GO TO 96
S2050 P7F
S  MT  ITIME
S  BFU  P7FSS
98 END
Given $\alpha_{ti}$, $\delta_{ti}$, $t_i$, $\phi_i$, $\lambda_{Ei}$, $H_i$ for $i = 1, 2, 3$ and the constants $d\theta/dt$, $f$, $a_e$, $\mu$, $k$, compute the following:

$$\tau_1 = k_e (t_1 - t_2)$$  \hspace{1cm} (216)

$$\tau_3 = k_e (t_3 - t_2)$$  \hspace{1cm} (217)

$$S_1 = \frac{-\tau_3}{\tau_1 (\tau_1 - \tau_3)}$$  \hspace{1cm} (218)

$$S_2 = \frac{- (\tau_3 + \tau_1)}{\tau_1 \tau_3}$$  \hspace{1cm} (219)

$$S_3 = \frac{-\tau_1}{\tau_3 (\tau_3 - \tau_1)}$$  \hspace{1cm} (220)

$$S_4 = \frac{2}{\tau_1 (\tau_1 - \tau_3)}$$  \hspace{1cm} (221)

$$S_5 = \frac{2}{\tau_1 \tau_3}$$  \hspace{1cm} (222)

$$S_6 = \frac{2}{\tau_3 (\tau_3 - \tau_1)}$$  \hspace{1cm} (223)
For $i = 1, 2, 3$, calculate:

$$L_{x_i} = \cos \delta_{ti} \cos \alpha_{ti}$$  \hspace{1cm} (224)

$$L_{y_i} = \cos \delta_{ti} \sin \alpha_{ti}$$  \hspace{1cm} (225)

$$L_{z_i} = \sin \delta_{ti}$$  \hspace{1cm} (226)

and determine

$$L_2 = S_1L_1 + S_2L_2 + S_3L_3$$  \hspace{1cm} (227)

$$L_2 = S_4L_1 + S_5L_2 + S_6L_3$$  \hspace{1cm} (228)

For $i = 1, 2, 3$, proceed as follows:

$$Tu = \frac{J.D. - 2415020}{36525}$$  \hspace{1cm} (229)

$$\theta_0 = 99^\circ 6909833 + 36000^\circ 7689 Tu + 0^\circ 00038708 Tu^2$$  \hspace{1cm} (230)

$$G_{1i} = \frac{a_e}{\sqrt{1 - (2\ell - f^2) \sin^2 \phi_i}} + H_i$$  \hspace{1cm} (231)
\[ G_{2i} = \frac{(1 - f)^2 a_e}{\sqrt{1 - (2f - f^2) \sin^2 \phi_i}} + H_i \]  

(232)

Continue calculating with

\[ \theta_i = \theta_{g0} + \frac{d\theta}{dt} (t_i - t_0) + \lambda_{Ei} \]  

(233)

\[ X_i = -G_{1i} \cos \phi_i \sin \theta_i \]  

(234)

\[ Y_i = -G_{1i} \cos \phi_i \sin \theta_i \]  

(235)

\[ Z_i = -G_{2i} \sin \phi_i \]  

(236)

If the observations are not from a single station, that is, \( \phi_1 \neq \phi_2 \neq \phi_3 \neq \phi_1 \) and \( \lambda_{E1} \neq \lambda_{E2} \neq \lambda_{E3} \neq \lambda_{E1} \), continue calculating with equation (237); if the observations are from a single station, proceed to equation (239).

\[ \hat{R}_2 = S_1 R_1 + S_2 R_2 + S_3 R_3 \]  

(237)

\[ \cdots \]  

\[ \hat{R}_2 = S_4 R_1 + S_5 R_2 + S_6 R_3 \]  

(238)

Proceed to equation (241)

\[ \hat{R}_2 = \begin{bmatrix} -Y_2 \\ -X_2 \\ \frac{1}{k_e} \frac{d\theta}{dt} \end{bmatrix} \]  

(239)
Numerically evaluate the following determinants:

$$\ddot{r}_2 = \begin{bmatrix} -x_2 & 1 \frac{de}{dt} \\ -y_2 & k_e^{-2} \\ 0 & \end{bmatrix}^2$$  \hspace{1cm} (240)

$$\Delta = 2 \begin{bmatrix} L_{x2} & \dot{L}_{x2} & \ddot{L}_{x2} \\ L_{y2} & \dot{L}_{y2} & \ddot{L}_{y2} \\ L_{z2} & \dot{L}_{z2} & \ddot{L}_{z2} \end{bmatrix}$$  \hspace{1cm} (241)

$$D_a = \begin{bmatrix} L_{x2} & \dot{L}_{x2} & \ddot{x}_2 \\ L_{y2} & \dot{L}_{y2} & \ddot{y}_2 \\ L_{z2} & \dot{L}_{z2} & \ddot{z}_2 \end{bmatrix}$$  \hspace{1cm} (242)

$$D_b = \begin{bmatrix} L_{x2} & \dot{L}_{x2} & x_2 \\ L_{y2} & \dot{L}_{y2} & y_2 \\ L_{z2} & \dot{L}_{z2} & z_2 \end{bmatrix}$$  \hspace{1cm} (243)

$$D_c = \begin{bmatrix} L_{x2} & \ddot{x}_2 & \dot{L}_{x2} \\ L_{y2} & \ddot{y}_2 & \dot{L}_{y2} \\ L_{z2} & \ddot{z}_2 & \dot{L}_{z2} \end{bmatrix}$$  \hspace{1cm} (244)

$$D_d = \begin{bmatrix} L_{x2} & x_2 & \dot{L}_{x2} \\ L_{y2} & y_2 & \dot{L}_{y2} \\ L_{z2} & z_2 & \dot{L}_{z2} \end{bmatrix}$$  \hspace{1cm} (245)
and form:

\[ A_2^* = \frac{2D_a}{\Delta} \]  \hspace{1cm} (246)

\[ B_2^* = \frac{2D_b}{\Delta} \]  \hspace{1cm} (247)

\[ C_2^* = \frac{D_c}{\Delta} \]  \hspace{1cm} (247)

\[ D_2^* = \frac{D_d}{\Delta} \]  \hspace{1cm} (249)

\[ C_\psi = -2 \left( L_2 \cdot R_2 \right) \]  \hspace{1cm} (250)

\[ a = -\left( C_\psi A_2^* + A_2^{*2} + R_2^2 \right) \]  \hspace{1cm} (251)

\[ b = -\mu \left( C_\psi B_2^* + 2A_2^{*} B_2^* \right) \]  \hspace{1cm} (252)

\[ c = -\mu^2 B_2^{*2} \]  \hspace{1cm} (253)

Solve

\[ r_2^8 + ar_2^6 + br_2^3 + c = 0 \]  \hspace{1cm} (254)
to obtain the applicable real root $r_2$, and continue calculating with

$$\rho_2 = A_2^* + \frac{\mu B_2^*}{r_2^3}$$  (255)

$$\dot{\rho}_2 = C_2^* + \frac{\mu D_2^*}{r_2^3}$$  (256)

$$\tau_2 = \rho_2 \cdot \nu_2 - R_2$$  (257)

$$\dot{\tau}_2 = \dot{\rho}_2 \cdot \nu_2 + \rho_2 \cdot \dot{\nu}_2 - \dot{R}_2$$  (258)

Continue by calculating for classical elements.
LAPLACE FLOWCHART

START

ALPHA(1), DELTA(1), T(1), PHI(1), H(1), YAME(1) FOR I = 1, 2, 3; DT, THETA, FLAT, AE, XNU, XK, TJD, T(4)

ECHO

CHECK

ITIME = 0

DO 12
   I = 1, 3

DO 27
   I = 1, 3

A

A

PHI(i) = PHI(2)

PHI(2) = PHI(3)

YAME(1) = YAME(2)

YAME(3) = YAME(2)

39

32

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86
LAPLACE FLOWCHART (CONT'D)

B

45

D

DO 69
I = 1, 25

REX (I), I

ABS [REX (I) - CLC] < 10^-10

I <= 1

ABS [REX(I) - FPR - DELR] < 10^-10

DELR = 0.05 RLC(2)

XLCV(2), YLCV(2), ZLCV(2)

SOLUTION FOR CLASSICAL ELEMENT

ITIME, ALC, ELC, TE, OMEGA, OINCL, W

STOP
LAPLACE PRELIMINARY ORBIT DETERMINATION METHOD
ANGLES ONLY (ESCAPEAL, PAGE 267)

DO 74 K=1,25

DIMENSION TAU(3), S(6), XL(3), YL(3), ZL(3), XLV(3), YLV(3), ZLV(3),
D2ENIM: CS(3), TP(3), XP(3), YP(3), ZP(3), XL(3), YL(3), ZL(3),
CZL(3), YLCV(3), ZLCV(3), YLCV(3), ZLCV(3), RCIR(3), ALPH(3), DEL(3),
GAMMA(3), PHI(3), H(3)

READ ANGLE INPUT DATA

READ 10*, FLAT, AF, XK, XMU, DTETA
READ 10*, T(4), T(1), T(2), T(3), TUD
READ 10*, ALPH(1), ALPH(2), ALPH(3), DELTA(1), DELTA(2)
READ 10*, DELTA(1), YAF(1), YAF(2), YAF(3), PHI(1)
READ 10*, PHI(1), PHI(2), PHI(3), H(1), H(2), H(3)

108 FORMAT(5F16.8)

EXEC CHECK

PRINT 110, FLAT, AF, XK, XMU, DTETA, T(4), TUD, T(1), T(2), T(3)

110 FORMAT(11H1F, 4F16.8, 3F16.8, 2F16.8, 2F16.8, 2F16.8, 4F16.8)

BEGIN COMPUTATIONS

ALL METSYMBOL IS ITIME SUBROUTINE

ITIME=0

LCA = 0.0

STA = 0.05

BRM = 0.025

SB205 = 0.020

SOUT = 0.025

S1R =

TAU(1) = YAF(T(1) - T(2))
TAU(2) = YAF(T(3) - T(2))
S(1) = TAU(3)*TAU(1) + (TAU(1) + TAU(3))*S(1)
S(2) = (TAU(3) + TAU(1))*S(2)/(TAU(1) + TAU(3))
S(3) = TAU(1)/((TAU(3) + TAU(1))*S(1))

88
AS(P) = (P*PA)/DCL
BS(P) = (P*PB)/DCL
CS(P) = DC/DCL
DS(P) = DB/DCL
CH = P*(YL(2)*P + YL(2)*P + ZL(2)*P)
R = SQRT(Y(2)*P + Z(2)*P)
ALC = (CH*AS(P) + AS(P)*P + AS(2)*P)
BL = X*AS(P) + AS(2)*P
CLC = X*AS(P)*P
RLC(P) = 1

ITERATIVE LOOP FOR DETERMINING APPLICABLE REAL ROOT OF RLC(P)

59 DO 49 J = 1, 25
RX(J) = RLC(2)*J*J + RLC(2)*J + RLC(2)*J + RLC(2)*J + RLC(2)
CJ = -1
PRINT 101, CJ
49 CONTINUE
PRINT 103, RX(1), RLC(2), J
107 FORMAT(15 E16.8, 4 E16.8, 5 I1) I = 1
ITIME = 0
IF (ABS(REX(1)) > RX(1-1)) GOTO 60
IF (ABS(REX(1)) < RX(1-1)) GOTO 61
IF (REX(1) = RX(1-1)) GOTO 62
63 ITIME = ITIME + 1
64 RX(J) = RX(1) - RX(1-1)
65 RL = RLC(1)/RP
66 TE = 67
68 DEL = -1*RLC(2)
69 RLC(2) = RLC(2)*DEL

SOLVE FOR INITIAL POSITIVE AND VELOCITY VECTORS

70 P(1) = AS(P) + (YMU*RS(2)/RLC(2)*P3)
P(2) = CS(P) + (X*RS(P)/RLC(P)*P3)
XL(2) = P1 + YL(2)
YC(2) = Y1 + YL(2)
ZL(2) = Z1 + ZL(2)
XL(2) = P1 + YL(2)*1 + R(2)*Y(2) + R(2)*Y(2) + R(2)*Y(2) + R(2)*Y(2)
XL(2) = P1 + YL(2)*1 + R(2)*Z(2) + R(2)*Z(2) + R(2)*Z(2) + R(2)*Z(2)
CJP = ITIME
PRINT 101, CJ
PRINT 107, XLCV(P1), YLCV(2), ZLCV(2)
104 FORMAT(*, 6 F16.8)

SOLUTION FOR CLASSICAL ELEMENTS

ITIME = 0
RLC(2) = RLC(2) + RLC(2) + YLC(P) + ZLC(2)*P + ZLC(2)*P
RYC2 = YLC(2) + YLC(2) + YLC(2) + YLC(2) + YLC(2) + YLC(2) + YLC(2) + YLC(2)
RLC(2) = RLC(2) + RLC(2)
W = RYC2 + YLC(2) + YLC(2) + ZLC(2)*P + ZLC(2)*P
ALC = (RLC(2) + YMU) / (2*3 + YMU + 2*RLC(2))
CS(P) = (P + RLC(P) / ALC)
```
\text{HX} = YLC(2) \ast ZLC(2) \ast YLC(2) \ast ZLC(2)
\text{HZ} = XLC(2) \ast YLC(2) \ast ZLC(2) \ast XLC(2)
\text{VA} = \text{ATAN}(\sin x \ast \cos y)
\sin x = \text{X}
\cos y = \text{Y}
\theta = \text{ATAN}(\sin x, \cos y)
\text{EXP} = \sqrt{x^2 + y^2}
\text{INCL} = \text{ATAN}(\text{EXP}, \text{Y})

\text{UM} = YLC(2) \ast \sin(\theta) \ast \cos(\text{INCL}) + YLC(2) \ast \cos(\theta) \ast \cos(\text{INCL}) +
ZLC(2) \ast \sin(\text{INCL})
\text{DEM} = XLC(2) \ast \cos(\theta) \ast \sin(\theta) + YLC(2) \ast \sin(\theta) \ast \cos(\theta)
\text{V} = \text{VA} \ast \text{CF}
\text{CTR} = \text{IF}\text{NE}
\text{PRINT} 107, \text{CTR}
\text{PRINT} 107, \text{ALC}, \text{PAT}, \text{TF}, \theta, \text{DEM}, \text{INCL}, \text{W}
\text{FORMAT}(107, 8, \text{ALC} = 'E16.8', \text{TF} = 'E16.8',
\theta = 'E16.8', \text{DE} = 'E16.8', \text{W} = 'E16.8')
107 \text{FORMAT}(107, 8, \text{ALC} = 'E16.8', \text{TF} = 'E16.8',
\theta = 'E16.8', \text{DE} = 'E16.8', \text{W} = 'E16.8')
107 \text{FORMAT}(107, 8, \text{ALC} = 'E16.8', \text{TF} = 'E16.8',
\theta = 'E16.8', \text{DE} = 'E16.8', \text{W} = 'E16.8')
74 \text{CONTINUE}
\text{GO TO} 75
\text{S2057} \text{P2F}
\text{S} \text{V1} \text{L1 TIME}
\text{S} \text{P1} \ast \text{P2P}
75 \text{FNC}
```
APPENDIX I
DOUBLE R-ITERATION PODM, ANGLES ONLY

Given $\alpha_{ti}$, $\delta_{ti}$, $t_i$, $\phi_i$, $\lambda_{Ei}$, $H_i$, for $i = 1, 2, 3$, and the constants $d\theta/dt$, $f$, $a_e$, $\mu$, and $k_e$, proceed as follows:

$$\tau_1 = k_e (t_1 - t_2) \quad (259)$$

$$\tau_3 = k_e (t_3 - t_2) \quad (260)$$

$$Tu = \frac{J.D. - 2415020}{36525} \quad (261)$$

$$\theta_{g0} = 99°6909833 + 36000°7689 Tu + 0°000038708 Tu^2 \quad (262)$$

For $i = 1, 2, 3$, compute:

$$L_{xi} = \cos \delta_{ti} \cos \alpha_{ti} \quad (263)$$

$$L_{yi} = \cos \delta_{ti} \sin \alpha_{ti} \quad (264)$$

$$L_{zi} = \sin \delta_{ti} \quad (265)$$

$$G_{1i} = \frac{a_e}{\sqrt{1 - (2f - f^2) \sin^2 \phi_i}} + H_i \quad (266)$$
\[ G_{2i} = \frac{(1 - f)^2 \, a_e}{\sqrt{1 - (2f - f^2) \sin^2 \phi_i}} + H_i \quad (267) \]

\[ \theta_i = \theta_{g0} + \frac{d\theta}{dt} (t_i - t_0) + \lambda_{Ei} \quad (268) \]

\[ X_i = -G_{1i} \cos \phi_i \cos \theta_i \quad (269) \]

\[ Y_i = -G_{1i} \cos \phi_i \sin \theta_i \quad (270) \]

\[ Z_i = -G_{2i} \sin \phi_i \quad (271) \]

\[ C_{\psi i} = 2L_i \cdot R_i \quad i = 1, 2, 3 \quad (272) \]

As a first approximation, set

\[ r_1 = r_{1g} \quad r_2 = r_{2g} \quad (273) \]

For near-Earth orbits, set

\[ r_{1g} = r_{2g} = 1.1 \text{ e.r.} \quad (274) \]
and compute $\rho_i$ from

$$\rho_i = \frac{1}{2} \left[ - C_{\psi_i} + \sqrt{C_{\psi_i}^2 - 4 (R_i^2 - r_i^2)} \right] \tag{275}$$

Continue calculating with

$$r_i = \rho_i L_i - R_i \quad , \quad i = 1, 2 \tag{276}$$

Compute $\tilde{W}$ as

$$\tilde{W}_x = \frac{y_1 z_2 - y_2 z_1}{r_1 r_2} \tag{277}$$

$$\tilde{W}_y = \frac{x_2 z_1 - x_1 z_2}{r_1 r_2} \tag{278}$$

$$\tilde{W}_z = \frac{x_1 y_2 - x_2 y_1}{r_1 r_2} \tag{279}$$

Continue calculating with

$$\rho_3 = \frac{R_3 \cdot \tilde{W}}{L_3 \cdot \tilde{W}} \tag{280}$$

$$r_3 = \rho_3 L_3 - R_3 \tag{281}$$

$$r_3 = \sqrt{r_3 \cdot r_3} \tag{282}$$
\[ \cos (\nu_j - \nu_k) = \frac{r_j \cdot r_k}{r_j r_k} \quad j = 2, 3, k = 1, 2 \]  

If \( W_z > 0 \), calculate

\[ \sin (\nu_j - \nu_k) = \frac{x_k y_j - x_j y_k}{|x_k y_j - x_j y_k|} \sqrt{1 - \cos^2 (\nu_j - \nu_k)} \]  

If \( W_z < 0 \), calculate

\[ \sin (\nu_j - \nu_k) = -\frac{x_k y_j - x_j y_k}{x_k y_j - x_j y_k} \sqrt{1 - \cos^2 (\nu_j - \nu_k)} \]  

