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PROGRAM TECHNICAL REPORT

TASK MSC/TRW A-7

APOLLO CIRCUMLUNAR ABORT GUIDANCE CAPABILITY

NAS 9-4810

31 AUGUST 1965

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TRW SYSTEMS

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TASK MSC/TRW A-7

APOLLO CIRCUMLUNAR ABORT GUIDANCE CAPABILITY

31 AUGUST 1965

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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Apollo MTCP

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TRW SYSTEMS

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INTRODUCTION

This report is generated in response to MSC/TRW Task Assignment A-7 "Apollo Circumunar Abort Guidance Capability Study." This task assignment and subsequent amendments specified the generation of a computer simulation to determine abort trajectories for the Apollo mission. This computer program was to generate these trajectories for the interval from insertion into parking orbit (geocentric) to reentry, exclusive of LEM lunar operations. The basis of this program was to be the MIT simulation described in Reference 1.

The integration scheme used in this simulation was the MSC/MAB Lunar Landing Missions Program. This is a large, flexible simulation using the Encke integration method. Since all the capabilities of this simulation were not needed, many were removed in order to reduce the size of the program.

The logic of Reference 1 has been used, with minor modification, for those abort conditions considered originally by the MIT logic. Where new logic was required to expand the capabilities of the program, an attempt was made to maintain sufficient similarity in computational method to make efficient use of subroutines.

In addition to the abort trajectory determination logic, this task was concerned with the guidance (steering) laws to be used during the abort maneuver. The "abort from midcourse" section of Reference 2 was used as a source for the guidance model. Reference 2 was also used as the source for a set of navigation equations. A rudimentary simulation of these navigation equations has been included in the completed program in order to increase its value as an analytical tool.

The MIT logic was configured originally with emphasis on conserving computer storage requirements; the program described here has had the emphasis shifted to flexibility of computation and operation.

This report is intended to present the philosophy expressed by this logic, discuss its shortcomings, and review alternate approaches. The specifics of the simulation, including detailed logic flow charts, equations used in the formulation, and a users' manual for the simulation are also presented.

1. SUMMARY

The computer program described in this report is an abort logic based on a model developed by the Instrumentation Laboratory, MIT. The MIT logic has been used, with modification, for each of the modes considered by the original simulation. Where the program has been expanded to increase its capability, an attempt was made to maintain enough similarity with the original logic to permit the maximum amount of subroutine sharing.

The simulation computes return trajectories for that interval on Apollo missions from insertion into earth-parking orbit to return; LEM lunar operations are not treated. The simulation is configured to generate the abort trajectory, or family of trajectories, which satisfy the specified constraints or optimization criteria. These trajectories are first generated analytically, and consist of simple conics or patched conics, depending on the region in earth-moon space which contains the abort. Following the analytic generation of the abort, an option is given to generate the precise (integrated) trajectory which satisfies the analytic return conditions. Where optimization occurs, it is performed around the analytic, rather than the precise trajectories. Further option is given in that the abort maneuver may be performed in the simulation either impulsively or with consideration of a finite thrusting mode. The thrusting interval occurs within the constraints of a guidance (steering) law applicable to these thrusting intervals. The target parameters for the guidance model may be determined, during the search for the precise trajectory, so that no errors are introduced by consideration of the finite burn, or so that the integrating portion of the search may be done with an impulsive thrust simulation, and only the final (converged) trajectory simulates the guidance. This mode produces errors in the terminal conditions attributable to the effects of the finite burn compared to the impulsive simulation.

To make the simulation more realistic and to increase its value as an analytical tool, a rudimentary simulation of the navigation equations, intended for on-board computation, is coupled to the guidance equations. As an option, the navigation equations may be entered initially with preset errors in position and velocity.

The simulation has been used to generate abort trajectories from a number of abort situations. These studies were made to determine areas of needed improvement in the logic. Where these problem areas were found, the original logic was modified. Other areas of inadequacy or inefficiency were seen and are pointed out in this report for further study.

These areas include:

1. The ordering of computation in the orbital mode, outside-the-sphere
2. The method of selecting iteration limits in the conic subroutines
3. The optimization logic in the inside-the-sphere and circumlunar sections
4. The control logic for the inside-the-sphere section
5. The generation of the precision trajectory inside-and outside-the-sphere.

2. CHARACTERISTICS OF THE ABORT LOGIC

The objective of this task was to generate a logic which would determine, for a variety of abort situations, the trajectory which returns to earth with acceptable reentry conditions, subject to a variety of constraints. These constraints have led to the division of the logic into distinct modes, with differing requirements. These modes are:

1. Landing-site mode, in which the spacecraft is returned to a specified landing area
2. Time-critical mode, in which the spacecraft returns in the minimum elapsed time, subject to a specified amount of velocity available for the abort
3. Fuel-critical mode, in which the return is accomplished with minimum expenditure of propellants.

Returns are computed analytically as simple conics or patched conics. Where the entire abort trajectory is near the earth, the conic is geocentric, and the computation is called "outside the sphere." Where the abort is determined near the moon, two conics - one selenocentric, the other geocentric - are determined and "patched." At some point on both conics, the position vectors are coincident, and the velocity vectors differ by the velocity of the moon. The solutions associated with these conics are called "inside the sphere." In a third category, the abort is "outside" the sphere, but the post-abort trajectory enters the sphere of lunar action prior to return. These returns are called circumlunar.

The final constraint, that of return to a water landing, may be generated either in the time- or fuel-critical modes, and may be either inside the sphere, outside the sphere, or circumlunar.

In both the inside- and outside-the-sphere modes, the abort maneuver may be performed at the earliest possible time, or the logic may advance the pre-abort trajectory past the earliest possible time before computing the abort maneuver. The first of these techniques is called "midcourse"; the second "orbital."

3. COMPUTATIONAL METHODS

In this section, each of the major categories of the logic will be discussed separately. The order in which they are grouped follows the organization of the computer program. Since some reorganization was done to the MIT logic, the order does not follow the organization of Reference 1.

3.1 Outside the Sphere, Midcourse, Time and Fuel Critical

3.1.1 Description

This computational mode is a separate subroutine (TC-FC) in the program. The subroutine is entered when time- or fuel-critical modes are selected and the initial state vector is greater than 35,000 statute miles from the moon. The return trajectory will abort with no lateral maneuver (in-plane), and solutions will be produced for reentry range angles of 30° and 85°. The return trajectory to the reentry altitude is the same in both cases, but the latitude and longitude of the landing site are computed for both values of the reentry maneuver angle. For these calculations, an average reentry range angle rate of 4 rad/hr is assumed.

The computation consists of the required velocity at abort in terms of the flight-path angle at abort, the orientation of the pre-abort trajectory, and the magnitudes of the position vectors at abort and at reentry.

The computation is an iterative solution of the required velocity at abort, using the cotangent of the flight-path angle at abort as the independent parameter. In both time- and fuel-critical modes, the initial computation is the determination of the minimum fuel trajectory. If the mode is fuel-critical, the fuel-critical solution is examined. If the required velocity exceeds the velocity available for abort, the minimum fuel solution is returned with a warning concerning the circumstances. If there exists a greater velocity capability for abort than is required for the fuel-critical solution, the iterative loop is reentered to drive the required change in velocity to that value available. Implicit in this technique is the assumption that the minimum time return will always occur when the total velocity available for abort is used. No exception to this assumption is apparent. The bounds on the cotangent of the flight-path angle (COGA) were originally selected so that the minimum value produced a parabolic return conic and the maximum value produced a return conic which could not enter the moon's sphere of action prior to reentry. This set of values is still used, unless a limiting value for the maximum reentry velocity has been input. In this case, the limits are the positive and negative roots of the solution which results in the maximum reentry velocity.