If \( \nu_3 - \nu_1 > \pi \), determine \( p \) from

\[ c_1 = \frac{r_2 \sin (\nu_3 - \nu_2)}{r_1 \sin (\nu_3 - \nu_1)} \]  

\[ c_3 = \frac{r_2 \sin (\nu_2 - \nu_1)}{r_3 \sin (\nu_3 - \nu_1)} \]  

\[ p = \frac{c_1 r_1 + c_3 r_3 - r_2}{c_1 + c_3 - 1} \]
If $v_3 - v_1 \leq \pi$, determine $p$ from

$$c_1 = \frac{r_1}{r_2} \sin \left(\frac{v_3 - v_1}{2}\right)$$

$$c_3 = \frac{r_1}{r_3} \sin \left(\frac{v_3 - v_2}{2}\right)$$

$$p = \frac{r_1 + c_3r_3 - c_1r_2}{1 + c_3 - c_1}$$

Continue calculating with

$$e \cos v_i = \frac{p}{r_i} - 1 \quad , \quad i = 1, 2, 3$$

and for $v_2 - v_1 \neq \pi$, obtain

$$e \sin v_2 = -\frac{\cos (v_2 - v_1)(e \cos v_2) + (e \cos v_1)}{\sin (v_2 - v_1)}$$

or, if $v_2 - v_1 = \pi$, obtain

$$e \sin v_2 = \frac{\cos (v_3 - v_2)(e \cos v_2) - (e \cos v_3)}{\sin (v_3 - v_1)}$$

Evaluate

$$e = \sqrt{(e \cos v_2)^2 + (e \sin v_2)^2}$$
\[ a = \frac{p}{1 - e^2} \]  \hfill (295b)

For orbit determination in this paper, \( e^2 < 1 \), therefore continue calculating with

\[ n = k_e \sqrt{\frac{\mu}{a^3}} \]  \hfill (296)

\[ s_e = \frac{r_2}{p} \sqrt{1 - e^2} \ e \sin \nu_2 \]  \hfill (297)

\[ c_e = \frac{r_2}{p} (e^2 + e^2 \cos \nu_2) \]  \hfill (298)

\[ \sin (E_3 - E_2) = \frac{r_3}{\sqrt{ap}} \sin (\nu_3 - \nu_2) - \frac{r_3}{p} \left[ 1 - \cos (\nu_3 - \nu_2) \right] s_e \]  \hfill (299)

\[ \cos (E_3 - E_2) = 1 - \frac{r_3r_2}{ap} \left[ 1 - \cos (\nu_3 - \nu_2) \right] \]  \hfill (300)

\[ \sin (E_2 - E_1) = \frac{r_1}{\sqrt{ap}} \sin (\nu_2 - \nu_1) + \frac{r_1}{p} \left[ 1 - \cos (\nu_2 - \nu_1) \right] s_e \]  \hfill (301)

\[ \cos (E_2 - E_1) = 1 - \frac{r_2r_1}{ap} \left[ 1 - \cos (\nu_2 - \nu_1) \right] \]  \hfill (302)

\[ M_3 - M_2 = E_3 - E_2 + 2s_e \sin^2 \left( \frac{E_3 - E_2}{2} \right) - c_e \sin (E_3 - E_2) \]  \hfill (303)
\[ M_1 - M_2 = -(E_2 - E_1) + 2S_e \sin^2 \left( \frac{E_2 - E_1}{2} \right) + C_e \sin (E_2 - E_1) \quad (304) \]

\[ F_1 = \tau_1 - k_e \left( \frac{M_1 - M_2}{n} \right) \quad (305) \]

\[ F_2 = \tau_3 - k_e \left( \frac{M_3 - M_2}{n} \right) \quad (306) \]

Save \( F_1, F_2, r_1 \); increment \( r_1 \) by \( \Delta r_1 \) (about 4 percent) and return to equation (275). The end result of this calculation will be \( F_1 (r_1 + \Delta r_1, r_2) \), \( F_2 (r_1 + \Delta r_1, r_2) \), so that

\[ \frac{\Delta F_1}{\Delta r_1} = \frac{F_1 (r_1 + \Delta r_1, r_2) - F_1 (r_1, r_2)}{\Delta r_1} \quad (307) \]

\[ \frac{\Delta F_2}{\Delta r_1} = \frac{F_2 (r_1 + \Delta r_1, r_2) - F_2 (r_1, r_2)}{\Delta r_1} \quad (308) \]

Save \( \frac{\Delta F_1}{\Delta r_1} \), \( \frac{\Delta F_2}{\Delta r_1} \); set \( r_1 \) back to the original value; increment \( r_2 \) by \( \Delta r_2 \) (about 4 percent); and return to equation (275). The end result of this calculation will be \( F_1 (r_1, r_2 + \Delta r_2) \), \( F_2 (r_1, r_2 + \Delta r_2) \), so that

\[ \frac{\Delta F_1}{\Delta r_2} = \frac{F_1 (r_1, r_2 + \Delta r_2) - F_1 (r_1, r_2)}{\Delta r_2} \quad (309) \]
\[
\frac{\partial F_2}{\partial r_2} = \frac{F_2 (r_1, r_2 + \Delta r_2) - F_2 (r_1, r_2)}{\Delta r_2}
\]  

(310)

Continue calculating with

\[
\Delta = \left( \frac{\partial F_1}{\partial r_1} \right) \left( \frac{\partial F_2}{\partial r_2} \right) - \left( \frac{\partial F_2}{\partial r_1} \right) \left( \frac{\partial F_1}{\partial r_2} \right)
\]

(311)

\[
\Delta_1 = \left( \frac{\partial F_2}{\partial r_2} \right) F_1 - \left( \frac{\partial F_1}{\partial r_2} \right) F_2
\]

(312)

\[
\Delta_2 = \left( \frac{\partial F_1}{\partial r_1} \right) F_2 - \left( \frac{\partial F_2}{\partial r_1} \right) F_1
\]

(313)

\[
\Delta r_1 = - \frac{\Delta_1}{\Delta}
\]

(314)

\[
\Delta r_2 = - \frac{\Delta_2}{\Delta}
\]

(315)

Check to see if

\[
|\Delta r_1| < \varepsilon
\]

(316a)

\[
|\Delta r_2| < \varepsilon
\]

(316b)

where \(\varepsilon\) is a tolerance, i.e. \(10^{-10}\). If the test is not satisfied, let

\[
(r_1)_{n+1} = (r_1)_n + \Delta r_1
\]

(317a)

\[
(r_2)_{n+1} = (r_2)_n + \Delta r_2
\]

(317b)
and return to equation (275); if it is satisfied, continue calculating with

\[ f = 1 - \frac{a}{r_2} \left[ 1 - \cos (E_3 - E_2) \right] \]  
\[ g = \tau_3 \sqrt{\frac{a^3}{\mu}} \left[ (E_3 - E_2) - \sin (E_3 - E_2) \right] \]  
\[ \dot{r}_2 = \frac{r_3 - fr_2}{g} \]

Continue by calculating for the classical elements.
START

ALPHA(1), DELTA (1), T(1), PHI(1), YAME(1), H(1), FOR I = 1,2,3; DTHETA, FLAT, AE, XMU, XK, TJD, T(4)

ECHO CHECK

ITIME = 0

DO 17 I = 1, 3

DO 96 1, 25

DO 82 J = 1, 3

A

A

J ≠ 1

T

F

23

J ≠ 2

T

F

26

28

31

35

K = 1, 2

DO 35

WB2 < 0

T

46

F

B

B

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PAGE 102
DOUBLE R-ITERATION FLOWCHART (CONT'D)
DOUBLE R-ITERATION FLOWCHART (CONT'D)

1. If $i = 25$?
   - Yes: STOP
   - No: Continue

2. XLCV (2), YLCV (2), ZLCV (2)

3. SOLUTION FOR CLASSICAL ELEMENTS

4. ITIME, ALC, ELC, TE, OMEGA, OINCL, W

5. STOP
17. \( R(I) = \sin(\theta(I) \times X(I)) \times Y(I) \times Z(I) \)
\( RLC(I) = RLC(I) \times \sin(\theta(I)) \)

18. \( D \_Y = 1, \theta, \phi \)
19. \( D \_Z = J, J, J \)
20. IF (J = 1) \( D \_X = \theta, \phi, \phi \)
21. \( RLC(1) = RLC(1) \times \sin(\theta) \)
22. \( RLC(1) = RLC(1) \times \sin(\phi) \)

23. \( P(x) = F(0) \times \sin(\theta) \times \sin(\phi) \)
24. \( XLP(x) = F(0) \times \sin(\theta) \times \sin(\phi) \)
25. \( YLP(x) = F(0) \times \sin(\theta) \times \sin(\phi) \)
26. \( ZLP(x) = F(0) \times \sin(\theta) \times \sin(\phi) \)

27. \( XYLP = XLP \times YLP \times ZLP \)
28. \( CVTLP = XLP \times YLP \times ZLP \)
29. \( CVTY = YLP \times ZLP \)
30. \( CVTS = XLP \times YLP \times ZLP \)

31. \( CVTR = XLC \times YLC \times ZLC \)
32. \( CVTL = XLP \times YLP \times ZLP \)
33. \( CVTLC = XLP \times YLP \times ZLC \)
34. \( CVTLC = XLP \times YLC \times ZLC \)
35. \( CVTLC = XLP \times YLC \times ZLC \)

36. \( CVTLC = XLP \times YLC \times ZLC \)
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75. \( CVTLC = XLP \times YLC \times ZLC \)

76. \( CVTLC = XLP \times YLC \times ZLC \)
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81. \( CVTLC = XLP \times YLC \times ZLC \)
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85. \( CVTLC = XLP \times YLC \times ZLC \)

86. \( CVTLC = XLP \times YLC \times ZLC \)
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98. \( CVTLC = XLP \times YLC \times ZLC \)
99. \( CVTLC = XLP \times YLC \times ZLC \)
100. \( CVTLC = XLP \times YLC \times ZLC \)

101. \( CVTLC = XLP \times YLC \times ZLC \)
102. \( CVTLC = XLP \times YLC \times ZLC \)
103. \( CVTLC = XLP \times YLC \times ZLC \)
104. \( CVTLC = XLP \times YLC \times ZLC \)
105. \( CVTLC = XLP \times YLC \times ZLC \)
93  IF(ABS(DELR(P))>0.0000000001) 94, 94, 95
94  GO TO 97
95  RLC1(1+1)=ABS(RLC1(I)+DELR(1))
   RLC2(1+1)=ABS(RLC2(I)+DELR(1))
96  CONTINUE

C  SOLVE FOR INERTIAL VELOCITY VECTOR

97  RLC=FLC(1)
   FLC=1.0-(ALC/RLC)*(1.0-COS(ETHMT))
   GLC=TAN(3.0)*SORT(1/LC+X*YLC)*ETHMT/SETHTMT
   XLCV(P)=XLC(3)*FLC+YLC(P)/FLC
   YLCV(P)=YLC(3)*FLC+YLC(P)/FLC
   ZLCV(P)=ZLC(3)*FLC+ZLC(P)/FLC
   CTP=ITIME
   PRINT 100, CTP
   PREP=1.07, XLCV(P), YLCV(P), ZLCV(P)
   FORMAT(1HO, XLCV(P)=E16.8, YLCV(P)=E16.8, ZLCV(P)=E16.8)

C

100  FORMAT(*illi## CEC=##)

107
PRINT 109, ALT, ELC, TE, MEGA, INCL, W
FORMAT (1HO, 4E16.8, E16.8, E16.8, E16.8)
109 CONTINUE
GO TO 120
S2050 PZE
S MIN TIME
S BRU *POSYS
120 END
Given the mixed data \( \dot{\rho}_i, \alpha_{ti}, \tau, \delta_{ti} \) for \( i = 1, 2, 3 \) along with \( \phi_i, \lambda_{Ei}, H_i \) and the constants, \( a_e, k_e, \mu, f, \frac{d\theta}{dt} \), proceed as follows:

\[
\tau_1 = k_e (t_1 - t_2) \tag{321}
\]

\[
\tau_3 = k_e (t_3 - t_2) \tag{322}
\]

\[
S_1 = \frac{-\tau_3}{\tau_1 (\tau_1 - \tau_3)} \tag{323}
\]

\[
S_2 = -\frac{(\tau_3 + \tau_1)}{\tau_1 \tau_3} \tag{324}
\]

\[
S_3 = \frac{-\tau_1}{\tau_3 (\tau_3 - \tau_1)} \tag{325}
\]

\[
Tu = \frac{J.D. - 2415020}{36525} \tag{326}
\]

\[
\theta_{g0} = 99\degree 6909833 + 36000\degree 7689 Tu + 0\degree 000038708 Tu^2 \tag{327}
\]

For \( i = 1, 2, 3 \), compute

\[
\theta_i = \theta_{g0} + \frac{d\theta}{dt} (t_i - t_0) + \lambda_{Ei} \tag{328}
\]
\[ G_{1i} = \frac{a_e}{\sqrt{1 - (2f - f^2) \sin^2 \phi_i}} + H_i \]  
\[ G_{2i} = \frac{(1 - f)^2 a_e}{\sqrt{1 - (2f - f^2) \sin^2 \phi_i}} + H_i \]  
\[ L_{xi} = \cos \delta_{ti} \cos \alpha_{ti} \]  
\[ L_{yi} = \cos \delta_{ti} \sin \alpha_{ti} \]  
\[ L_{zi} = \sin \delta_{ti} \]  

Continue calculating with

\[ \rho_2 = S_1 \dot{\rho}_1 + S_2 \dot{\rho}_2 + S_3 \dot{\rho}_3 \]  
\[ \dot{L}_2 = S_1 \dot{L}_1 + S_2 \dot{L}_2 + S_3 \dot{L}_3 \]  
\[ X_2 = -G_{12} \cos \phi_2 \cos \theta_2 \]  
\[ Y_2 = -G_{12} \cos \phi_2 \sin \theta_2 \]  
\[ Z_2 = -G_{22} \sin \phi_2 \]
As a first approximation, set $r_2 = r_{2G}$, where $r_{2G}$ is an assumed value of $r_2$, i.e., 1.1 e.r., and initiate the following iterative scheme:

$$
\rho_2 = \frac{A + \left( \frac{B}{r_2^3} \right)}{C + \left( \frac{D}{r_2^3} \right)}
$$

(346)
\[ F(r_2) = \rho_2^2 + \rho_2 c_\psi + R_2^2 - r_2^2 \]  

(347)

\[ F'(r_2) = \left( \frac{3}{r_2^4} \right) \frac{(2 \rho_2 + c_\psi)(D \rho_2 - B)}{C + \left( \frac{D}{r_2^3} \right)} - 2r_2 \]  

(348)

and obtain a better value of \( r_2 \), that is,

\[ (r_2)_{n+1} = (r_2)_n - \frac{F(r_2)_n}{F'(r_2)_n}, \quad n = 1, 2, \ldots, q \]  

(349)

If the improved value of \( r_2 \) does not vary, that is,

\[ |(r_2)_{n+1} - (r_2)_n| < \varepsilon \]  

(350)

where \( \varepsilon \) is a specified tolerance, i.e., \( 10^{-10} \), proceed to equation (351); if not, return to equation (346) and using the latest value of \( r_2 \), repeat equational loop (347) to (349).

Continue calculating with

\[ r_2 = \rho_2 \text{L}_2 - R_2 \]  

(351)

\[ \dot{r}_2 = \rho_2 \dot{\text{L}}_2 + \rho_2 \dot{L}_2 - \dot{R}_2 \]  

(352)

Continue by calculating for classical elements.
MODIFIED LAPLACIAN FLOWCHART

START

PV(1), ALPHA (1), DELTA (1)
PHI (1), YAME(1), H(1), FOR I = 1,2,3, AE, XK, XMU, FLAT, DTHETA, TJD

ECCHO CHECK

ITIME = 0

DO 9 I = 1,3

DO 41 I = 1,25

RLC2 (I)

STOP

A

ABS [RLC2 (I - 1) - RLC2 (I)] < 10^-10

T

T

I = 25

B

XLCV (2), YLCV (2), ZLCV (2)

SOLUTION FOR CLASSICAL ELEMENTS

ITIME, ALC, ELC, TE OMEGA OINCL, W

F
MODIFIED L'PLACCI EQUILIBRUM BRIT DETERMINATION - MS T-T

DIMENSION T(4,10),T(4),T(2),T(1),T(3)

READ 100, T(1), T(2), T(3), T(4), T(5)
READ 100, ALPHA(1), ALPHA(2), YAM(1), YAM(2), YAM(3), PHI(1), PHI(2)
READ 100, PHI(3), PHI(4), PHI(5)
FORMAT (15,6,9)

FORMAT (251,5,9)

PRINT 1,0, FLAT, AL, YK, VK, JUTA, ETA, T(4), T(3), T(2), T(1)
FORMAT (15,6,9)

FORMAT (15,6,9)

PRINT 1, 1, ALPHA(1), ALPHA(2), ALPHA(3), DELTA(1), DELTA(2), DELTA(3), YAM(1), YAM(2), YAM(3), CYAM(1), YAM(1), YAM(2), YAM(3)

FORMAT (15,6,9)

FORMAT (15,6,9)

PRINT 1, 1, PHI(1), PHI(2), PHI(3), PHI(4), PHI(5), PHI(6), PHI(7)
FORMAT (15,6,9)

FORMAT (15,6,9)

PRINT 1, 1, T(1) = T(1) - T(2), T(3) - T(2), T(1) - T(3)

BEGIN CONDITIONS

ALL MET = SYM = 0.0
SUBROUTINE

T(1) = T(1) - T(2)
T(3) = T(3) - T(2)
S(1) = T(1) - T(3)

114
S(2) = (TA(3) + TA(1)) / (TA(3) * TA(1))
S(3) = TA(1) / (TA(3) * TA(1) - TA(1))
T(1) = (T(1) + T(2)) / T(1)
T(2) = T(1) * T(2)
X(1) = COS(DELTA(I)) * X(LP(3, I))
Y(1) = COS(DELTA(I)) * Y(LP(3, I))
Z(1) = SIN(DELTA(I))
DELTA(I) = T(1) * T(2) * (S(1) + (S(1) + S(2)) * (S(2) + S(3) + S(4)) + S(5))

R(1) = S(1) * Y(1) + S(2) * Z(1)
R(2) = S(1) * X(1) + S(2) * Z(1)

X(1) = X(1) + S(1) * X(2) + S(2) * Z(1)
Y(1) = Y(1) + S(1) * X(2) + S(2) * Z(1)
Z(1) = Z(1) + S(1) * Y(1) + S(2) * Z(1)

ITERATIONS FOR BASE VECTORS FOR CENTRAL DATE

FOR I = 1 TO 34
P(I) = (X(I) / X(LCP(I)) + X(LCP(I)) / X(I))
FINLCP = P(I) * P(I) + P(I) * P(I) - RLCP(I) * P(I)
EPLCP = (P(I) * P(I) + P(I) * P(I) - RLCP(I) * P(I))
EPLCP = EPLCP + FINLCP

CONTINUE

COMPUTE INERTIAL POSITION AND VELOCITY VECTORS

XLC(2) = P(I) * YL(1) - X(LC(1))
YLC(2) = P(I) * YL(1) - Y(LC(1))
ZLC(2) = P(I) * ZL(1) - Z(LC(1))
APPENDIX K
R-ITERATION PODM, MIXED DATA

Given the mixed data $\rho_i$, $\alpha_{ti}$, $\delta_{ti}$, $t_i$, for $i = 1, 2, 3$, along with $\phi_i$, $\lambda_{Ei}$, $H_i$ and the constants $a_e$, $k_e$, $\mu$, $f$, $d\theta/dt$, proceed as follows:

$$\tau_1 = k_e (t_1 - t_2)$$  \hspace{1cm} (353)

$$\tau_3 = k_e (t_3 - t_2)$$  \hspace{1cm} (354)

$$S_1 = \frac{- \tau_3}{\tau_1 (\tau_1 - \tau_3)}$$  \hspace{1cm} (355)

$$S_2 = - \left( \frac{\tau_3 + \tau_1}{\tau_1 \tau_3} \right)$$  \hspace{1cm} (356)

$$S_3 = \frac{- \tau_1}{\tau_3 (\tau_3 - \tau_1)}$$  \hspace{1cm} (357)

$$Tu = \frac{J, D. - 2415020}{36525}$$  \hspace{1cm} (358)

$$\theta_0 = 99^\circ 6909833 + 36000^\circ 7689 Tu + 0^\circ 00038708 Tu^2$$  \hspace{1cm} (359)

For $i = 1, 2, 3$, compute

$$L_{xi} = \cos \delta_{ti} \cos \alpha_{ti}$$  \hspace{1cm} (360)
\[ L_{yi} = \cos \delta_{ti} \sin \alpha_{ti} \]  
(361)

\[ L_{zi} = \sin \delta_{ti} \]  
(362)

\[ \theta_i = \theta_{g0} + \frac{d\theta}{dt} (t_i - t_0) + \lambda_{Ei} \]  
(363)

\[ G_{1i} = \frac{ae}{\sqrt{1 - (2f - f^2) \sin^2 \phi_i}} + H_i \]  
(364)

\[ G_{2i} = \frac{(1 - f)^2 a_e}{\sqrt{1 - (2f - f^2) \sin^2 \phi_i}} + H_i \]  
(365)

\[ X_i = -G_{1i} \cos \phi_i \cos \theta_i \]  
(366)

\[ Y_i = -G_{1i} \cos \phi_i \sin \theta_i \]  
(367)

\[ Z_i = -G_{2i} \sin \phi_i \]  
(368)

\[ \ddot{R}_i = \frac{1}{k_e} \begin{bmatrix} -Y_i \\ X_i \end{bmatrix} \frac{d\theta}{dt} \]  
(369)
\[ C_\psi = -2(L_{X2}X_2 + L_{Y2}Y_2 + L_{Z2}Z_2) \tag{370} \]

As a first approximation, set \( r_2 = r_g \). For near-Earth orbits, set \( r_g = 1.1 \) and obtain

\[ \rho_2 = \frac{1}{2} \left\{ -C_\psi + \left[ C_\psi^2 - 4(R_2^2 - r_2^2) \right]^{\frac{1}{2}} \right\} \tag{371} \]

Compute the radius vector at the central date from

\[ r_2 = \rho_2 L_2 - R_2 \tag{372} \]

Obtain the numerical derivative

\[ \dot{L}_2 = S_1 L_1 + S_2 L_2 + S_3 L_3 \tag{373} \]

Continue calculating with

\[ \dot{r}_2 = \dot{\rho}_2 L_2 + \rho_2 \dot{L}_2 - \dot{R}_2 \tag{374} \]

\[ \dot{r}_2 = \frac{r_2 \cdot \dot{r}_2 - 2}{r_2} \tag{375} \]

\[ v_2 = \sqrt{\dot{r}_2 \cdot \dot{r}_2} \tag{376} \]

Utilize the derivatives of the \( f \) and \( g \) series to compute

\[ \hat{f}_i = \hat{f}(v_2, r_2, r_2, \tau_i) \quad , \quad i = 1, 3 \tag{377} \]
\[ \dot{g}_i = \dot{g}(V_2, r_2, \dot{r}_2, \tau_1), \quad i = 1, 3 \quad (378) \]

Continue calculating with:

\[
E = \dot{f}_1 \dot{g}_3 L_1 \cdot L_2 - \dot{f}_3 \dot{g}_1 L_3 \cdot L_2 \\
+ \dot{g}_1 \dot{g}_3 L_2 \cdot (L_1 - L_3) \quad (379)
\]

\[
A = \{\dot{f}_1 \dot{g}_3 L_1 \cdot R_2 - \dot{f}_3 \dot{g}_1 L_3 \cdot R_2 \\
+ \dot{g}_1 \dot{g}_3 (L_1 - L_3) \cdot \dot{R}_2 - \dot{g}_3 L_1 \cdot \dot{R}_1 \} \\
+ \dot{g}_1 L_3 \cdot \dot{R}_3 / E \quad (380)
\]

\[
B = \frac{\dot{g}_3}{E} \quad (381)
\]

\[
C = - \frac{\dot{g}_1 \dot{g}_3 L_2 \cdot (L_1 - L_3)}{E} \quad (382)
\]

\[
D = - \frac{\dot{g}_1}{E} \quad (383)
\]

\[
\rho_2 = A + \dot{\rho}_1 B + \dot{\rho}_2 C + \dot{\rho}_3 D \quad (384)
\]

If

\[
|\rho_2_{n+1} - \rho_2_n| < \varepsilon \quad (385)
\]
where $\varepsilon$ is a specified tolerance, i.e., $10^{-10}$, proceed to equation (386); if not, return to equation (372) with the latest value of $\rho_2$ obtained from equation (384) and repeat equational loop (372) to (385).

Continue calculating with

\[ r_2 = \rho_2 \frac{L_2}{R_2} \quad \text{(386)} \]

\[ r_2 = \rho_2 \frac{L_2}{R_2} + \rho_2 \frac{\dot{L}_2}{L_2} - \frac{\dot{R}_2}{R_2} \quad \text{(387)} \]

Continue by calculating for classical elements.
R-ITERATION FLOWCHART

START

PV(i), ALPHA (i)
DELTA (i), T (i)
PHI (i), LAM (i)
H(i) FOR I = 1, 2, 3.
AE, XK, XMU,
FLAT, DTTHETA,
TJD

ECHO CHECK

ITIME = 0

DO 21
I = 1, 3

DO 53
I = 1, 25

DO 45
J = 1, 3, 2

A

P2 (i+1), I

ABS [(P2 (i+1) - P2 (I)) < 10-10

I = 25

XLCV (2), YLCV (2), ZLCV (2)

SOLUTION FOR CLASSICAL ELEMENTS

ITIME, ALC, ELC, TE, OMEGA,
OINCL, W

STOP

B
READ RANGE RATE AND ANGULAR INPUT DATA

FORMAT (7E14.8)

FORMAT (2F16.8)

FORMAT (*1H2)

PRINT 101, FLAT, AL, XY, YMU, DT, T(1), T(2), T(3), T(4)

FORMAT (1H20, 12F12.8)

PRINT 110, LTA, 1, LTA, 2, LTA, 3, LTA, 4, LTA, 5, LTA, 6

FORMAT (1H20, 12F12.8)

PRINT 111, LTA, 1, LTA, 2, LTA, 3, LTA, 4, LTA, 5, LTA, 6

BEGIN CONTINUES
PINCL=ATA' (EXP,17)
ULUMC=XLIC(2)*SIN(OMEGA)*COS(P1*CL)+YLIC(2)*COS(BL*E*A)*COS(1*CL)+
CZLC(2)*SIN(9*CL)
DEM=XLIC(2)*COS(OMEGA)+YLIC(2)*COS(OMEGA)
U=ATA' (U)*COS(0)
W=0.0000
C0=ITIME
PRINT 107,CTR
PRINT 107, A1, E1, A2, E2, P1, CL, X
FORMAT(1151,1LC=15.8,1LC=15.8,1LC=15.8,1LC=15.8,1LC=15.8,1LC=15.8)
FORMAT(1151,1LC=15.8,1LC=15.8,1LC=15.8,1LC=15.8,1LC=15.8,1LC=15.8)
107 CONTINUE
59 CONTINUE
30 TF F0
S E
1 1111
S 0 0 0 0 0 0
60 EXP 0000
APPENDIX L
TRILATERATION PODM, MIXED DATA

Given the mixed data \( p_j, \dot{p}_j, t_j, j = 1, 2, ..., q \), for a set of observing stations with coordinates \( \phi_i, \lambda_{E_i}, H_i, i = 1, 2, 3 \), and constants \( a_e, f, \frac{d\phi}{dt} \), proceed as follows. Reduce the range and range-rate data to a common simultaneous time such that \( p_i, \dot{p}_i, i = 1, 2, 3 \), are available for an arbitrary modified time \( t_0 \) and compute

\[
T_u = \frac{J.D. - 2415020}{36525}
\]  

(388)

\[
\theta_{g0} = 99\degree 6909833 + 36000\degree 7689 T_u + 0\degree 00038708 T_u^2
\]  

(389)

For \( i = 1, 2, 3 \), compute

\[
G_{1i} = \frac{a_e}{\sqrt{1 - (2f - f^2) \sin^2 \phi_i}} + H_i
\]  

(390)

\[
G_{2i} = \frac{(1 - f)^2 a_e}{\sqrt{1 - (2f - f^2) \sin^2 \phi_i}} + H_i
\]  

(391)

\[
\theta_i = \theta_{g0} + \frac{d\theta}{dt} (t_i - t_0) + \lambda_{E_i}
\]  

(392)

\[
X_i = - G_{1i} \cos \phi_i \cos \theta_i
\]  

(393)

\[
Y_i = - G_{1i} \cos \phi_i \sin \theta_i
\]  

(394)
\[ Z_i = - G_{2i} \sin \phi_i \]  
(395)

\[ R_i = R_i \cdot R_i \]  
(396)

\[ \xi_{21} = \frac{1}{2} \left[ \rho_2^2 - \rho_1^2 - (R_2^2 - R_1^2) \right] \]  
(397)

\[ \xi_{31} = \frac{1}{2} \left[ \rho_3^2 - \rho_1^2 - (R_3^2 - R_1^2) \right] \]  
(398)

\[ \Delta_1 = (Z_3 - Z_1)(Y_2 - Y_1) - (Z_2 - Z_1)(Y_3 - Y_1) \]  
(399)

\[ A = \frac{(X_2 - X_1)(Y_3 - Y_1) - (X_3 - X_1)(Y_2 - Y_1)}{\Delta_1} \]  
(400)

\[ B = \frac{\xi_{31}}{\Delta_1} (Y_2 - Y_1) - \xi_{21} (Y_3 - Y_1) \]  
(401)

\[ \Delta_2 = (Y_3 - Y_1)(Z_2 - Z_1) - (Y_2 - Y_1)(Z_3 - Z_1) \]  
(402)

\[ C = \frac{(X_2 - X_1)(Z_3 - Z_1) - (X_3 - X_1)(Z_2 - Z_1)}{\Delta_2} \]  
(403)

\[ D = \frac{\xi_{31}}{\Delta_2} (Z_2 - Z_1) - \xi_{21} (Z_3 - Z_1) \]  
(404)
\[ \varepsilon_1 = A^2 + C^2 + 1 \]  
(405)

\[ \varepsilon_2 = 2(AB + CD + X_1 + CY_1 + AZ_1) \]  
(406)

\[ \varepsilon_3 = B^2 + D^2 + 2DY_1 + 2BZ_1 + R_1^2 - \rho_1^2 \]  
(407)

\[ x_{0j} = -\frac{\varepsilon_2 + \sqrt{\varepsilon_2^2 - 4\varepsilon_1\varepsilon_3}}{2\varepsilon_1} \]  
(408)

\[ y_{0j} = Cx_{0j} + D \]  
(409)

\[ z_{0j} = Ax_{0j} + B \]  
(410)

\[ r_{0j}^2 = r_{0j} \cdot r_{0j} \]  
(411)

Reject the \( r_{0j} \) that does not satisfy

\[ \rho_1^2 = r_{0j}^2 + 2r_{0j} \cdot R_1 + R_1^2 \]  
(412)

and continue calculating for \( i = 1, 2, 3 \), with

\[ \dot{\mathbf{R}}_i = \frac{1}{k_e} \begin{bmatrix} -Y_i \\ X_i \\ \frac{d\theta}{dt} \\ Z_i \end{bmatrix} \]  
(413)
\[ \varepsilon_i = r_0 + R_i \]  

(414)

\[ E_i = \rho_i \dot{\rho}_i - \dot{R}_i \cdot \rho_i \]  

(415)

Invert the matrix

\[ M_s = \begin{bmatrix} \rho_{x1} & \rho_{y1} & \rho_{z1} \\ \rho_{x2} & \rho_{y2} & \rho_{z2} \\ \rho_{x3} & \rho_{y3} & \rho_{z3} \end{bmatrix} \]  

(416)

and obtain

\[
\begin{bmatrix}
\dot{x}_0 \\
\dot{y}_0 \\
\dot{z}_0
\end{bmatrix} = \left[ M_s \right]^{-1} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}
\]  

(417)

Continue by calculating for classical elements.
TRILATERATION FLOWCHART

START

ECHO CHECK

ITIME = 0

DO 11 J = 1, 3

DO 31 J = 1, 2

RLDR (J), PRLCR (J), J

A

ABS [RLDR (I) - PRLCR (1)]

T

ITIME = 0

RLDR (J), PRLCR (J), J

A

ECHO CHECK

SOLUTION FOR CLASSICAL ELEMENTS

PAGE 132
TRILATERATION FLOWCHART (CONT'D)
\[ \text{THETA} (J) = \text{GTHETA} + \text{THETA} * (T(2) - T(4)) + \text{YAME} (J) \]
\[ X(J) = \text{G!} (J) * \text{CBS} (\text{PHI (J)}) * \text{CBS} (\text{THETA} (J)) \]
\[ Y(J) = \text{G!} (J) * \text{CBS} (\text{PHI (J)}) * \text{SIN} (\text{THETA} (J)) \]
\[ Z(J) = \text{GSPH} (J) * \text{SIN} (\text{PHI (J)}) \]

11
\[ R(J) = \text{SQRT} (X(J) * X(J) + Y(J) * Y(J) + Z(J) * Z(J)) \]
\[ DDEL3(J) = 1.5 * TP(3) * R(J) * (R(J) * R(J) - R(J) * R(J)) \]
\[ DDEL(T) = R(J) * R(J) * R(J) * R(J) * (R(J) * R(J) - R(J) * R(J)) \]
\[ DDEL90T(J) = (Z(J) + (Y(J) + Z(J))/2) * (Y(J) - Z(J)) * (Z(J) - (Y(J) + Z(J))/2) \]
\[ A = ((X(J) + X(J))/2) * ((Y(J) + Y(J))/2) * ((Z(J) + Z(J))/2) \]

26
\[ \text{EPS} = (X(J) + X(J)) + (Y(J) + Y(J)) + (Z(J) + Z(J)) \]
\[ \text{EPS} = (X(J) + X(J)) + (Y(J) + Y(J)) + (Z(J) + Z(J)) \]

101
\[ \text{FORMAT} (16.8) \]

39
\[ \text{FORMAT} (16.8) \]

48
\[ \text{FORMAT} (16.8) \]

134
SOLVE FOR THE LAGRANGIAN LAGRANGE VECTORS

XLC(2) = pDA(1,1) * AT*E(1) + CPF*(2,1) / AT*E(2) + CPF*(1,1) / AT*E(1)

YLC(2) = -pDA(1,2) / AT*E(1) + CPF*(2,2) / AT*E(2) + CPF*(1,2) / AT*E(1)

ZLC(2) = pDA(1,3) / AT*E(1) + CPF*(2,3) / AT*E(2) + CPF*(1,3) / AT*E(1)

CT = ITI

AP = IT,1',1.,0.

AT = 1, 2, YLC(2), YLC(1), YLC(2), YLC(1)

I = F16 + 16, YLC(2) = 16,8, ZLC(1) = 16 + 8

SOLUTION FOR CLASSICAL ELEMENTS

IT1 = 0

PLC = PDA(1,1) * E(1) + YLC(2) * ZLC(1) + ZLC(2) * ZLC(1)

PSR = PLC * XLC(2) + YLC(2) * YLC(2) + ZLC(2) * ZLC(2)

WLC = PLC * PLC

VLC = PLC * PLC + YLC(2) * YLC(2) + ZLC(2) * ZLC(2)

CS = ELC/PLC

SR = VLC/PLC

F = VLC/PLC

PSF = PLC * PLC

KS = PLC * PLC

CSY = PLC * PLC

SI = VLC/PLC

TE = PLC * PLC

HC = PLC * PLC

VH = PLC * PLC

HA = PLC * PLC

VH = PLC * PLC

VH = PLC * PLC

135
DE\(^n\) = XLG(\(\theta\)) \times \cos(\(\Omega\)) + YLG(\(\theta\)) \times \sin(\(\Omega\))

'\(=\) ATAN(\(\theta\)/\(\Omega\)), \(\Omega\) \(=\) \(\Omega\)\(\text{MAX}\).

CTG = IT \(\text{MAX}\).

PRINT 100, CTG

FORMAT(107, A, XLG, TF, YMEG, P, INCL, W)

107 FORMAT('XLG=IF16.8, //', 'TF=IF16.8, //', 'YMEG=IF16.8, //', 'P=IF16.8, //', 'INCL=IF16.8, //', 'W=IF16.8, //')

100 FORMAT('** LISP = IF')

50 CONTINUE

GO TO 60

520 CONTINUE

S  \(\text{IF} \), LIE

S  \(\text{IF} \), x2550S

60  END
Appendix M
Herrick-Gibbs PODM, Mixed Data

Given the mixed data \( \rho_i, \alpha_{ti}, \delta_{ti} \), for some \( t_i \) with \( i = 1, 2, 3 \), along with station data \( \phi_i, \lambda_{Ei}, H_i \) and the constants \( a_e, K_e, \mu, \nu, f, \frac{d\phi}{dt} \), proceed as follows:

\[
Tu = \frac{JD - 2415020}{36525}
\]  

(418)

\[
\theta_0 = 99^\circ.6909833 + 36000^\circ.7689 Tu + 0^\circ.00038708 Tu^2
\]  

(419)

For \( i = 1, 2, 3 \) compute

\[
L_{xi} = \cos \delta_{ti} \cos \alpha_{ti}
\]  

(420)

\[
L_{yi} = \cos \delta_{ti} \sin \alpha_{ti}
\]  

(421)

\[
L_{zi} = \sin \alpha_{ti}
\]  

(422)

\[
G_{1i} = \frac{a_e}{1 - (2f - f^2) \sin^2 \phi_i} + H_i
\]  

(423)

\[
G_{2i} = \frac{(1 - f)^2 a_e}{1 - (2f - f^2) \sin^2 \phi_i} + H_i
\]  

(424)
\[ \theta_i = \theta_0 + \frac{d\theta}{dt} (t_i - t_0) + \lambda \xi_i \]  
\[ X_i = -G_{1i} \cos \phi_i \cos \theta_i \]  
\[ Y_i = -G_{1i} \cos \phi_i \sin \theta_i \]  
\[ Z_i = -G_{2i} \sin \phi_i \]  
\[ \eta_i = \rho_i \frac{L_i}{R_i} - R_i \]  

From the observation times, one may compute the respective modified times, that is

\[ \tau_{ij} = K_e (t_j - t_i) \]  

with \( j = 1, 2, 3 \) and \( i = 2 \)

\[ G^{-1}_1 = \frac{\tau_{23}}{\tau_{12} \tau_{13}} \]  
\[ G^{-1}_3 = \frac{\tau_{12}}{\tau_{23} \tau_{13}} \]  
\[ G^{-1}_2 = G^{-1}_1 - G^{-1}_3 \]
with \( \tau_{13} \equiv \tau_3 - \tau_1 \) (434)

Continue by computing

\[
H^{-1} = \frac{\mu \tau_{23}}{12} \tag{435}
\]

\[
H^{-3} = \frac{\mu \tau_{12}}{12} \tag{436}
\]

\[
H^{-2} = H^{-1} - H^{-3} \tag{437}
\]

and form the coefficients

\[
d_i = G^{-1}_i + \frac{H^{-1}_i}{r_i} \quad \text{for} \quad i = 1, 2, 3 \tag{438}
\]

\[
\hat{r}_2 = -d_1 r_1 + d_2 r_2 + d_3 r_3 \tag{439}
\]

Continue by calculating for the classical elements.
HERRICK-GIBBS FLOWCHART

START

P(I), H(I), PHI(I)
YAME(I), DELTA(I)
ALPHA(I), T(I), FOR
I = 1, 2, 3. AE, FLAT,
DTHETA, TJD, XMU,
XK, T(4)