3.1.2 Discussion

This subroutine is free from singularity and converges rapidly in all circumstances. The only alteration to the logic of the original MIT program is in setting the limits on the independent variable and detecting that circumstance where insufficient fuel is available for the fuel-critical solution, when in the time-critical mode. These changes were made to allow for a hyperbolic reentry and to enhance the efficiency of the subroutine.

3.2 Outside the Sphere, Midcourse, Landing Site

3.2.1 Description

This computational mode is a separate subroutine in the program. The subroutine is called when the abort position is outside the lunar sphere of action, the period of the pre-abort orbit is greater than 10 hours, and the mode is landing-site. The return trajectories in this logic return to the four landing locations assembled in the program. All geometric possibilities for each location are computed. For each location, the solution characterized by a minimum change in velocity at abort is saved. From these minimum-fuel cases, the minimum-return-time solution is used to generate the precision trajectory.

For each landing location, return inclinations are considered between a minimum value equal to the magnitude of the latitude of the landing site and a maximum vale of 38°. The interval is divided into 5° increments.

For each inclination interval, the velocity required for plane change is computed for one of the possible return planes with the specified inclination. If the plane-change velocity requirement exceeds the allowable expenditure of fuel, the other solution is examined. If neither solution satisfies the plane-change capability, the inclination is incremented. If the fuel constraints are not violated by the plane-change requirements, one of the intersections of the return plane with the locus of the return-site latitude is selected, and the computations proceed.

The location of the landing site is determined at a time corresponding to a parabolic return, and the difference in right ascension between this location and the previously determined intersection is found. This location when converted to equivalent time (earth's rotation) with the parabolic flight time, determines the transit time to the landing location. The reentry conic subroutine is used to determine the conic solution or to determine that a solution does not exist. If a solution is not found, or if the solution found violates the constraints imposed on the reentry-range angle or the velocity available for abort, the transit time is incremented by a sidereal day, and the computations are repeated. The remainder of the solutions are examined, in turn, by combining the landing locations with the geometric parameters for the return.

3.2.2 Discussion

This logic restricts transit time so that the return is to be not less than the parabolic trip time. This implies that solutions may not be examined for hyperbolic return. To extend the capability to hyperbolic, the computation of transit time corresponding to the maximum value of reentry velocity is required. While this does not represent a major computation, it was not felt that the additional complexity was justified in this mode.

This section of the logic has been found to be reliable and reasonably fast in computation. No modifications were made to the original logic specified by Reference 1.

3.3 Outside the Sphere, Orbital

3.3.1 Description

This computation mode is entered when the abort point is outside-the-sphere, the period of the pre-abort trajectory is less than 10 hours, and the mode is landing-site. In this mode, the abort maneuver is performed at some time after the earliest possible time. The landing locations and the range of inclinations are treated as in 3.2.

The computation is initiated by selecting an inclination and one of each of the two geometrical parameters for the return. The location of the landing site is computed for the abort time. The normal to the return plane (containing the landing site) is constructed. The intersection of this plane and the plane of the pre-abort trajectory determines the abort location. The angle between the initial position and the abort position is determined. If this angle exceeds 270°, the geometrical parameters for the return are changed individually until a solution is determined which does not exceed this constraint, or until the range of inclinations has been exhausted. When a parameter set is found which passes the previous test, the conditions on the pre-abort trajectory at the abort position are computed and used to determine the velocity requirement for plane change. If the velocity requirements exceed the available velocity, the geometrical parameters are again varied individually until a solution is found, or the range is exhausted. When the above test is passed, the transit angle from the abort position to reentry is computed with an assumed reentry-range angle of 30°. Should this angle be negative, the procedure discussed previously is reentered to find an acceptable parameter set. The next test is on the contangent of the path angle at the abort position for the post-abort trajectory.