ECHO
CHECK

TIME = 0

DO 14
I = 1, 3

A

DO 24
I = 1, 3

XLCV(2)
YLCV(2)
ZLCV(2)

SOLUTION FOR
CLASSICAL
ELEMENTS

TIME, ALC,
ELC, TE,
OMEGA,
QINCL, W

STOP

140
HERRICK-GIBBS PRELIMINARY SPIT DETERMINATION METHOD
RANGE AND ANGLES (ESECBAL, PAGE 325)

DE 59 \( n = 1, 25 \)

DIMENSION XL(3), YL(3), ZL(3), DENS(3), G1(3), G2(3), THEA(3), X(3),
CY(3), Z(3), XL(3), YLC(3), ZLC(3), RLC(3), T(4), P(3), APLX(3),
GELTA(3), Y1(3), Y2(3), A(3), XL(3), YLC(3), ZLC(3), RL(3), P(1),
CYX(3), P1(3), P2(3)

READ RANGE AND ANGULAR INPUT DATA

READ 108, FLAT, AT, YK, YM, DT, TA
READ 109, T(4), T(1), T(2), T(3), T(4)
READ 110, ALPH(A), ALPH(2), LPH(3), DDTA(1), DDTA(2)
READ 111, ELLTA(3), Y1E(1), Y2E(2), YATE(3), P1(1), P2(1)
READ 112, P3(1), P4(1), P5(1)

108 FORMAT(5F16.8)
109 FORMAT(5F16.8)

110 FORMAT(1X, 6E16.8)

PRINT 111, ALPH(1), ALPH(2), ALPH(3), DDTA(1), DDTA(2), YATE(3),
CYX(1), YATE(2), YATE(3)

PRINT 111, ELLTA(1), ELLTA(2), ELLTA(3), DDTA(1), DDTA(2),
CYX(1), YATE(2), YATE(3)

BEGIN COM PATING

ALL METER SYSTOLIC 7111 CMHDLIFE

ITL=0

START

ENTRY

112 FORMAT(1X, 6E16.8)

PRINT 111, DDTA(1), DDTA(2), DDTA(3), YATE(1), YATE(2), YATE(3)

PRINT 111, DDTA(1), DDTA(2), DDTA(3), YATE(1), YATE(2), YATE(3)

ENTRY

ITL=0

START

ENTRY

PRINT 111, DDTA(1), DDTA(2), DDTA(3), YATE(1), YATE(2), YATE(3)

ENTRY

ITL=0

START

ENTRY

PRINT 111, DDTA(1), DDTA(2), DDTA(3), YATE(1), YATE(2), YATE(3)

ENTRY

ITL=0

START

ENTRY

PRINT 111, DDTA(1), DDTA(2), DDTA(3), YATE(1), YATE(2), YATE(3)

ENTRY

ITL=0

START

ENTRY

PRINT 111, DDTA(1), DDTA(2), DDTA(3), YATE(1), YATE(2), YATE(3)

ENTRY

ITL=0

START

ENTRY

PRINT 111, DDTA(1), DDTA(2), DDTA(3), YATE(1), YATE(2), YATE(3)

ENTRY

ITL=0

START

ENTRY

PRINT 111, DDTA(1), DDTA(2), DDTA(3), YATE(1), YATE(2), YATE(3)

ENTRY

ITL=0

START

ENTRY

PRINT 111, DDTA(1), DDTA(2), DDTA(3), YATE(1), YATE(2), YATE(3)
YL(I) = CAS(DELTA(I)) * SIN(ALPHA(I)),
ZE(I) = SIN(DELTA(I))

DEN(I) = SQRT(4 + 2 * FLAT * FLAT ** 2) * (SIN(PHI(I))) ** 2
G1(I) = AF / DEN(I) + H(I)
G2(I) = (1 + FLAT) ** 2 * AF / DEN(I) + H(I)

THETA(I) = THETA(I) + THETA(I)(T(I) - T(4)) + YAME(I)

X(I) = G1(I) * COS(PHI(I)) * COS(THETA(I))
Y(I) = G1(I) * COS(PHI(I)) * SIN(THETA(I))
Z(I) = G2(I) * SIN(PHI(I))

XLC(I) = P(I) * YLC(I) - X(I)
YLC(I) = P(I) * YLC(I) - Y(I)
ZLC(I) = P(I) * ZLC(I) - Z(I)

RLC(I) = SQRT(YLC(I) ** 2 + YLC(I) ** 2 + ZLC(I) ** 2)

D1P3 = XK * (T(3) - T(2))
D1T3 = XK * (T(3) - T(1))
GR(1) = D1P3 / (D1T3 * D1T3)
GB(3) = D1T3 / (D1T3 * D1T3)
GB(2) = GB(1) - GB(3)
HP(1) = (X * X + T3) / 12.
HR(1) = (X * X + T2) / 12.
HB(2) = HP(1) - HP(3)

I = 1, 3

D(I) = GR(I) + HP(I) / RLC(I) ** 2

XLC(I) = G(I) * XLC(I) + H(I) * YLC(I) + Z(I) * ZLC(I)
YLC(I) = G(I) * YLC(I) + H(I) * YLC(I) + Z(I) * ZLC(I)
ZLC(I) = G(I) * ZLC(I) + H(I) * ZLC(I)

C1 = IT^2

PRINT 16, CT
PRINT 16, YLC(I), YLC(I), YLC(I)
FORMAT(16, 20, YLC(I) ** 2 + YLC(I) ** 2 + YLC(I) ** 2)

SOLUTION FOR CLASSICAL ELEMENTS

I1**3 = 0

RLC(I) = SQRT(YLC(I) ** 2 + YLC(I) ** 2 + ZLC(I) ** 2)

RR = TY(I) * YLC(I) + YLC(I) * YLC(I) + ZLC(I) * ZLC(I)

RLC(Z) = SQRT(YLC(I) ** 2 + YLC(I) ** 2 + ZLC(I) ** 2)

V = SQRT(YLC(I) ** 2 + YLC(I) ** 2 + ZLC(I) ** 2)

ALC = TY(I) / (X * X + Y * Y + Z * Z)

CS = (1 + RLC(Z) / RLC(Z)) / SQRT(X * X + Y * Y + Z * Z)

ELC = 10 / (-X) * (CS / X)

CASE = AN = 'L(V) = 10(-X / X)'

X = (YLC(I) ** 2) / (X * X)

CS == X * YLC(I) / (X * X + YLC(I) ** 2)

CASE = AN == 'L(V) = (X * X + YLC(I) ** 2) / (X * X + YLC(I) ** 2)'

CASE = AN == 'L(V) = (X * X + YLC(I) ** 2) / (X * X + YLC(I) ** 2)'

CASE = AN == 'L(V) = (X * X + YLC(I) ** 2) / (X * X + YLC(I) ** 2)'

VAME = AT(I) / (SIN, COS)
## ORBITAL PARAMETERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semimajor Axis</td>
<td>006931.15 km or 004306.81 mi</td>
</tr>
<tr>
<td>Eccentricity</td>
<td>0.00216</td>
</tr>
<tr>
<td>Inclination</td>
<td>032.863°</td>
</tr>
<tr>
<td>Mean Anomaly</td>
<td>351.947°</td>
</tr>
<tr>
<td>Argument of Perigee</td>
<td>226.399°</td>
</tr>
<tr>
<td>RA of Ascending Node</td>
<td>187.347°</td>
</tr>
<tr>
<td>Anomalistic Period</td>
<td>0095.70901 min</td>
</tr>
<tr>
<td>Height of Perigee</td>
<td>000537.76 km or 000334.15 mi</td>
</tr>
<tr>
<td>Height of Apogee</td>
<td>000567.76 km or 000352.79 mi</td>
</tr>
<tr>
<td>Velocity at Perigee</td>
<td>027360 km/hr or 017001 mi/hr</td>
</tr>
<tr>
<td>Velocity at Apogee</td>
<td>027242 km/hr or 016928 mi/hr</td>
</tr>
<tr>
<td>Geocentric Latitude of Perigee</td>
<td>-23.138°</td>
</tr>
<tr>
<td>Parameter</td>
<td>Value</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>Semimajor Axis</td>
<td>011129.48 km or 006915.5 mi</td>
</tr>
<tr>
<td>Eccentricity</td>
<td>0.24115°</td>
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<tr>
<td>Inclination</td>
<td>046.323°</td>
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<tr>
<td>Mean Anomaly</td>
<td>291.027°</td>
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<tr>
<td>Argument of Perigee</td>
<td>248.553°</td>
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<tr>
<td>RA of Ascending Node</td>
<td>161.988°</td>
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<tr>
<td>Anomalistic Period</td>
<td>0194.74113 min</td>
</tr>
<tr>
<td>Height of Perigee</td>
<td>002067.24 km or 001284.52 mi</td>
</tr>
<tr>
<td>Height of Apogee</td>
<td>007434.94 km or 004619.85 mi</td>
</tr>
<tr>
<td>Velocity at Perigee</td>
<td>027554 km/hr or 017121 mi/hr</td>
</tr>
<tr>
<td>Velocity at Apogee</td>
<td>016847 km/hr or 010468 mi/hr</td>
</tr>
<tr>
<td>Geocentric Latitude of Perigee</td>
<td>-42.311°</td>
</tr>
</tbody>
</table>
## APPENDIX P

### STATION COORDINATES

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude ($\phi$)</th>
<th>Longitude ($\lambda_E$)</th>
<th>Height (H)</th>
<th>e.r. ($10^{-7}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Degrees</td>
<td>Radians</td>
<td>Degrees</td>
<td>Radians</td>
</tr>
<tr>
<td>Fort Myers</td>
<td>26° 32' 53.78</td>
<td>0.46335476</td>
<td>278° 08' 04.60</td>
<td>4.8543647</td>
</tr>
<tr>
<td>Newfoundland</td>
<td>47° 44' 28.94</td>
<td>0.83324413</td>
<td>307° 16' 46.71</td>
<td>5.3630414</td>
</tr>
<tr>
<td>Quito</td>
<td>00° 37' 20.55</td>
<td>0.01086249</td>
<td>281° 25' 15.62</td>
<td>4.9117231</td>
</tr>
<tr>
<td>Lima</td>
<td>-11° 46' 34.86</td>
<td>-0.20553608</td>
<td>282° 50' 59.14</td>
<td>4.9366596</td>
</tr>
<tr>
<td>Santiago</td>
<td>-33° 08' 56.23</td>
<td>-0.57855837</td>
<td>289° 19' 52.88</td>
<td>5.0497847</td>
</tr>
<tr>
<td>Winkfield</td>
<td>51° 26' 45.43</td>
<td>0.89790126</td>
<td>359° 18' 13.57</td>
<td>6.2710337</td>
</tr>
<tr>
<td>Johannesburg</td>
<td>-25° 53' 00.98</td>
<td>-0.45175414</td>
<td>27° 42' 28.49</td>
<td>0.48359432</td>
</tr>
<tr>
<td>Madagascar</td>
<td>-19° 00' 25.21</td>
<td>-0.33173478</td>
<td>47° 18' 00.46</td>
<td>0.82554296</td>
</tr>
<tr>
<td>Orroral</td>
<td>-35° 37' 37.51</td>
<td>-0.62180996</td>
<td>148° 57' 10.71</td>
<td>2.5997184</td>
</tr>
</tbody>
</table>
APPENDIX Q
RANGE, RANGE RATE, AND ANGULAR DATA COMPUTATIONAL ALGORITHM AND
COMPUTER PROGRAM LISTING

Given \( \mathbf{r}(x, y, z) \) and \( \dot{\mathbf{r}}(\dot{x}, \dot{y}, \dot{z}) \) at a time \( t \) with constants \( \phi, H, \lambda_E, \frac{d\theta}{dt}, k_e, \mu, t_g, a_e, f \), proceed as follows:

\[
Tu = \frac{\text{J.D.} - 2415020}{36525} \tag{440}
\]

\[
\theta_g = 99^\circ 6909833 + 36000^\circ 7689 Tu + 0^\circ 00038708 Tu^2
\]

\[
\theta = \theta_g + \frac{d\theta}{dt} (t - t_g) - (2\pi - \lambda_E) \tag{441}
\]

\[
G_1 = \frac{a_e}{\sqrt{1 - (2f - f^2) \sin^2 \phi}} + H \tag{442}
\]

\[
G_2 = \frac{(1 - f)^2 a_e}{\sqrt{1 - (2f - f^2) \sin^2 \phi}} + H \tag{443}
\]

\[
X = - G_1 \cos \phi \cos \theta \tag{444}
\]

\[
Y = - G_1 \cos \phi \sin \theta \tag{445}
\]

\[
Z = - G_2 \sin \phi \tag{446}
\]

\[
\dot{X} = - \frac{d\theta}{dt} Y \tag{447}
\]

147
\begin{align}
\dot{Y} &= \frac{d\theta}{dt} x \\
\dot{z} &= 0.0 \\
\rho &= r + R \\
\dot{\rho} &= \dot{r} + \dot{R} \\
\frac{\dot{\rho}}{\rho} &= \frac{\dot{r}}{r} + \frac{\dot{R}}{R} \\
r_p &= \sqrt{x^2 + y^2} \\
r &= \sqrt{x^2 + y^2 + z^2} \\
\cos \delta &= \frac{r_p}{r} \\
\sin \delta &= \frac{z}{r} \\
\cos \alpha &= \frac{x}{r_p} \\
\sin \alpha &= \frac{y}{r_p}
\end{align}
C
COMPUTATION FOR DISTRIBUTED SYSTEM

READ 107, X, Y, I, T, X, Y
READ 108, X, Y, I, T, X, Y
READ 109, X, Y, I, T, X, Y

107 FOR AT = (x, y) DO

108 FOR AT = (x, y) DO

109 FOR AT = (x, y) DO

110 FOR AT = (x, y) DO

111 FOR AT = (x, y) DO

112 FOR AT = (x, y) DO

C
END
APPENDIX R

SOLUTION FOR CLASSICAL ELEMENTS

Given $r_1 (x_1, y_1, z_1)$ or $r_2 (x_2, y_2, z_2)$ and the velocity $\dot{r}_1 (\dot{x}_1, \dot{y}_1, \dot{z}_1)$ or $\dot{r}_2 (\dot{x}_2, \dot{y}_2, \dot{z}_2)$, proceed as follows:

\[ r_1 = \sqrt{\mathbf{r}_1 \cdot \mathbf{r}_1} \]  
(460)

\[ r_1 \dot{r}_1 = x_1 \dot{x}_1 + y_1 \dot{y}_1 + z_1 \dot{z}_1 \]  
(461)

\[ \dot{r}_1 = \frac{r_1 \cdot \dot{r}_1}{r_1} \]  
(462)

\[ v = \sqrt{\dot{r}_1 \cdot \dot{r}_1} \]  
(463)

Semimajor axis, $a$,
\[ a = \frac{r_1 \mu}{2\mu - V^2 r_1} \]  
(464)

Coefficcient of eccentricity, $e$,
\[ C_e = 1 - \frac{r_1}{a} \]  
(465)

\[ S_e = \frac{\dot{r}_1 r_1}{\sqrt{\mu a}} \]  
(466)

Eccentricity, $e$,
\[ e = \sqrt{S_e^2 + C_e^2} \]  
(467)
\[ \cos E = \frac{a - r_1}{a_e} \]  

(468)

\[ x_w = a (\cos E - e) \]  

(469)

\[ \cos \nu = \frac{x_w}{r_1} \]  

(470)

\[ \sin \nu = \frac{\sqrt{r_1^2 - x_w^2}}{r_1} \]  

(471)

\[ \sin E = \sqrt{1 - e^2} \left( \frac{\sin \nu}{1 + e \cos \nu} \right) \]  

(472)

Time of perifocal passage, \( T \)

\[ T = t_1 - \frac{(E - e \sin E)}{k_e \sqrt{\mu a^3}} \]  

(473)

\[ h_x = y_1 \ddot{x}_1 - z_1 \dot{y}_1 \]  

(474)

\[ h_y = - (x_1 \ddot{z}_1 + z_1 \dot{x}_1) \]  

(475)

\[ h_z = x_1 \dot{y}_1 - y_1 \dot{x}_1 \]  

(476)

Longitude of ascending node, \( \Omega \)

\[ \tan \Omega = \frac{h_x}{-h_y} \]  

(477)
Orbit inclination, $i$

$$
\tan i = \frac{\sqrt{h_x^2 + h_y^2}}{h_z}
$$

(478)

$$
\tan u = \frac{-x_1 \sin\Omega \cos i + y_1 \cos\Omega \cos i + z_1 \sin i}{x_1 \cos\Omega + y_1 \sin\Omega}
$$

(479)

Augment of perigee, $\omega$

$$
\omega = u - \nu
$$

(480)
APPENDIX S
FLOWCHART SYMBOL DEFINITIONS

<table>
<thead>
<tr>
<th>Symbol Shape</th>
<th>Definition</th>
<th>Information Inside Symbol</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start/stop</td>
<td>Start or stop</td>
<td></td>
<td>START</td>
</tr>
<tr>
<td>Card</td>
<td>Input items</td>
<td></td>
<td>XLC(1), YLC(1), ZLC(1)</td>
</tr>
<tr>
<td>Printer</td>
<td>Output items</td>
<td></td>
<td>F(1), 1</td>
</tr>
<tr>
<td>Assignment</td>
<td>One or more statements</td>
<td></td>
<td>DELV = 0.05 VLC(1)</td>
</tr>
<tr>
<td>DO</td>
<td>Repetition parameters</td>
<td></td>
<td>DO 31 I = 1, 25</td>
</tr>
<tr>
<td>Decision</td>
<td>True and false conditions</td>
<td></td>
<td>1 = 25</td>
</tr>
<tr>
<td>IF statements</td>
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<tr>
<td>Symbol Shape</td>
<td>Definition</td>
<td>Information Inside Symbol</td>
<td>Example</td>
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<tr>
<td></td>
<td></td>
<td>Inside Symbol</td>
<td>Example</td>
</tr>
<tr>
<td></td>
<td>Unconditional transfer or GO TO statement</td>
<td>Numerical statement</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Off-page connector label</td>
<td>Alphabetical letter</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>On-page connector label</td>
<td>Alphabetical letter</td>
<td>F</td>
</tr>
</tbody>
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## APPENDIX T
### ASSUMED VALUES OF GEOPHYSICAL CONSTANTS

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<th>Constant</th>
<th>Symbol</th>
<th>Assumed Value</th>
<th>FORTRAN Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flatness coefficient</td>
<td>$f$</td>
<td>$0.33528919 \times 10^{-2}$</td>
<td>FLAT</td>
</tr>
<tr>
<td>Canonical unit of length</td>
<td>CUL</td>
<td>$0.63781660 \times 10^7$ meters</td>
<td>-</td>
</tr>
<tr>
<td>Earth radius</td>
<td>e.r.</td>
<td>$0.10000000 \times 10$ CUL</td>
<td>AE</td>
</tr>
<tr>
<td>Gravitational constant of Earth</td>
<td>$k_e$</td>
<td>$0.74366728 \times 10^{-1} \left( \frac{\text{e.r.}^2}{\text{min.}} \right)$</td>
<td>XK</td>
</tr>
<tr>
<td>Sum of masses</td>
<td>$\mu$</td>
<td>$0.100000000 \times 10$</td>
<td>XMU</td>
</tr>
<tr>
<td>Rotation of Earth</td>
<td>$\frac{d\theta}{dt}$</td>
<td>$0.43752691 \times 10^{-2} \left( \text{radians} \div \text{min.} \right)$</td>
<td>DTHETA</td>
</tr>
<tr>
<td>Julian Date</td>
<td>J.D.</td>
<td>$0.24397835 \times 10^7$</td>
<td>TJD</td>
</tr>
<tr>
<td>OSO-III EPOCH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RELAY-II EPOCH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canonical unit of time</td>
<td>CUT</td>
<td>$0.13446874 \times 10^2$ min.</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure 2. Results of Lambert-Euler PODM for OSO-III Orbit
Figure 3. Results of Lambert-Euler PODM for Relay-II Orbit

\[ \Delta \text{NUMBER OF ITERATIONS} \]

\[ \Delta \text{ANOMALY ANGULAR DIFFERENCE OF } \dot{\gamma}_2, \ i.e., \ y_2 - \dot{\gamma}_2 \]
Figure 4. Results of F and G Series PODM for OSO-III Orbit
Figure 5. Results of F and G Series PODM for Relay-II Orbit
Figure 6. Results of Iteration of Semiparameter PODM for OSO-III Orbit
Figure 7. Results of Iteration of Semiparameter PODM for Relay-II Orbit
Figure 8. Results of Gaussian PODM for OSO-III Orbit
Figure 9. Results of Gaussian PODM for Relay-II Orbit
Figure 10. Results of Iteration of True Anomaly PODM for OSO-III Orbit
Figure 11. Results of Iteration of True Anomaly PODM for Relay-II Orbit
Figure 12. Elliptical Orbit
### Table 1. OSO-III Position and Velocity Orbit Data*

<table>
<thead>
<tr>
<th>Data Point</th>
<th>Position Vector (Canonical Units of Length)</th>
<th>Time from Epoch (Minutes)</th>
<th>Resultant Velocity Vector (Canonical Unit of Length Per Canonical Unit of Time)</th>
<th>Change in True Anomaly from Data Point 1 (Degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>X</strong></td>
<td><strong>Y</strong></td>
<td><strong>Z</strong></td>
<td><strong>X DOT</strong></td>
</tr>
<tr>
<td>1</td>
<td>0.63397379 E00</td>
<td>0.87714911 E00</td>
<td>-0.57285980 E-01</td>
<td>0.42900000 E03</td>
</tr>
<tr>
<td>2</td>
<td>0.58274812 E00</td>
<td>0.90885977 E00</td>
<td>-0.95773336 E-01</td>
<td>0.43000000 E03</td>
</tr>
<tr>
<td>3</td>
<td>0.47289180 E00</td>
<td>0.96034300 E00</td>
<td>-0.17136390 E00</td>
<td>0.43200000 E03</td>
</tr>
<tr>
<td>4</td>
<td>0.29327509 E00</td>
<td>0.10061443 E01</td>
<td>-0.27810960 E00</td>
<td>0.43500000 E03</td>
</tr>
<tr>
<td>5</td>
<td>-0.92932753 E-01</td>
<td>0.97992039 E00</td>
<td>-0.45733638 E00</td>
<td>0.44100000 E03</td>
</tr>
<tr>
<td>6</td>
<td>-0.46473516 E00</td>
<td>0.80288180 E00</td>
<td>-0.56523331 E00</td>
<td>0.44700000 E03</td>
</tr>
<tr>
<td>7</td>
<td>-0.76519048 E00</td>
<td>0.50282255 E00</td>
<td>0.58621929 E00</td>
<td>0.45300000 E03</td>
</tr>
<tr>
<td>8</td>
<td>-0.94868622 E00</td>
<td>0.12595263 E00</td>
<td>-0.51737772 E00</td>
<td>0.45900000 E03</td>
</tr>
<tr>
<td>9</td>
<td>-0.98742402 E00</td>
<td>-0.27017428 E00</td>
<td>-0.36935944 E00</td>
<td>0.46500000 E03</td>
</tr>
<tr>
<td>10</td>
<td>-0.62955513 E00</td>
<td>-0.88498102 E00</td>
<td>0.65285990 E-01</td>
<td>0.47700000 E03</td>
</tr>
<tr>
<td>11</td>
<td>0.76766068 E00</td>
<td>-0.49528024 E00</td>
<td>0.58396071 E00</td>
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<tr>
<td>12</td>
<td>0.61361294 E00</td>
<td>0.89000851 E00</td>
<td>-0.77740201 E-01</td>
<td>0.52500000 E03</td>
</tr>
</tbody>
</table>

*From reference 3.
Table 2. Relay-II Position and Velocity Orbit Data*

<table>
<thead>
<tr>
<th>Data Point</th>
<th>Position Vector (Canonical Units of Length)</th>
<th>Time from Epoch (Minutes)</th>
<th>Resultant Velocity Vector (Canonical Unit of Length Per Canonical Unit of Time)</th>
<th>Change in True Anomaly from Data Point 1 (Degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
<td>Z</td>
<td>X DOT</td>
</tr>
<tr>
<td>1</td>
<td>-0.62706086 E00</td>
<td>0.13026303 E01</td>
<td>-0.2678816 E00</td>
<td>0.66500000 E03</td>
</tr>
<tr>
<td>2</td>
<td>-0.67640560 E00</td>
<td>0.13001240 E01</td>
<td>-0.22446287 E00</td>
<td>0.66600000 E03</td>
</tr>
<tr>
<td>3</td>
<td>-0.72456249 E00</td>
<td>0.12954130 E01</td>
<td>-0.18069118 E00</td>
<td>0.66700000 E03</td>
</tr>
<tr>
<td>4</td>
<td>-0.81727365 E00</td>
<td>0.12796195 E01</td>
<td>-0.92290918 E-01</td>
<td>0.66900000 E03</td>
</tr>
<tr>
<td>5</td>
<td>-0.98699837 E00</td>
<td>0.12244558 E01</td>
<td>0.85668977 E-01</td>
<td>0.67300000 E03</td>
</tr>
<tr>
<td>6</td>
<td>-0.12598173 E01</td>
<td>0.10352957 E01</td>
<td>0.43259412 E00</td>
<td>0.68100000 E03</td>
</tr>
<tr>
<td>7</td>
<td>-0.14383867 E01</td>
<td>0.76921052 E00</td>
<td>0.74830389 E00</td>
<td>0.68900000 E03</td>
</tr>
<tr>
<td>8</td>
<td>-0.15150151 E01</td>
<td>0.53705523 E00</td>
<td>0.95602583 E00</td>
<td>0.69500000 E03</td>
</tr>
<tr>
<td>9</td>
<td>-0.15435262 E01</td>
<td>0.33061169 E00</td>
<td>0.11069735 E01</td>
<td>0.70000000 E03</td>
</tr>
<tr>
<td>10</td>
<td>-0.15282029 E01</td>
<td>-0.11262472 E-01</td>
<td>0.13085324 E01</td>
<td>0.70800000 E00</td>
</tr>
<tr>
<td>11</td>
<td>0.69346644 E-01</td>
<td>-0.17919632 E01</td>
<td>0.10225903 E01</td>
<td>0.76800000 E03</td>
</tr>
<tr>
<td>12</td>
<td>0.10671941 E01</td>
<td>-0.13527369 E01</td>
<td>-0.76286469 E-01</td>
<td>0.79900000 E03</td>
</tr>
<tr>
<td>13</td>
<td>-0.64038080 E00</td>
<td>0.13030522 E01</td>
<td>-0.15192970 E00</td>
<td>0.86000000 E03</td>
</tr>
</tbody>
</table>

*From reference 3.
Table 3. Results of Lambert-Euler PODM for OSO-III Orbit

<table>
<thead>
<tr>
<th>True Anomaly Difference of r1 → r2</th>
<th>Computed X Dot (CUL/CUT)</th>
<th>Computed Y Dot (CUL/CUT)</th>
<th>Computed Z Dot (CUL/CUT)</th>
<th>Iterations Required to Obtain an Epsilon (ε) of &lt;10^-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>i.e., v2 - v1 (Degrees)</td>
<td>-0.67081054 E0</td>
<td>0.45235122 E0</td>
<td>-0.51959007 E0</td>
<td>7</td>
</tr>
<tr>
<td>11.4</td>
<td>-0.67103078 E0</td>
<td>0.45243688 E0</td>
<td>-0.51971812 E0</td>
<td>7</td>
</tr>
<tr>
<td>22.8</td>
<td>-0.67130422 E0</td>
<td>0.45244467 E0</td>
<td>-0.51981342 E0</td>
<td>7</td>
</tr>
<tr>
<td>45.6</td>
<td>-0.67165405 E0</td>
<td>0.45226798 E0</td>
<td>-0.51976476 E0</td>
<td>8</td>
</tr>
<tr>
<td>68.4</td>
<td>-0.67164899 E0</td>
<td>0.45215526 E0</td>
<td>-0.51947102 E0</td>
<td>7</td>
</tr>
<tr>
<td>91.2</td>
<td>-0.67080666 E0</td>
<td>0.47883872 E0</td>
<td>-0.52650669 E0</td>
<td>8</td>
</tr>
<tr>
<td>114.0</td>
<td>-0.67166326 E0</td>
<td>0.45243605 E0</td>
<td>-0.51859662 E0</td>
<td>7</td>
</tr>
<tr>
<td>136.8</td>
<td>-0.67198271 E0</td>
<td>0.45278865 E0</td>
<td>-0.51775009 E0</td>
<td>7</td>
</tr>
<tr>
<td>180.0</td>
<td>Computer halted after second iteration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>270.0</td>
<td>0.65513605 E0</td>
<td>-0.39298239 E0</td>
<td>0.48590209 E0</td>
<td>I=25*</td>
</tr>
<tr>
<td>360.0</td>
<td>Computer halted after six iterations.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Did not converge.
Table 4. Results of Lambert-Euler PODM for Relay-II Orbit

<table>
<thead>
<tr>
<th>True Anomaly Angular Difference of $r_1 \rightarrow r_2$ i.e., $\nu_2 - \nu_1$ (Degrees)</th>
<th>Computed $X$ Dot Reference Orbit $X$ Dot is -0.67069755 EO (CUL/CUT)</th>
<th>Computed $Y$ Dot Reference Orbit $Y$ Dot is -0.18565986 E-01 (CUL/CUT)</th>
<th>Computed $Z$ Dot Reference Orbit $Z$ Dot is 0.58071281 EO (CUL/CUT)</th>
<th>Iterations Required to Obtain an Epsilon ($\epsilon$) of $\leq 10^{-10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>-0.67100717 EO</td>
<td>-0.18597544 E-01</td>
<td>0.58100110 EO</td>
<td>15</td>
</tr>
<tr>
<td>5.0</td>
<td>-0.67073406 EO</td>
<td>-0.18589597 E-01</td>
<td>0.58076722 EO</td>
<td>9</td>
</tr>
<tr>
<td>10.0</td>
<td>-0.67072314 EO</td>
<td>-0.18613539 E-01</td>
<td>0.58077790 EO</td>
<td>15</td>
</tr>
<tr>
<td>21.0</td>
<td>-0.67063993 EO</td>
<td>-0.18632342 E-01</td>
<td>0.58072454 EO</td>
<td>10</td>
</tr>
<tr>
<td>40.0</td>
<td>-0.67060216 EO</td>
<td>-0.18680951 E-01</td>
<td>0.58071562 EO</td>
<td>9</td>
</tr>
<tr>
<td>60.0</td>
<td>-0.67058860 EO</td>
<td>-0.18723884 E-01</td>
<td>0.58070555 EO</td>
<td>8</td>
</tr>
<tr>
<td>72.0</td>
<td>-0.67057670 EO</td>
<td>-0.18726358 E-01</td>
<td>0.58066965 EO</td>
<td>14</td>
</tr>
<tr>
<td>85.0</td>
<td>-0.67057675 EO</td>
<td>-0.18730622 E-01</td>
<td>0.58064458 EO</td>
<td>14</td>
</tr>
<tr>
<td>105.0</td>
<td>-0.67058715 EO</td>
<td>-0.18733006 E-01</td>
<td>0.58060167 EO</td>
<td>8</td>
</tr>
<tr>
<td>237.0</td>
<td>Computer halted after two iterations.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>290.0</td>
<td>Computer halted after two iterations.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>360.0</td>
<td>Computer halted after fifteen iterations.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5. Results of F and G Series PODM for OSO-III Orbit

<table>
<thead>
<tr>
<th>True Anomaly Angle Difference of $r_1 - r_2$ (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot is -0.67128213 E0 (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot is 0.45237915 E0 (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot is -0.51983933 E0 (CUL/CUT)</th>
<th>Iterations Required to Obtain an Epsilon ($\varepsilon$) of $\leq 10^{-10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>-0.67081054 E0</td>
<td>0.45235122 E0</td>
<td>-0.51959007 E0</td>
<td>3</td>
</tr>
<tr>
<td>11.4</td>
<td>-0.67103078 E0</td>
<td>0.45243689 E0</td>
<td>-0.51971812 E0</td>
<td>4</td>
</tr>
<tr>
<td>22.8</td>
<td>-0.67130428 E0</td>
<td>0.45244469 E0</td>
<td>-0.51981347 E0</td>
<td>5</td>
</tr>
<tr>
<td>45.6</td>
<td>-0.67165853 E0</td>
<td>0.45226850 E0</td>
<td>-0.51976718 E0</td>
<td>10</td>
</tr>
<tr>
<td>68.4</td>
<td>0.45123977 E0</td>
<td>-0.51913683 E0</td>
<td>0.33426901 E0</td>
<td>I=25*</td>
</tr>
<tr>
<td>91.2</td>
<td>0.23846019 E1</td>
<td>0.70582817 E0</td>
<td>-0.23591702 E1</td>
<td>I=25*</td>
</tr>
<tr>
<td>114.0</td>
<td>Computer halted after six iterations.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>136.8</td>
<td>Computer halted after three iterations.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>180.0</td>
<td>Computer halted after one iteration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>270.0</td>
<td>Computer halted after one iteration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>360.0</td>
<td>Computer halted after two iterations.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Did not converge.
Table 6. Results of F and G Series PODM for Relay-II Orbit

<table>
<thead>
<tr>
<th>True Anomaly Angular Difference of r₁ + r₂ i.e., ν₂ - ν₁ (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot is -0.67069755 EO (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot is -0.18565986 E-01 (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot is 0.58071281 EO (CUL/CUT)</th>
<th>Iterations Required to Obtain an Epsilon (ε) of &lt;10⁻¹⁰</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>-0.67100717 E0</td>
<td>-0.18597544 E-01</td>
<td>0.58100110 E0</td>
<td>3</td>
</tr>
<tr>
<td>5.0</td>
<td>-0.67073406 E0</td>
<td>-0.18589597 E-01</td>
<td>0.58076722 E0</td>
<td>3</td>
</tr>
<tr>
<td>10.0</td>
<td>-0.67072313 E0</td>
<td>-0.18613540 E-01</td>
<td>0.58077789 E0</td>
<td>4</td>
</tr>
<tr>
<td>21.0</td>
<td>-0.67063956 E0</td>
<td>-0.18632358 E-01</td>
<td>0.58072423 E0</td>
<td>5</td>
</tr>
<tr>
<td>40.0</td>
<td>-0.67058782 E0</td>
<td>-0.18673756 E-01</td>
<td>0.58069903 E0</td>
<td>8</td>
</tr>
<tr>
<td>60.0</td>
<td>-0.67050862 E0</td>
<td>-0.18611443 E-01</td>
<td>0.58056860 E0</td>
<td>13</td>
</tr>
<tr>
<td>72.0</td>
<td>-0.67043325 E0</td>
<td>-0.18305457 E-01</td>
<td>0.58028936 E0</td>
<td>17</td>
</tr>
<tr>
<td>85.0</td>
<td>-0.19824139 E-01</td>
<td>0.57848394 EO</td>
<td>0.53834986 EO</td>
<td>I=25*</td>
</tr>
<tr>
<td>105.0</td>
<td>-0.24107564 E-01</td>
<td>0.57356778 EO</td>
<td>0.43500250 EO</td>
<td>I=25*</td>
</tr>
<tr>
<td>237.0</td>
<td></td>
<td></td>
<td>Computer halted after four iterations.</td>
<td></td>
</tr>
<tr>
<td>290.0</td>
<td></td>
<td></td>
<td>Computer halted after one iteration.</td>
<td></td>
</tr>
<tr>
<td>360.0</td>
<td></td>
<td></td>
<td>Computer halted after one iteration.</td>
<td></td>
</tr>
</tbody>
</table>

* Did not converge.
Table 7. Results of Iteration of Semiparameter PODM for OSO-III Orbit

<table>
<thead>
<tr>
<th>True Anomaly Angular Difference of ( r_1 \odot r_2 ) i.e., ( \nu_2 - \nu_1 ) (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot</th>
<th>Computed Y Dot Reference Orbit Y Dot</th>
<th>Computed Z Dot Reference Orbit Z Dot</th>
<th>Iterations Required to Obtain an Epsilon (( \varepsilon )) of (&lt;10^{-10})</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>-0.67081054 E0</td>
<td>0.45235122 E0</td>
<td>-0.5199007 E0</td>
<td>14</td>
</tr>
<tr>
<td>11.4</td>
<td>-0.67103078 E0</td>
<td>0.45243688 E0</td>
<td>-0.51971812 E0</td>
<td>20</td>
</tr>
<tr>
<td>22.8</td>
<td>-0.67130422 E0</td>
<td>0.45244466 E0</td>
<td>-0.51981342 E0</td>
<td>10</td>
</tr>
<tr>
<td>45.6</td>
<td>-0.67165405 E0</td>
<td>0.45226799 E0</td>
<td>-0.51976476 E0</td>
<td>16</td>
</tr>
<tr>
<td>68.4</td>
<td>-0.67164899 E0</td>
<td>0.45215526 E0</td>
<td>-0.51947102 E0</td>
<td>7</td>
</tr>
<tr>
<td>91.2</td>
<td>-0.67080666 E0</td>
<td>0.47893870 E0</td>
<td>0.5260669 E0</td>
<td>8</td>
</tr>
<tr>
<td>114.0</td>
<td>-0.67166326 E0</td>
<td>0.45243607 E0</td>
<td>-0.51859662 E0</td>
<td>9</td>
</tr>
<tr>
<td>136.8</td>
<td>-0.67198271 E0</td>
<td>0.45278865 E0</td>
<td>-0.51775009 E0</td>
<td>8</td>
</tr>
<tr>
<td>180.0</td>
<td>Computer halted after one iteration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>270.0</td>
<td>Computer halted after two iterations.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>360.0</td>
<td>Computer halted after two iterations.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 8. Results of Iteration of Semiparameter PODM for Relay-II Orbit

<table>
<thead>
<tr>
<th>True Anomaly Angular Difference of $\bar{r}_1 + \bar{r}_2$ i.e., $\nu_2 - \nu_1$ (Degrees)</th>
<th>Computed X Dot</th>
<th>Computed Y Dot</th>
<th>Computed Z Dot</th>
<th>Iterations Required to Obtain an Epsilon ($\epsilon$) of $\leq 10^{-10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>-0.67100717 EO</td>
<td>-0.18597543 E-01</td>
<td>0.58100110 EO</td>
<td>15</td>
</tr>
<tr>
<td>5.0</td>
<td>-0.67073406 EO</td>
<td>-0.18589597 E-01</td>
<td>0.58076722 EO</td>
<td>9</td>
</tr>
<tr>
<td>10.0</td>
<td>-0.67072314 EO</td>
<td>-0.18613537 E-01</td>
<td>0.5807790 EO</td>
<td>8</td>
</tr>
<tr>
<td>21.0</td>
<td>-0.67063993 EO</td>
<td>-0.18632343 E-01</td>
<td>0.58072454 EO</td>
<td>9</td>
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<td>-0.67060216 EO</td>
<td>-0.18680947 E-01</td>
<td>0.58071562 EO</td>
<td>7</td>
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<tr>
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<td>-0.67058860 EO</td>
<td>-0.18723889 E-01</td>
<td>0.58070555 EO</td>
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<tr>
<td>72.0</td>
<td>-0.67057669 EO</td>
<td>-0.18726365 E-01</td>
<td>0.58066965 EO</td>
<td>11</td>
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<tr>
<td>85.0</td>
<td>-0.67057675 EO</td>
<td>-0.18730629 E-01</td>
<td>0.58064458 EO</td>
<td>8</td>
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<tr>
<td>105.0</td>
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<tr>
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<td>Computer halted after two iterations.</td>
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<td></td>
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<tr>
<td>360.0</td>
<td>Computer halted after two iterations.</td>
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</table>

Computer halted after five iterations.