If this parameter indicates that the return conic is hyperbolic, the search logic is again entered. When this test is passed, the logic computes the time at which the landing location will be reached. This time is compared with the previously computed value which was initially set as the time the logic was entered. When the difference between these times is large, the location of the landing site is recomputed for the time just determined as the return time. The computations are then restarted, and the process continued until the time difference at the landing site is small. When the time loop is converged, the velocity required for abort is computed and compared with the available velocity. If the velocity required for abort is less than that available, the solution is stored. This procedure is repeated until each of the possible solutions for each landing location has been explored.

3.3.2 Discussion

Some difficulty exists in this subroutine because some of the parameters for the return are examined before the time loop is converged. For example, on the first pass through this logic, if the velocity required for plane change is too large, the logic will resort to a different solution, even though the solution which failed the test was computed for the incorrect location of the landing site. This procedure may fail, for this reason, to find all of the possible acceptable solutions. During the course of the task, the logic was altered to fail these tests on constraints only if the time loop had converged. As in the midcourse landing site problem, the return is precluded from examining hyperbolic returns. The shortcoming may be overcome by changing the test on the cotangent of the flight-path angle (COGA) from the parabolic limit to a value computed for the maximum reentry velocity. This will necessitate a change in the time computations to allow their solution for hyperbolic conics.

An infrequent source of difficulty in this subroutine has been an oscillation in the time loop. This has not been found to be a frequent or serious occurrence. A permanent "fix" could easily be made by damping in the time loop. This damping, however, has not been added. A fixed damping factor would slow the rate of convergence for all cases, including the majority which do not oscillate. An alternative would be to add logic to detect oscillation and to damp only those solutions. This was not done, since it was felt that the few instances of occurrences did not justify the added complexity.

3.4 Reentry Conic Subroutine

3.4.1 Description

This subroutine is used to solve for the parameters of the return conic, given a reentry flight-path angle, the time on the return conic to the landing site, and the transit angle to the landing site. The logic consists of an iteration on the cotangent of the flight-path angle at the abort point to simultaneously satisfy the transit angle and the transit time. The reentry portion of the trajectory is assigned the average rate of 4 rad/hr. The reentry-range angle is not bounded.

3.4.2 Discussion

This subroutine has been found to be trouble-free and computationally efficient.

3.5 Conic Subroutine

3.5.1 Description

The conic subroutine is designed to solve three distinct conic problems involving time. These are Lambert's problem, in which the initial and final position vectors and transit time are specified; Kepler's problem, in which the initial position and velocity and transit time are specified; and the time-theta problem, in which the initial position and velocity are specified with the transit angle. In each of these problems, a solution is made for the missing parameters among initial and final position and velocity and time.

These conic solutions are written around Battin's parameter, a universal conic variable, so that no distinction need be made according to the type of conic.

The solution to Lambert's problem consists of an iteration on the contangent of the flight-path angle and the universal parameter. The other solutions iterate only on the latter.

3.5.2 Discussion

In both of the iterative loops, the form of the logic driving the iteration was modified to provide a linear search (falsi) on the independent variable. The change was made to provide more rapid convergence. An attempt was made to "gain" the loop driving both iterations, but several instances of instability were observed. The present formulation is a linear search. One persistent difficulty has been found in assigning the maximum allowable value for the universal variable. The parameter has value to infinity and, in the practical sense, to very large numbers. These large values are observed primarily when a solution is made on the hyperbola when the radial distance (true anomaly) is large. The use of a very large value can result in overflow in computation of internally generated functions; the use of too small a value may result in failure to converge.

With the exception of this minor problem area, the subroutine has been found to be an excellent tool, furnishing rapid convergence and freedom from singularities coupled with a simple formulation.

Because of the way in which this routine is used in the abort logic, an exceptional degree of accuracy and consistency has been required. These requirements have made it necessary to formulate the subroutine with double precision. While this undesirable situation might be avoided by altering the logic in the remainder of the program, or by modification to this routine, neither was deemed justifiable.