Computer halted after two iterations.

Computer halted after two iterations.
Table 9. Results of Gaussian PODM for OSO-III Orbit

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<tr>
<th>True Anomaly Angular Difference of ( r_1 + r_2 ), i.e., ( \nu_2 - \nu_1 ) (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot is (-0.67128213) EO (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot is (0.45237915) EO (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot is (-0.51983933) EO (CUL/CUT)</th>
<th>Iterations Required to Obtain an Epsilon ((\varepsilon)) of &lt;10(^{-10})</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>(-0.67081054) EO</td>
<td>(0.45235122) EO</td>
<td>(-0.51959007) EO</td>
<td>4</td>
</tr>
<tr>
<td>11.4</td>
<td>(-0.67103078) EO</td>
<td>(0.45243688) EO</td>
<td>(-0.51971812) EO</td>
<td>6</td>
</tr>
<tr>
<td>22.8</td>
<td>(-0.67130423) EO</td>
<td>(0.45244466) EO</td>
<td>(-0.51981342) EO</td>
<td>8</td>
</tr>
<tr>
<td>45.6</td>
<td>(-0.91948458) EO</td>
<td>(-0.37633925) EO</td>
<td>(0.11297649) EO</td>
<td>I=25*</td>
</tr>
<tr>
<td>68.4</td>
<td>(-0.79344996) EO</td>
<td>(-0.83165543) E-02</td>
<td>(-0.38585390) EO</td>
<td>I=25*</td>
</tr>
<tr>
<td>91.2</td>
<td>Computer halted during first iteration.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>114.0</td>
<td>Computer halted during first iteration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>136.8</td>
<td>Computer halted during first iteration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>180.0</td>
<td>Computer halted during first iteration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>270.0</td>
<td>Computer halted during first iteration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>360.0</td>
<td>Computer halted during first iteration.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Did not converge.
Table 10. Results of Gaussian PODM for Relay-II Orbit

<table>
<thead>
<tr>
<th>True Anomaly Angular Difference of ( \hat{r}_1 \rightarrow \hat{r}_2 ), i.e., ( \nu_2 - \nu_1 ) (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot is (-0.67069755) E0 (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot is (-0.18565986) E-01 (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot is (0.58071281) E0 (CUL/CUT)</th>
<th>Iterations Required to Obtain an Epsilon ((\varepsilon)) of (&lt;10^{-10})</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>(-0.67100717) E0</td>
<td>(-0.18597544) E-01</td>
<td>(0.58100110) E0</td>
<td>3</td>
</tr>
<tr>
<td>5.0</td>
<td>(-0.67073406) E0</td>
<td>(-0.18589598) E-01</td>
<td>(0.58076722) E0</td>
<td>4</td>
</tr>
<tr>
<td>10.0</td>
<td>(-0.67072314) E0</td>
<td>(-0.18613541) E-01</td>
<td>(0.58077790) E0</td>
<td>6</td>
</tr>
<tr>
<td>21.0</td>
<td>(-0.67063993) E0</td>
<td>(-0.18632347) E-01</td>
<td>(0.58072454) E0</td>
<td>8</td>
</tr>
<tr>
<td>40.0</td>
<td>(-0.67060215) E0</td>
<td>(-0.18680959) E-01</td>
<td>(0.58071562) E0</td>
<td>15</td>
</tr>
<tr>
<td>60.0</td>
<td>(0.18744650) E-01</td>
<td>(-0.38893012) E-01</td>
<td>(0.79794763) E-02</td>
<td>I=25*</td>
</tr>
<tr>
<td>72.0</td>
<td>(0.29766430) E-01</td>
<td>(-0.61606750) E-01</td>
<td>(0.12576050) E-01</td>
<td>I=25*</td>
</tr>
<tr>
<td>85.0</td>
<td>(0.38514860) E-01</td>
<td>(-0.79439075) E-01</td>
<td>(0.16103859) E-01</td>
<td>I=25*</td>
</tr>
<tr>
<td>105.0</td>
<td>Computer halted after first iteration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>237.0</td>
<td>Computer halted during first iteration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>290.0</td>
<td>Computer halted during first iteration.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>360.0</td>
<td>Computer halted during first iteration.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Did not converge.
Table 11. Results of Iteration of True Anomaly PODM for OSO-III Orbit

<table>
<thead>
<tr>
<th>True Anomaly Angular Difference of $r_1 \rightarrow r_2$ i.e., $\nu_2 - \nu_1$ (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot is -0.67128213 E0 (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot is 0.45237915 E0 (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot is -0.51983933 E0 (CUL/CUT)</th>
<th>Iterations Required to Obtain an Epsilon ($\epsilon$) of $\leq 10^{-10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>-0.67081054 E0</td>
<td>0.45235122 E0</td>
<td>-0.51959007 E0</td>
<td>15</td>
</tr>
<tr>
<td>11.4</td>
<td>-0.67103078 E0</td>
<td>0.45243688 E0</td>
<td>-0.51971812 E0</td>
<td>12</td>
</tr>
<tr>
<td>22.8</td>
<td>-0.67130422 E0</td>
<td>0.45244467 E0</td>
<td>-0.51981342 E0</td>
<td>10</td>
</tr>
<tr>
<td>45.6</td>
<td>-0.67165404 E0</td>
<td>0.45226800 E0</td>
<td>-0.51976476 E0</td>
<td>10</td>
</tr>
<tr>
<td>68.4</td>
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<td>0.45215526 E0</td>
<td>-0.51947102 E0</td>
<td>8</td>
</tr>
<tr>
<td>91.2</td>
<td>-0.67744460 E0</td>
<td>0.50667361 E0</td>
<td>0.53936484 E0</td>
<td>I=25*</td>
</tr>
<tr>
<td>114.0</td>
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<td>0.45243607 E0</td>
<td>-0.51859662 E0</td>
<td>8</td>
</tr>
<tr>
<td>136.8</td>
<td>-0.67198271 E0</td>
<td>0.45278862 E0</td>
<td>-0.51775008 E0</td>
<td>7</td>
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<tr>
<td>180.0</td>
<td>-0.17226110 E01</td>
<td>0.11138352 E01</td>
<td>-0.19506859 E01</td>
<td>I=25*</td>
</tr>
<tr>
<td>270.0</td>
<td>0.12672460 E0</td>
<td>-0.85052773 E-01</td>
<td>0.97780343 E-01</td>
<td>I=25*</td>
</tr>
<tr>
<td>360.0</td>
<td>Computer halted after six iterations.</td>
<td></td>
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<td></td>
</tr>
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</table>

* Did not converge.
<table>
<thead>
<tr>
<th>True Anomaly Angular Difference of $\dot{\mathbf{r}}_1 + \dot{\mathbf{r}}_2$ i.e., $\nu_2 - \nu_1$ (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot is -0.67069755 E0 (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot is -0.18565986 E-01 (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot is 0.58071281 E0 (CUL/CUT)</th>
<th>Iterations Required to Obtain an Epsilon ($\epsilon$) of $&lt;10^{-10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>-0.67100717 E0</td>
<td>-0.18597543 E-01</td>
<td>0.58100110 E0</td>
<td>14</td>
</tr>
<tr>
<td>5.0</td>
<td>-0.67073406 E0</td>
<td>-0.18589597 E-01</td>
<td>0.58076722 E0</td>
<td>19</td>
</tr>
<tr>
<td>10.0</td>
<td>-0.67072314 E0</td>
<td>-0.18613537 E-01</td>
<td>0.58077790 E0</td>
<td>13</td>
</tr>
<tr>
<td>21.0</td>
<td>-0.67063993 E0</td>
<td>-0.18632342 E-01</td>
<td>0.58072454 E0</td>
<td>14</td>
</tr>
<tr>
<td>40.0</td>
<td>-0.67060216 E0</td>
<td>-0.18680947 E-01</td>
<td>0.58071562 E0</td>
<td>12</td>
</tr>
<tr>
<td>60.0</td>
<td>-0.67058860 E0</td>
<td>-0.18723889 E-01</td>
<td>0.58070555 E0</td>
<td>10</td>
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<tr>
<td>72.0</td>
<td>-0.67057669 E0</td>
<td>-0.18726361 E-01</td>
<td>0.58066965 E0</td>
<td>I=25*</td>
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<tr>
<td>85.0</td>
<td>-0.67057675 E0</td>
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<td>0.58060167 E0</td>
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<tr>
<td>237.0</td>
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<tr>
<td>290.0</td>
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<tr>
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</table>

*Did not converge.
<table>
<thead>
<tr>
<th>True Anomaly Angular Difference of $r_1 - r_2$ i.e., $v_2 - v_1$ (Degrees)</th>
<th>Nominal Semimajor Axis from Reference Orbit (Earth Radii)</th>
<th>Gaussian PODM</th>
<th>F and G Series PODM</th>
<th>Iteration of F and G True Anomaly PODM</th>
<th>Iteration of Semiparameter PODM</th>
<th>Lambert-Euler PODM</th>
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<td>No data</td>
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</tr>
</tbody>
</table>

No data indicates program failed in computing these values.
Table 14. Position and Time PODM Classical Orbital Element Comparisons - Eccentricity

<table>
<thead>
<tr>
<th>True Anomaly Angular Difference of ( p_1 - p_2 ) i.e., ( v_2 - v_1 ) (Degrees)</th>
<th>Nominal Eccentricity from Reference Orbit</th>
<th>Gaussian PODM</th>
<th>F and G Series PODM</th>
<th>Iteration of True Anomaly PODM</th>
<th>Iteration of Semiparameter PODM</th>
<th>Lambert-Euler PODM</th>
</tr>
</thead>
<tbody>
<tr>
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| 10.0                                            | 0.24091843                               | 0.24091762     | 0.24091843        | 0.24091843                  | 0.24091843                 | 0.24091843        |
| 21.0                                            | 0.24082014                               | 0.24079030     | 0.24082016        | 0.24082016                  | 0.24082016                 | 0.24082016        |
| 40.0                                            | No data                                 | 0.24060980     | 0.24076101        | 0.24076101                  | 0.24076101                 | 0.24076101        |
| 60.0                                            | 0.99999997                              | 0.2404882      | 0.24071194        | 0.24071194                  | 0.24071194                 | 0.24071194        |
| 72.0                                            | 0.99999982                              | 0.53935368     | 0.24068833        | 0.24068833                  | 0.24068833                 | 0.24068833        |
| 85.0                                            | No data                                 | 0.63807485     | 0.24066680        | 0.24066680                  | 0.24066680                 | 0.24066680        |
| 105.0                                           | No data                                 | No data        | No data           | No data                     | No data                     | No data           |
| 237.0                                           | No data                                 | No data        | No data           | No data                     | No data                     | No data           |
| 290.0                                           | No data                                 | No data        | No data           | No data                     | No data                     | No data           |
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No data indicates program failed in computing these values.
Table 16. Position and Time PODM Classical Orbital Element Comparisons - Orbital Inclination

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<th>Gaussian PODM</th>
<th>F and G Series PODM</th>
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RELAY-II 0.80848228

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| 21.0 | 0.80873900 | 0.80873900 | 0.80873900 | 0.80873900 | 0.80873900 | 0.80873900 |
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| 60.0 | No data | 0.80871476 | 0.80871476 | 0.80871476 | 0.80871476 | 0.80871476 |
| 72.0 | 2.3329988 | 0.80869383 | 0.80869383 | 0.80869383 | 0.80869383 | 0.80869383 |
| 85.0 | 2.3329201 | 1.9210250 | 0.80867257 | 0.80867257 | 0.80867257 | 0.80867257 |
| 105.0 | No data | 1.9725943 | 0.80863180 | 0.80863180 | 0.80863180 | 0.80863180 |
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Table 17. Position and Time PODM Classical Orbital Element Comparisons - Nominal Argument of Perigee

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<td>3981</td>
</tr>
<tr>
<td>R-Iteration</td>
<td>4458</td>
</tr>
<tr>
<td>Trilateration</td>
<td>4231</td>
</tr>
<tr>
<td>Herrick-Gibbs</td>
<td>3525</td>
</tr>
<tr>
<td>Computation for Range, Range Rate, and Angle Data</td>
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Table 19. PODM Computation Time

<table>
<thead>
<tr>
<th>PODM</th>
<th>Total Time for Program with One Iteration (Milliseconds)</th>
<th>Total Time Without &quot;Solution for Classical Elements&quot; (Milliseconds)</th>
<th>Time for Each Additional Iteration (Milliseconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Position and Time</strong></td>
<td></td>
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<tr>
<td>F and G Series</td>
<td>21</td>
<td>15</td>
<td>8</td>
</tr>
<tr>
<td>Gaussian</td>
<td>17</td>
<td>11</td>
<td>5</td>
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<tr>
<td>Iteration of Semiparameter</td>
<td>16.5</td>
<td>10.5</td>
<td>6</td>
</tr>
<tr>
<td>Iteration of the True Anomaly</td>
<td>16.5</td>
<td>10.5</td>
<td>6</td>
</tr>
<tr>
<td>Lambert-Euler Angles Only</td>
<td>16</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Laplace</td>
<td>19</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>Double R-Iteration Method of Gauss (1)</td>
<td>19</td>
<td>13</td>
<td>9</td>
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<tr>
<td>Modified Laplacian</td>
<td>26</td>
<td>16</td>
<td>5 &amp; 8</td>
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<tr>
<td>Trietration</td>
<td>17</td>
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<td>5</td>
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(1) Method of Gauss has two iteration loops
### Table 20. Ease of Convergence

<table>
<thead>
<tr>
<th>PODM</th>
<th>OSO-III</th>
<th>Relay-II</th>
<th>Combined Average</th>
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</thead>
<tbody>
<tr>
<td>Lambert-Euler</td>
<td>7</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>F and G Series</td>
<td>6</td>
<td>8</td>
<td>7</td>
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<tr>
<td>Gaussian</td>
<td>9</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Iteration of Semiparameter</td>
<td>12</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Iteration of True Anomaly</td>
<td>10</td>
<td>14</td>
<td>12</td>
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</table>

### Table 21. Best Overall Results for Radius Vector Spread

<table>
<thead>
<tr>
<th>Range of Radius Vector Spread</th>
<th>PODM</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0^\circ &lt; v &lt; 45^\circ$</td>
<td>F and G Series</td>
</tr>
<tr>
<td>$45^\circ &lt; v &lt; 140^\circ$</td>
<td>Gaussian</td>
</tr>
<tr>
<td></td>
<td>Lambert-Euler</td>
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<td></td>
<td>Iteration of True Anomaly</td>
</tr>
<tr>
<td></td>
<td>Iteration of Semiparameter</td>
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### Table 22. Order of Selection for Optimum PODM

<table>
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<tr>
<th>PODM</th>
<th>Computation Time</th>
<th>Ease of Convergence</th>
<th>Best Overall Accuracy</th>
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<td>Lambert-Euler</td>
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<td>1-2</td>
<td>1-2</td>
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<tr>
<td>Iteration of Semiparameter</td>
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<td>3-4</td>
<td>1-2</td>
</tr>
<tr>
<td>Iteration of True Anomaly</td>
<td>2-3</td>
<td>3-4</td>
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</tr>
<tr>
<td>Gaussian</td>
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<td>1-2</td>
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<tr>
<td>F and G Series</td>
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<td>5</td>
<td>4</td>
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<td>Range Rate ( \dot{\rho} ) (CUL/CUT)</td>
<td>Declination ( \delta ) (Radians)</td>
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<td>-----------------</td>
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<td>0.24410711 E0</td>
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<td>-0.58424762 E0</td>
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<td>Declination $\delta$ (Radians)</td>
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Table 24. Relay-II Range/Range Rate and Angular Data
(Topocentric Coordinate System)
Epoch 67Y 11M 13D 00H 00M 00S

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<th>Declination ( \delta ) (Radians)</th>
<th>Right Ascension ( \alpha ) (Radians)</th>
<th>Time from Epoch (Minutes)</th>
<th>Station Name</th>
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<td>Declination $\delta$ (Radians)</td>
<td>Right Ascension $\alpha$ (Radians)</td>
<td>Time from Epoch (Minutes)</td>
<td>Station Name</td>
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Table 24. Relay-II Range/Range Rate and Angular Data (Topocentric Coordinate System)  
Epoch 67Y 11M 130 OOH OOM 00s (Cont'd)
Table 25. OSO-III Data Points and Stations Used for PODMs Requiring Angular and Mixed Data Inputs

<table>
<thead>
<tr>
<th>Data Points Used</th>
<th>Station for Three-Station Inputs</th>
<th>Station for Single-Station Input</th>
<th>Three Stations with Input Resolved to Single Time Input</th>
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191
Table 25. OSO-III Data Points and Stations Used for PODMs Requiring Angular and Mixed Data Inputs (Cont'd)

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Table 26. Relay-II Data Points and Stations Used for PODMs Requiring Angular and Mixed Data Inputs

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Table 26. Relay-II Data Points and Stations Used for PODMs Requiring Angular and Mixed Data Inputs (Cont'd)

<table>
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<th>Data Points Used</th>
<th>Station for Three-Station Inputs</th>
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Table 27. Results of Method of Gauss PODM for OSO-III

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular Difference $\nu_2 - \nu_1$ (Degrees)</th>
<th>Computed X Dot Reference Orbit (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit (CUL/CUT)</th>
<th>Number of Iterations (1)</th>
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<td>Angular Difference $\nu_3 - \nu_1$ (Degrees)</td>
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<td>0.40013314 E0</td>
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<td>0.40013314 E0</td>
<td>-0.51534094 E0</td>
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<td>-0.77864062 E0</td>
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Table 27. Results of Method of Gauss PODM for OSO-III (Cont'd)

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular $\vec{r}_1 \rightarrow \vec{r}_2$ (Degrees)</th>
<th>Difference $\vec{r}_3 - \vec{r}_1$ i.e., $v_2 - v_1$ (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot at T2 (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot at T2 (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot at T2 (CUL/CUT)</th>
<th>Number of Iterations</th>
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<td>(4) 3.8</td>
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<td>0.40013314 E0</td>
<td>-0.51534094 E0</td>
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(1) Method of Gauss has two iteration loops (1/2)
(2) Computer halted after third iteration of second loop
(3) Computer halted after fifth iteration of second loop
(4) Computer halted after third iteration of second loop
(5) Computer halted after sixth iteration of second loop
Table 28. Results of Method of Gauss PODM for Relay-II

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<th>True Anomaly</th>
<th>Angular Difference $r_1 + r_2$ (Degrees)</th>
<th>Computed $X$ Dot at $T_2$ (CUL/CUT)</th>
<th>Computed $Y$ Dot at $T_2$ (CUL/CUT)</th>
<th>Computed $Z$ Dot at $T_2$ (CUL/CUT)</th>
<th>Number of Iterations (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r_3 + r_1$ i.e., $v_2 - v_1$ (Degrees)</td>
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<td>-0.48674037 E-1</td>
<td>0.58641897 E0</td>
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<td>-0.48674037 E-1</td>
<td>0.58641873 E0</td>
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<td>-0.22604802 E0</td>
<td>-0.49460573 E0</td>
<td>0.49560149 E0</td>
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<td>0.49582764 E0</td>
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<td>-0.22604802 E0</td>
<td>-0.49460573 E0</td>
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<td>32.0</td>
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<td>-0.54240256 E0</td>
<td>0.43382895 E0</td>
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<td>-0.56593395 E0</td>
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<td>-0.65562172 E0</td>
<td>-0.48674037 E-1</td>
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Table 28. Results of Method of Gauss PODM for Relay-II (Cont'd)

<table>
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<tr>
<th>True Anomaly</th>
<th>Angular $\bar{r}_1 + \bar{r}_2$ i.e., $\nu_2 - \nu_1$ (Degrees)</th>
<th>Difference $\bar{r}_3 + \bar{\nu}_1$ i.e., $\nu_3 - \nu_1$ (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot at $T_2$ (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
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<tbody>
<tr>
<td>(4) 21.0</td>
<td>360.0</td>
<td>NO DATA -0.53391142 E0</td>
<td>NO DATA -0.23461233 E0</td>
<td>NO DATA</td>
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<td>(5) 60.0</td>
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<td>NO DATA -0.22604802 E0</td>
<td>NO DATA -0.49460573 E0</td>
<td>NO DATA</td>
<td>25/3</td>
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</tr>
</tbody>
</table>

(1) Method of Gauss has two iteration loops (1/2)
(2) Computer halted after fifth iteration of second loop
(3) Computer halted after third iteration of second loop
(4) Computer halted after third iteration of second loop
(5) Computer halted after third iteration of second loop
Table 29. Results of Laplace PODM for OSO-I11

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular Difference $r_1 - r_2$ i.e., $v_2 - v_1$ (Degrees)</th>
<th>Computed X Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Y Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Z Dot at $T_2$ (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>11.4</td>
<td>-0.62214854 E0</td>
<td>-0.42083550 E1</td>
<td>-0.18298844 E2</td>
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<tr>
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<td>-0.70685743 E0</td>
<td>0.40013314 E0</td>
<td>-0.51534094 E0</td>
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</tr>
<tr>
<td>3.8</td>
<td>22.8</td>
<td>-0.12509150 E1</td>
<td>0.81876243 E0</td>
<td>0.26324664 E1</td>
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<td>-0.70685743 E0</td>
<td>0.40013314 E0</td>
<td>-0.51534094 E0</td>
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<tr>
<td>3.8</td>
<td>45.6</td>
<td>0.62338167 E0</td>
<td>-0.97365651 E0</td>
<td>-0.91009868 E1</td>
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<td>-0.70685743 E0</td>
<td>0.40013314 E0</td>
<td>-0.51534094 E0</td>
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</tr>
<tr>
<td>11.4</td>
<td>45.6</td>
<td>-0.17521341 E1</td>
<td>0.10642148 E1</td>
<td>0.36921444 E0</td>
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<td>-0.76862972 E0</td>
<td>0.29068616 E0</td>
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<td>22.8</td>
<td>45.6</td>
<td>-0.11041127 E1</td>
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<td>-0.47175310 E0</td>
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<td>-0.83592404 E0</td>
<td>0.11781151 E0</td>
<td>-0.45992297 E0</td>
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<tr>
<td>22.8</td>
<td>45.6</td>
<td>-0.44101836 E1</td>
<td>-0.17955487 E1</td>
<td>-0.11655648 E1</td>
<td>19</td>
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<td>-0.55646495 E0</td>
<td>-0.77864062 E0</td>
<td>0.55149247 E-1</td>
<td></td>
</tr>
<tr>
<td>22.8</td>
<td>68.4</td>
<td>0.24578202 E0</td>
<td>-0.73672249 E0</td>
<td>0.23126402 E1</td>
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<tr>
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<td></td>
<td>-0.55646495 E0</td>
<td>-0.77864062 E0</td>
<td>0.55149247 E-1</td>
<td></td>
</tr>
<tr>
<td>22.8</td>
<td>111.6</td>
<td>0.25079742 E1</td>
<td>-0.11870397 E4</td>
<td>0.45458931 E1</td>
<td>25</td>
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<tr>
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<td></td>
<td>-0.55646495 E0</td>
<td>-0.77864062 E0</td>
<td>0.55149247 E-1</td>
<td></td>
</tr>
<tr>
<td>45.0</td>
<td>68.4</td>
<td>-0.19467675 E1</td>
<td>-0.27913786 E0</td>
<td>-0.18056729 E1</td>
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<td></td>
<td>-0.25549497 E0</td>
<td>-0.88905191 E0</td>
<td>0.24948641 E0</td>
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</table>
Table 29. Results of Laplace PODM for OSO-III (Cont'd)

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular Difference $r_1 \rightarrow r_2$ i.e., $v_2 - v_1$ (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot at T2 (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot at T2 (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot at T2 (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>68.4</td>
<td>111.6</td>
<td>0.95421127 E-1</td>
<td>-0.44695439 EO</td>
<td>0.27811717 EO</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.84194416 E-1</td>
<td>-0.86372645 EO</td>
<td>0.40548748 EO</td>
<td></td>
</tr>
<tr>
<td>3.8</td>
<td>360.0</td>
<td>-0.17796285 E1</td>
<td>0.78874290 EO</td>
<td>0.38617498 E1</td>
<td>10</td>
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<tr>
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<td></td>
<td>-0.70685743 E0</td>
<td>0.40013314 EO</td>
<td>-0.51534094 EO</td>
<td></td>
</tr>
<tr>
<td>45.6</td>
<td>360.0</td>
<td>0.42930140 E1</td>
<td>0.33948553 EO</td>
<td>-0.56191323 EO</td>
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<td></td>
<td>-0.87135390 E0</td>
<td>-0.23408489 EO</td>
<td>-0.32909258 EO</td>
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### Table 30. Results of Laplace PODM for Relay-II

<table>
<thead>
<tr>
<th>True Anomaly Angular Difference $r_1 \rightarrow r_2$ i.e., $v_2 - v_1$ (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot at $T_2$ (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>5.0</td>
<td>-0.72714109 E0</td>
<td>-0.71504655 E-1</td>
<td>-0.59489353 E0</td>
</tr>
<tr>
<td>2.5</td>
<td>10.0</td>
<td>-0.10267281 E1</td>
<td>-0.18628955 E1</td>
<td>-0.58641873 E1</td>
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<tr>
<td>2.5</td>
<td>21.0</td>
<td>-0.53878453 E4</td>
<td>-0.23647739 E5</td>
<td>-0.58641873 E0</td>
</tr>
<tr>
<td>5.0</td>
<td>21.0</td>
<td>-0.48696044 E0</td>
<td>-0.18666574 E1</td>
<td>-0.5999381 E0</td>
</tr>
<tr>
<td>10.0</td>
<td>21.0</td>
<td>-0.31209321 E1</td>
<td>-0.57152970 E2</td>
<td>-0.59994559 E0</td>
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<tr>
<td>20.0</td>
<td>32.0</td>
<td>-0.26693959 E0</td>
<td>-0.43433233 E0</td>
<td>-0.69540731 E0</td>
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<tr>
<td>20.0</td>
<td>45.0</td>
<td>-0.13796895 E0</td>
<td>-0.56147737 E0</td>
<td>-0.45146978 E0</td>
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<td>20.0</td>
<td>65.0</td>
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<td>-0.33983267 E0</td>
<td>-0.12063448 E0</td>
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<tr>
<td>32.0</td>
<td>45.0</td>
<td>-0.52113641 E0</td>
<td>-0.10880935 E1</td>
<td>-0.13009305 E1</td>
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<tr>
<td>45.0</td>
<td>65.0</td>
<td>-0.36805806 E-1</td>
<td>-0.59923005 E0</td>
<td>0.54858426 E0</td>
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Table 30. Results of Laplace PODM for Relay-II (Cont'd)

<table>
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<tr>
<th>True Anomaly</th>
<th>Angular ( \vec{r}_1 \rightarrow \vec{r}_2 ) (Degrees)</th>
<th>Difference ( \vec{r}_3 \rightarrow \vec{r}_1 ) i.e., ( \nu_3 - \nu_1 ) (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot at ( T_2 ) (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot at ( T_2 ) (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot at ( T_2 ) (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>360.0</td>
<td>-0.20583222 ( E1 )</td>
<td>0.42296244 ( E0 )</td>
<td>0.16115016 ( E2 )</td>
<td>25</td>
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<tr>
<td></td>
<td></td>
<td>-0.65562172 ( E0 )</td>
<td>-0.48674037 ( E-1 )</td>
<td>0.58641873 ( E0 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21.0</td>
<td>360.0</td>
<td>0.77590448 ( E1 )</td>
<td>0.89489232 ( E0 )</td>
<td>-0.16625441 ( E1 )</td>
<td>25</td>
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</tr>
<tr>
<td></td>
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<td>-0.53391142 ( E0 )</td>
<td>-0.23461233 ( E0 )</td>
<td>0.59733711 ( E0 )</td>
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<tr>
<td>60.0</td>
<td>360.0</td>
<td>0.14735411 ( E1 )</td>
<td>0.15238060 ( E1 )</td>
<td>-0.12408895 ( E1 )</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>-0.22604802 ( E0 )</td>
<td>-0.49460573 ( E0 )</td>
<td>0.49560149 ( E0 )</td>
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</tr>
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Table 31. Results of Double R-Iteration PODM for OSO-III

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular Difference $\hat{r}_1 + \hat{r}_2$ i.e., $\nu_2 - \nu_1$ (Degrees)</th>
<th>Computed X Dot at $T_2$ Reference Orbit (CUL/CUT)</th>
<th>Computed Y Dot at $T_2$ Reference Orbit (CUL/CUT)</th>
<th>Computed Z Dot at $T_2$ Reference Orbit (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>11.4</td>
<td>0.10753446 E-1</td>
<td>0.66555841 E-1</td>
<td>0.51606808 E-1</td>
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</tr>
<tr>
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<td></td>
<td>-0.70685743 E0</td>
<td>0.40013314 E0</td>
<td>-0.51534094 E0</td>
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<tr>
<td>3.8</td>
<td>22.8</td>
<td>-0.14092275 E0</td>
<td>-0.29962388 E-1</td>
<td>-0.91042634 E0</td>
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<td>-0.70685743 E0</td>
<td>0.40013314 E0</td>
<td>-0.51534094 E0</td>
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<td>3.8</td>
<td>45.6</td>
<td>0.13710653 E-1</td>
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<td>0.40013314 E0</td>
<td>-0.51534094 E0</td>
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<td>-0.76862972 E0</td>
<td>0.29068616 E0</td>
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<tr>
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<td>-0.83592404 E0</td>
<td>0.11781151 E0</td>
<td>-0.45992297 E0</td>
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<td>-0.7784062 E0</td>
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<tr>
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<td>NO DATA</td>
<td>NO DATA</td>
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<td>-0.7784062 E0</td>
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<tr>
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<td>-0.7784062 E0</td>
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<td></td>
<td>0.84194416 E-1</td>
<td>-0.86372645 E0</td>
<td>0.40548748 E0</td>
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</tr>
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</table>
Table 31. Results of Double R-Iteration PODM for OSO-III (Cont'd)

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular Difference $\tilde{v}_2 - \tilde{v}_1$ (Degrees)</th>
<th>Computed $X$ Dot at $T_2$ (CUL/CUT)</th>
<th>Computed $Y$ Dot at $T_2$ (CUL/CUT)</th>
<th>Computed $Z$ Dot at $T_2$ (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>360.0</td>
<td>-0.15743479 EO</td>
<td>-0.13771405 EO</td>
<td>-0.21949831 EO</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>-0.70685743 EO</td>
<td>0.40013314 EO</td>
<td>-0.51534094 EO</td>
<td></td>
</tr>
<tr>
<td>45.6</td>
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<td>NO DATA</td>
<td>NO DATA</td>
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<td>-0.87135390 EO</td>
<td>-0.23408489 EO</td>
<td>-0.32909258 EO</td>
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</tr>
</tbody>
</table>

(1) Computer halted after twenty-fifth iteration
(2) Computer halted after twenty-fifth iteration
(3) Computer halted after twenty-fifth iteration
Table 32. Results of Double R-Iteration PODM for Relay-II

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular Difference $r_2 - r_1$ (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot at $T_2$ (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
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<td>NO DATA</td>
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<tr>
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<td></td>
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<td>-0.48674037 E-1</td>
<td>0.58641873 E0</td>
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</tr>
<tr>
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<td>-0.48674037 E-1</td>
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</tr>
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<td>NO DATA</td>
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<td>0.49560149 E0</td>
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<td>0.52704750 E-1</td>
<td>0.58966469 E0</td>
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<td>-0.22604802 E0</td>
<td>-0.49460573 E0</td>
<td>0.49560149 E0</td>
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<td>20.0</td>
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<td>-0.22604802 E0</td>
<td>-0.49460573 E0</td>
<td>0.49560149 E0</td>
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<td>(5) 32.0</td>
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<td>NO DATA</td>
<td>NO DATA</td>
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<td>-0.35627838 E-1</td>
<td>-0.56593395 E0</td>
<td>0.37767977 E0</td>
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Table 32. Results of Double R-Iteration PODM for Relay-II (Cont'd)

<table>
<thead>
<tr>
<th>Angular True Anomaly</th>
<th>Difference Reference Orbit</th>
<th>Computed X Dot Reference Orbit</th>
<th>Computed Y Dot Reference Orbit</th>
<th>Computed Z Dot Reference Orbit</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\vec{f}_1 + \vec{f}_2$ i.e., $v_2 - v_1$ (Degrees)</td>
<td>$\vec{f}_3 + \vec{f}_1$ i.e., $v_3 - v_1$ (Degrees)</td>
<td>X Dot at $T_2$ (CUL/CUT)</td>
<td>Y Dot at $T_2$ (CUL/CUT)</td>
<td>Z Dot at $T_2$ (CUL/CUT)</td>
<td></td>
</tr>
<tr>
<td>2.5</td>
<td>360.0</td>
<td>-0.52220508 E-1</td>
<td>-0.34564548 E0</td>
<td>0.22778349 E-1</td>
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<td>NO DATA</td>
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<td>60.0</td>
<td>360.0</td>
<td>0.41528271 E-2</td>
<td>-0.38793737 E-1</td>
<td>-0.12068895 E-1</td>
<td>25</td>
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(1) Computer halted after twenty-fifth iteration  
(2) Computer halted after twenty-fifth iteration  
(3) Computer halted after twenty-fifth iteration  
(4) Computer halted after twenty-fifth iteration  
(5) Computer halted after twenty-fifth iteration  
(6) Computer halted after twenty-fifth iteration  
(7) Computer halted after twenty-fifth iteration
<table>
<thead>
<tr>
<th>Angular Difference (\vec{r}_1 + \vec{r}_2) i.e., (v_2 - v_1) (Degrees)</th>
<th>Difference (\vec{r}_3 + \vec{r}_1) i.e., (v_3 - v_1) (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot at T_2 (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot at T_2 (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot at T_2 (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>11.4</td>
<td>-0.71593645 EO</td>
<td>0.48563242 EO</td>
<td>-0.62694617 EO</td>
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</tr>
<tr>
<td>3.8</td>
<td>22.8</td>
<td>-0.70685743 EO</td>
<td>0.52655320 EO</td>
<td>-0.51534094 EO</td>
<td>5</td>
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<tr>
<td>3.8</td>
<td>45.6</td>
<td>-0.69070303 EO</td>
<td>0.54224031 EO</td>
<td>-0.68928764 EO</td>
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<tr>
<td>11.4</td>
<td>45.6</td>
<td>-0.10306731 E1</td>
<td>0.50739234 EO</td>
<td>-0.71356305 EO</td>
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<tr>
<td>22.8</td>
<td>45.6</td>
<td>-0.11293956 E1</td>
<td>0.28689117 EO</td>
<td>-0.47564288 EO</td>
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<tr>
<td>22.8</td>
<td>45.6</td>
<td>-0.83592404 EO</td>
<td>0.11781151 EO</td>
<td>-0.45992297 EO</td>
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<tr>
<td>22.8</td>
<td>68.4</td>
<td>-0.13744573 E0</td>
<td>-0.23924188 EO</td>
<td>0.38397540 E-1</td>
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<tr>
<td>22.8</td>
<td>111.6</td>
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<td>-0.41542275 EO</td>
<td>0.10946262 EO</td>
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<td>111.6</td>
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<td>-0.77864062 EO</td>
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<td>45.0</td>
<td>68.4</td>
<td>-0.32805748 E-1</td>
<td>-0.82710003 EO</td>
<td>0.49787300 EO</td>
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<tr>
<td>68.4</td>
<td>111.6</td>
<td>0.96889297 E-2</td>
<td>0.34904833 EO</td>
<td>-0.25621297 EO</td>
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</tr>
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<td>True Anomaly Difference</td>
<td>1.(e_1) - 1.(e_2) (\left(\text{Degrees}\right))</td>
<td>1.(e_1) (\left(\text{Degrees}\right))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------------------</td>
<td>---------------------------------</td>
<td>-----------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z Dot at T2 ((\text{Degrees}))</td>
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<tr>
<td>Number of (\xi_i), (v_2 - v_1)</td>
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<td></td>
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<tr>
<td>Iterations</td>
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<tr>
<td>45.6</td>
<td>3.8</td>
<td>360.0</td>
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<td>-0.13166452 (E_1)</td>
<td>-0.76805260 (E_0)</td>
<td>0.5495026 (E_1)</td>
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<td>0.4013314 (E_1)</td>
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<td>-0.51534094 (E_1)</td>
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<td>0.5154084 (E_0)</td>
<td>0.5154084 (E_0)</td>
<td>0.5154084 (E_0)</td>
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Table 33. Results of Modified Laplacian PODM for OSO-III (Cont'd)
Table 34. Results of Modified Laplacian PODM for Relay-II

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular Difference $\bar{r}_1 + \bar{r}_2$ (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot at $T_2$ (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
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<td>-0.48674037 E-1</td>
<td>0.58641873 E0</td>
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<tr>
<td>2.5</td>
<td>10.0</td>
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<td>-0.51458662 E-1</td>
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<td>-0.48674037 E-1</td>
<td>0.58641873 E0</td>
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<td>-0.48674037 E-1</td>
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<td>-0.77927626 E-1</td>
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<td>-0.49460573 E0</td>
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<td>-0.49460573 E0</td>
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<td>-0.11873926 E0</td>
<td>-0.54226741 E0</td>
<td>0.43373466 E0</td>
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<td>45.0</td>
<td>65.0</td>
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<td>0.25999349 E0</td>
<td>0.37270621 E-1</td>
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<td></td>
<td>-0.35627838 E-1</td>
<td>-0.56593395 E0</td>
<td>0.37767977 E0</td>
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Table 34. Results of Modified Laplacian PODM for Relay-II (Cont'd)