3.6 Inside the Sphere

3.6.1 Description

This subroutine is the largest single computation block in the program. The solution of each of the modes is contained, in addition to a fairly large optimization logic. The solution produced is, in each case, a patched conic exhibiting the desired earth-phase characteristics. The earth-phase solution, for the time-and fuel-critical solutions, is made with a fixed return inclination. The independent variable for optimization is the energy related quantity VSS. This quantity (VSS) is the square of the speed in the earth phase at the sphere, divided by μ . Since the magnitude of the position vector (geocentric) at this point varies little, the quantity is related to the semi-major axis for the transfer. The logic in this subroutine consists mainly of three sections: a logic to achieve a patch, a logic to select the fuel-optimum abort time, and an optimization loop. These will be described individually.

3.6.1.1 Patch Technique

The patch is produced by maintaining a position match and an energy match and by forcing the angle between the velocity vectors from the two conics to a small value.

To initiate the patching procedure, a selenocentric position at the exit to the moon's sphere of action (MSA) is assumed. A value for VSS is selected, along with a time at the MSA. The inclination for the earth-phase conic is generated according to the declination of the moon, if the mode is time-or fuel-critical. These data are used to determine the earth-phase conic. The velocity on this conic at the exit point is transformed to the lunar phase, and a conic, whose exit speed is the same as this velocity, is generated containing the abort position and the exit position. The angular difference between the velocity vectors from the two conics (that generated in the earth phase and that generated in the moon phase) at the exit point is the error in the patch. This error will be removed by altering the position of the exit point. The change in the position of the exit is computed as a rotation through the angle between the velocity vectors and parallel to the plane defined by the two vectors. At the exit point, the moon-phase conic has a large true anomaly; thus, the position and velocity vectors are separated by a relatively small angle. This implies that the motion of the position vector will well represent the motion of the velocity vector. The earth-phase conic velocity vector at the sphere (for constant VSS) is relatively invariant with the location of the exit point. Since a constant vector difference (the velocity of the moon) exists between this vector and that vector transformed to the moon phase, the moon-phase velocity from the earth-phase conic is insensitive to the motion of the exit point. The change in the exit point is made, then, to rotate the moon-phase conic velocity through the angle representing the error. This procedure is repeated until this angular error is small.

When the patch has been achieved, the transit time on the moon-phase conic is computed, used to calculate the time at the exit point, and compared with the previous calculation of this time. If the difference is large, the exit time is set equal to the time derived from the transit, the moon is "repositioned," and the entire computation is repeated. The patch is considered complete when the time difference is small.

3.6.1.2 Minimum De-orbit Logic

The logic inside the sphere, like that used outside the sphere, contains both midcourse and orbital modes. Again, the midcourse logic demands abort at the earliest possible time; the orbital logic delays abort until a later time determined by optimization. The parameter for optimization in this case is the amount of fuel required for abort. Also, in similar fashion to the outside-the-sphere logic, the choice between midcourse and orbital modes is made internal to the logic, based on the pre-abort trajectory. The mode is set orbital if the eccentricity of the pre-abort trajectory is less than 0.7, or if the radial velocity (selenocentric) is positive, or if the distance from the selenocenter is less than 10,000 statute miles. If none of these conditions is met, the mode is midcourse. In addition, if the solution desired is fuel-critical, the mode is set orbital regardless of the previous tests.

Even though the earth-phase conic must be direct, the patch allows the moon-phase conic to be either direct or retrograde. This choice is made, based on the sub-regime (orbital or midcourse) and the angle between the abort position and the exit (MSA) position. The motion is retrograde if the angle between the abort position and the exit point is less than 180° (for retrograde motion). If the transfer angle is greater than 180° and the mode is midcourse, motion will be direct.