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular Difference $\bar{\alpha}_1 \rightarrow \bar{\alpha}_2$ (Degrees)</th>
<th>Reference Orbit X Dot at $T_2$ (CUL/CUT)</th>
<th>Reference Orbit Y Dot at $T_2$ (CUL/CUT)</th>
<th>Reference Orbit Z Dot at $T_2$ (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>360.0</td>
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<td>-0.19624521 E-1</td>
<td>0.56898767 E0</td>
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<td>-0.48674037 E-1</td>
<td>0.58641873 E0</td>
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</tr>
<tr>
<td>21.0</td>
<td>360.0</td>
<td>-0.63087748 E0</td>
<td>0.44128080 E-1</td>
<td>0.58437370 E0</td>
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<td>-0.23461233 E0</td>
<td>0.59733711 E0</td>
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<td>60.0</td>
<td>360.0</td>
<td>0.20119010 E0</td>
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<td>-0.22604802 E0</td>
<td>-0.49460573 E0</td>
<td>0.49560149 E0</td>
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Table 35. Results of R-Iteration PODM for OSO-III

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular Difference $\dot{v}_1 + \dot{v}_2$ (Degrees)</th>
<th>Computed X Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Y Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Z Dot at $T_2$ (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>11.4</td>
<td>$-0.67303769$ EO</td>
<td>$0.47295788$ EO</td>
<td>$-0.61114236$ EO</td>
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<tr>
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<td>22.8</td>
<td>$-0.68262750$ EO</td>
<td>$0.52046653$ EO</td>
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<tr>
<td>3.8</td>
<td>45.6</td>
<td>$-0.72791534$ EO</td>
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<td>$-0.70650216$ EO</td>
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<tr>
<td>11.4</td>
<td>45.6</td>
<td>$-0.78954637$ EO</td>
<td>$0.47857224$ EO</td>
<td>$-0.67776446$ EO</td>
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<td>(1) 22.8</td>
<td>45.6</td>
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<td>68.4</td>
<td>$-0.50000178$ EO</td>
<td>$-0.84474399$ EO</td>
<td>$0.59120426$ E0</td>
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<tr>
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<td>$-0.45529692$ E-1</td>
<td>$-0.68089611$ E0</td>
<td>$0.83025921$ E0</td>
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<tr>
<td>45.0</td>
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<td>$-0.30194235$ E-1</td>
<td>$-0.87126672$ EO</td>
<td>$0.53275537$ EO</td>
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<tr>
<td>68.4</td>
<td>111.6</td>
<td>$-0.67218747$ E-1</td>
<td>$0.43304281$ E-3</td>
<td>$-0.13491177$ EO</td>
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</table>
Table 35. Results of R-Iteration PODM for OSO-III (Cont'd)

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular Difference $\frac{\pi}{2} \rightarrow \frac{\pi}{1}$ i.e., $v_2 - v_1$ (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot at $T_2$ (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>360.0</td>
<td>0.10841023 $E1$</td>
<td>-0.14663795 $E0$</td>
<td>0.15214168 $E0$</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.70685743 $E0$</td>
<td>0.40013314 $E0$</td>
<td>-0.51534094 $E0$</td>
<td></td>
</tr>
<tr>
<td>45.6</td>
<td>360.0</td>
<td>0.26869148 $E1$</td>
<td>0.61834314 $E0$</td>
<td>-0.45069544 $E0$</td>
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<tr>
<td></td>
<td></td>
<td>-0.87135390 $E0$</td>
<td>-0.23408489 $E0$</td>
<td>-0.32909258 $E0$</td>
<td></td>
</tr>
</tbody>
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(1) Computer halt prior to iteration loop
Table 36. Results of R-Iteration PODM for Relay-II

<table>
<thead>
<tr>
<th>True Anomaly (Degrees)</th>
<th>Angular Difference $\Delta \alpha = \beta_1 + \beta_2$ (Degrees)</th>
<th>Computed X Dot at T2 (CUL/CUT)</th>
<th>Computed Y Dot at T2 (CUL/CUT)</th>
<th>Computed Z Dot at T2 (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>5.0</td>
<td>-0.65536606 E0</td>
<td>-0.49981041 E-1</td>
<td>0.58661809 E0</td>
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</tr>
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<td>2.5</td>
<td>10.0</td>
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<td>-0.52202059 E-1</td>
<td>0.58695597 E0</td>
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<td>-0.6554322 E0</td>
<td>-0.54280921 E-1</td>
<td>0.58608381 E0</td>
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<td>5.0</td>
<td>21.0</td>
<td>-0.63575963 E0</td>
<td>-0.86952051 E-1</td>
<td>0.58974413 E0</td>
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<td>10.0</td>
<td>21.0</td>
<td>-0.60023973 E0</td>
<td>-0.14346819 E0</td>
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<tr>
<td>20.0</td>
<td>32.0</td>
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<td>-0.23651090 E0</td>
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<td>45.0</td>
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<tr>
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Table 36. Results of R-Iteration PODM for Relay-II (Cont'd)

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular Difference $\dot{r}_1 - \dot{r}_2$ (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot at $T_2$ (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>360.0</td>
<td>-0.19164933 E-1</td>
<td>-0.33057738 E0</td>
<td>0.49087828 E-1</td>
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<tr>
<td></td>
<td></td>
<td>-0.65562172 E0</td>
<td>-0.48674037 E-1</td>
<td>0.58641873 E0</td>
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</tr>
<tr>
<td>21.0</td>
<td>360.0</td>
<td>0.80376633 E0</td>
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<tr>
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<td>-0.49460573 E0</td>
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Table 37. Results of Herrick-Gibbs PODM for OSO-III

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<thead>
<tr>
<th>True Anomaly</th>
<th>Angular Difference $\frac{\vec{r}_1 \cdot \vec{r}_2}{\vec{r}_3 \cdot \vec{r}_1}$ (Degrees)</th>
<th>Computed $\vec{X}$ Dot at $T_2$ (CUL/CUT)</th>
<th>Computed $\vec{Y}$ Dot at $T_2$ (CUL/CUT)</th>
<th>Computed $\vec{Z}$ Dot at $T_2$ (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>11.4</td>
<td>-0.70645695 E0</td>
<td>0.40020864 E0</td>
<td>-0.51517444 E0</td>
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<td></td>
<td>-0.70685743 E0</td>
<td>0.40013314 E0</td>
<td>-0.51534094 E0</td>
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<td>3.8</td>
<td>22.8</td>
<td>-0.70643282 E0</td>
<td>0.40017858 E0</td>
<td>-0.51514648 E0</td>
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<td>0.40013314 E0</td>
<td>-0.51534094 E0</td>
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</tr>
<tr>
<td>3.8</td>
<td>45.6</td>
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<td>0.40012606 E0</td>
<td>-0.51504945 E0</td>
<td>N/A</td>
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<tr>
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<td>-0.70685743 E0</td>
<td>0.40013314 E0</td>
<td>-0.51534094 E0</td>
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<td>11.4</td>
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<td>-0.49945671 E0</td>
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<tr>
<td>22.8</td>
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<td>0.14025474 E1</td>
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<td>-0.77864062 E0</td>
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<td>111.6</td>
<td>-0.55417017 E0</td>
<td>-0.76854725 E0</td>
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<td>-0.77864062 E0</td>
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Table 37. Results of Herrick-Gibbs PODM for OSO-III (Cont'd)

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular $\bar{r}_1 \rightarrow \bar{r}_2$ i.e., $v_2 - v_1$ (Degrees)</th>
<th>Difference $\bar{r}_3 \rightarrow \bar{r}_1$ i.e., $v_3 - v_1$ (Degrees)</th>
<th>Computed X Dot Reference Orbit X Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Y Dot Reference Orbit Y Dot at $T_2$ (CUL/CUT)</th>
<th>Computed Z Dot Reference Orbit Z Dot at $T_2$ (CUL/CUT)</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.8</td>
<td>360.0</td>
<td></td>
<td>-0.70521277 E0</td>
<td>0.43640725 E0</td>
<td>-0.52981753 E0</td>
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<td>-0.70685743 E0</td>
<td>0.40013314 E0</td>
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<td>-0.23408489 E0</td>
<td>-0.32909258 E0</td>
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Table 38. Results of Herrick-Gibbs PODM for Relay-II

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular Difference $\bar{v}_1 + \bar{v}_2$ (Degrees)</th>
<th>Difference $\bar{v}_3 - \bar{v}_1$ (Degrees)</th>
<th>Computed X Dot at T2 (CUL/CUT)</th>
<th>Computed Y Dot at T2 (CUL/CUT)</th>
<th>Computed Z Dot at T2 (CUL/CUT)</th>
<th>Number of Iterations (1)</th>
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</thead>
<tbody>
<tr>
<td>2.5</td>
<td>5.0</td>
<td>-0.65566707 E0</td>
<td>-0.48663300 E-1</td>
<td>0.58645073 E0</td>
<td>N/A</td>
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<tr>
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<td>-0.65562172 E0</td>
<td>-0.48674037 E-1</td>
<td>0.58641873 E0</td>
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<tr>
<td>2.5</td>
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<td>0.58660992 E0</td>
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<td>-0.49460573 E0</td>
<td>0.49560149 E0</td>
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<td>-0.22604802 E0</td>
<td>-0.49460573 E0</td>
<td>0.49560149 E0</td>
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<td>-0.35627838 E-1</td>
<td>-0.56593395 E0</td>
<td>0.37767977 E0</td>
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</table>
Table 38. Results of Herrick-Gibbs PODM for Relay-II (Cont'd)

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Angular Difference</th>
<th>Computed X Dot</th>
<th>Computed Y Dot</th>
<th>Computed Z Dot</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>v₂ - v₁</td>
<td>v₃ - v₁</td>
<td>Reference Orbit</td>
<td>Reference Orbit</td>
<td>Reference Orbit</td>
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</tr>
<tr>
<td>(Degrees)</td>
<td>(Degrees)</td>
<td>X Dot at T₂</td>
<td>Y Dot at T₂</td>
<td>Z Dot at T₂</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(CUL/CUT)</td>
<td>(CUL/CUT)</td>
<td>(CUL/CUT)</td>
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<td>0.59939317 E0</td>
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<td>-0.48640377 E-1</td>
<td>0.58641873 E0</td>
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<tr>
<td>21.0</td>
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<td>0.59733711 E0</td>
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(1) No iteration loop exists
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<th>RELAY-II</th>
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<td>Computed Y-Dot</td>
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</tr>
<tr>
<td>Computed Z-Dot</td>
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Table 40. Angles Only and Mixed Data PODM Classical Orbital Element Comparisons - Semimajor Axis

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Nominal semimajor axis from reference orbit (Earth Radii) 1.0866609 for OSO-III

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Nominal semimajor axis from reference orbit (Earth Radii) 1.7448736 for RELAY-11
Table 41. Angles Only and Mixed Data PODM Classical Orbital Element Comparisons - Eccentricity

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Table 42. Angles Only and Mixed Data PODM Classical Orbital Element Comparisons - Longitude of Ascending Node

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Nominal longitude of ascending node from reference orbit
-2.2460589 (radians) for OSO-III

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<td>No Data</td>
<td>-3.0040220</td>
<td>2.1933827</td>
<td>2.326347</td>
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<tr>
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<td>360.0</td>
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<td>No Data</td>
<td>2.1855524</td>
<td>0.5813673</td>
<td>2.1972238</td>
</tr>
<tr>
<td>60.0</td>
<td>360.0</td>
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<td>No Data</td>
<td>-0.1977260</td>
<td>0.9717815</td>
<td>2.1973668</td>
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</tbody>
</table>
Table 43. Angles Only and Mixed Data PODM Classical Orbital Element Comparisons - Argument of Perigee

<table>
<thead>
<tr>
<th>True Anomaly</th>
<th>Method of Gauss (Angles Only)</th>
<th>Laplace (Angles Only)</th>
<th>Double-R Iteration (Angles Only)</th>
<th>Modified Laplacian (Mixed Data)</th>
<th>R-Iteration (Mixed Data)</th>
<th>Herrick-Gibbs (Mixed Data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$r_1 + r_2$</td>
<td>$r_1 + r_3$</td>
<td>$v_2 - v_1$ (Degrees)</td>
<td>$v_3 - v_1$ (Degrees)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Nominal argument of perigee from reference orbit
-3.4856807 (radians) for OSO-III

<table>
<thead>
<tr>
<th>Method</th>
<th>Laplace (Angles Only)</th>
<th>Double-R Iteration (Angles Only)</th>
<th>Modified Laplacian (Mixed Data)</th>
<th>R-Iteration (Mixed Data)</th>
<th>Herrick-Gibbs (Mixed Data)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>-3.1814587</td>
<td>-3.3619857</td>
<td>-3.6361456</td>
<td>-3.5210052</td>
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<tr>
<td></td>
<td>No Data</td>
<td>-5.2972215</td>
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<td>No Data</td>
<td>-0.21050044</td>
<td>-3.4828409</td>
<td>-3.373457</td>
<td>-3.6330051</td>
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<tr>
<td></td>
<td>No Data</td>
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<td>No Data</td>
<td>-3.3281029</td>
<td>-3.5415507</td>
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<tr>
<td></td>
<td>-2.6250891</td>
<td>-5.5696599</td>
<td>No Data</td>
<td>-2.6373267</td>
<td>-3.3808190</td>
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<tr>
<td></td>
<td>-1.3234038</td>
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<td>-0.7028705</td>
<td>-2.5557482</td>
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<td>-0.8143743</td>
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<td>-0.84080418</td>
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<tr>
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<td>-1.3133931</td>
<td>-1.41728807</td>
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<td>-2.0454965</td>
<td>-1.8559031</td>
</tr>
<tr>
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<td>-1.3125766</td>
<td>-3.8607012</td>
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<td>-5.5550579</td>
<td>-4.0303982</td>
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<tr>
<td></td>
<td>-1.3129503</td>
<td>-0.48932362</td>
<td>No Data</td>
<td>-3.5193846</td>
<td>-3.6142215</td>
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<tr>
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<td>-2.5321856</td>
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<td>-3.5871972</td>
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</tbody>
</table>

Nominal argument of perigee from reference orbit
-1.3234053 (radians) for RELAY-II

<table>
<thead>
<tr>
<th>Method</th>
<th>Laplace (Angles Only)</th>
<th>Double-R Iteration (Angles Only)</th>
<th>Modified Laplacian (Mixed Data)</th>
<th>R-Iteration (Mixed Data)</th>
<th>Herrick-Gibbs (Mixed Data)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Data</td>
<td>-1.2977156</td>
<td>-1.3042309</td>
<td>-1.319424</td>
<td>-1.1309387</td>
</tr>
<tr>
<td></td>
<td>No Data</td>
<td>-1.2662402</td>
<td>-1.2874691</td>
<td>-1.2278954</td>
<td>-1.3095217</td>
</tr>
<tr>
<td></td>
<td>No Data</td>
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<td>-1.2473971</td>
<td>-1.3121522</td>
<td>-1.3275518</td>
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<tr>
<td></td>
<td>No Data</td>
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<td>-1.4662223</td>
<td>-1.3121988</td>
<td>-1.3104176</td>
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<tr>
<td></td>
<td>No Data</td>
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<td>-2.3016439</td>
<td>-1.3052735</td>
<td>-1.316275</td>
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<tr>
<td></td>
<td>No Data</td>
<td>-2.9471956</td>
<td>-5.2429044</td>
<td>-1.3052735</td>
<td>-1.316275</td>
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<tr>
<td></td>
<td>No Data</td>
<td>-2.5315446</td>
<td>No Data</td>
<td>-4.2662515</td>
<td>-0.47568945</td>
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<tr>
<td>Method of Gauss (Angles Only)</td>
<td>Laplace (Angles Only)</td>
<td>Double-R Iteration (Angles Only)</td>
<td>Modified Laplacian (Mixed Data)</td>
<td>R-Iteration (Mixed Data)</td>
<td>Herrick-Gibbs (Mixed Data)</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>----------------------</td>
<td>----------------------------------</td>
<td>---------------------------------</td>
<td>------------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Gauss (Angles Only)</td>
<td>Gauss (Mixed Data)</td>
<td>Double-R Modified Laplace Iteration</td>
<td>Laplace (Mixed Data)</td>
<td>No Data</td>
<td>No Data</td>
</tr>
<tr>
<td>True Anomaly</td>
<td>True Anomaly</td>
<td>True Anomaly</td>
<td>True Anomaly</td>
<td>True Anomaly</td>
<td>True Anomaly</td>
</tr>
<tr>
<td>$r_1 + r_2$</td>
<td>$r_1 + r_3$</td>
<td>$r_1 + r_3$</td>
<td>$r_1 + r_3$</td>
<td>$r_1 + r_3$</td>
<td>$r_1 + r_3$</td>
</tr>
<tr>
<td>Orbit Inclination</td>
<td>Orbit Inclination</td>
<td>Orbit Inclination</td>
<td>Orbit Inclination</td>
<td>Orbit Inclination</td>
<td>Orbit Inclination</td>
</tr>
<tr>
<td>i.e., $v_2 - v_1$ (Degrees)</td>
<td>i.e., $v_3 - v_1$ (Degrees)</td>
<td>i.e., $v_3 - v_1$ (Degrees)</td>
<td>i.e., $v_3 - v_1$ (Degrees)</td>
<td>i.e., $v_3 - v_1$ (Degrees)</td>
<td>i.e., $v_3 - v_1$ (Degrees)</td>
</tr>
</tbody>
</table>

Nominal orbital inclination from reference orbit: 0.57356194 (radians) for OSO-III

Nominal orbital inclination from reference orbit: 0.80848228 (radians) for RELAY-II

No data indicates program failed in computing these values.
Table 45. Average Number of Iterations Using Both OSO-III and Relay-II Orbit Results

<table>
<thead>
<tr>
<th>Method of PODM</th>
<th>Number of Iterations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method of Gauss</td>
<td>19/11*</td>
</tr>
<tr>
<td>Laplace</td>
<td>25</td>
</tr>
<tr>
<td>Double R-Iteration</td>
<td>25</td>
</tr>
<tr>
<td>Modified Laplacian</td>
<td>14</td>
</tr>
<tr>
<td>R-Iteration</td>
<td>18</td>
</tr>
<tr>
<td>Herrick-Gibbs</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Trilateration</td>
<td>Not applicable</td>
</tr>
<tr>
<td>*Two iteration loops</td>
<td></td>
</tr>
</tbody>
</table>

Table 46. Best Overall Results for Radius Vector Spread to 360°

<table>
<thead>
<tr>
<th>Radius Vector Spread</th>
<th>PODM</th>
</tr>
</thead>
<tbody>
<tr>
<td>65° &lt; v &lt; 360°</td>
<td>Herrick-Gibbs</td>
</tr>
<tr>
<td>30° &lt; v &lt; 65°</td>
<td>Method of Gauss</td>
</tr>
<tr>
<td>v &lt; 30°</td>
<td>Modified Laplacian</td>
</tr>
<tr>
<td>Undetermined</td>
<td>R-Iteration</td>
</tr>
<tr>
<td></td>
<td>Double R-Iteration</td>
</tr>
<tr>
<td></td>
<td>Laplace</td>
</tr>
</tbody>
</table>
Table 47. Considerations for Selecting Optimum PODM

<table>
<thead>
<tr>
<th>PODM</th>
<th>Computation Time</th>
<th>Ease of Convergence</th>
<th>Best Overall Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herrick-Gibbs</td>
<td>1</td>
<td>N/A</td>
<td>1</td>
</tr>
<tr>
<td>Modified Laplacian</td>
<td>2-3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Method of Gauss</td>
<td>7</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>R-Iteration</td>
<td>6</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Double R-Iteration</td>
<td>4-5</td>
<td>4-5</td>
<td>5</td>
</tr>
<tr>
<td>Laplace</td>
<td>4-5</td>
<td>4-5</td>
<td>6</td>
</tr>
<tr>
<td>Trilaterations</td>
<td>2-3</td>
<td>N/A</td>
<td>7</td>
</tr>
</tbody>
</table>
REFERENCES


"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—National Aeronautics and Space Act of 1958

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