Once the post-abort type has been selected, the optimum departure time is selected by advancing along the pre-abort trajectory in fixed angular steps until an extremum in required velocity for abort is reached. This search procedure is facilitated by checking the angle between the abort and exit position, prior to entry into the de-orbit logic. When this angle is larger than 180° and the mode is orbital, the pre-orbit trajectory is integrated forward to a time corresponding to a time on the conic trajectory where the position vector is nearly 180° removed from the exit point. For those cases where the exit position is contained in the plane of the pre-abort trajectory, the angle will be exactly 180°. This procedure is followed because the velocity required for plane change is maximized when the exit position projected on the plane of the pre-abort trajectory is 180° from the abort position. The orbital logic is configured to find the velocity minimum on the "exit" side of this maximum. When the fuel-optimum departure position has been determined, the patching logic is re-entered.

3.6.1.3 Optimization Logic

This logic is written around the inside-the-sphere solution, and, with the exception of the determination of the earth-phase conic, is the only logic in this phase which distinguishes between the various abort modes (time-and fuel-critical and landing-site). For the landing-site mode, no genuine optimization is possible. In this mode, the first entry into this section compares the velocity requirements from the patched abort conic with the available. If the limit is exceeded, 24 hours are added to the transit time in the earth phase. If this action will result in a total elapsed time to return of less than 120 hours, the inside-the-sphere solution is repeated. If this action does not reduce the required fuel to acceptable limits, the logic returns no solution.

In the fuel-critical mode, this logic returns the first solution, corresponding to the minimum value of VSS if the pre-abort trajectory was elliptical (selenocentric). For hyperbolic conditions, pre-abort, the logic searches on VSS until an extremum is reached on the required velocity-VSS function, at which point the solution is returned. For the time-critical mode, two paths are furnished. The paths are selected by means of a flag set by the conditions of the pre-abort trajectory. The first path is selected if the pre-abort conic is hyperbolic and the mode is orbital. In this branch the initial patched conic is generated for the maximum value of VSS. If this conic solution satisfies the constraint of available velocity, the solution is accepted, and the subroutine exited. If the velocity constraint is violated, the parameter VSS is reduced by a fixed amount, and the inside-the-sphere problem is resolved until the velocity required is less than that available. When this condition is achieved, a linear search is made on VSS to derive the required velocity to the available velocity. When the difference between these is less than 5 statute miles per hour, the solution is accepted.

In the other branch, the initial solution for the earth-phase conic is made with the minimum value of VSS. A second solution is made immediately with the maximum value for VSS. The required velocity for the minimum VSS case is tested against 1.01 times the available velocity. If the required value exceeds this percentage of the available velocity and the solution exhibits direct motion, the mode is set to orbital, and the entire problem reinitiated. If the solution was retrograde, the solution with minimum VSS is accepted, even though it violates the velocity constraint.

If the velocity constraint is not exceeded by the minimum VSS case, the required velocity for the maximum VSS case is tested against 0.99 times the available velocity. If the required velocity is greater than this percentage of the available velocity, a linear search is made on VSS to drive the required velocity to within 5 statute miles per hour of the available velocity. If the required velocity is smaller than this fraction of the available velocity, the maximum VSS solution is accepted.

3.6.2 Discussion

The inside-the-sphere logic has been found, of all the program logic, to be the section most prone to failure. This failure is exhibited in either outright failure to converge, or in finding non-optimum solutions. In addition, the logic has been found to be relatively inflexible, thus reducing its value as an analytic tool. The most frequent failure was a tendency for the patching mechanism to oscillate in such a manner that the solution was not reached. This fault was corrected, at MIT suggestion, by damping the "patch" loop whenever successive solutions reversed direction. The damping was accomplished by averaging angular rotations of the exit-position vector. The fix has been entirely successful, at the cost of relatively small increase in program complexity. A second failure mode was found in the oscillation of the time loop. This occurred infrequently; however, this loop was damped in a similar fashion to the exit-position loop.

The non-optimum solutions, found by comparisions with similar simulations, were found to be attributable to the manner in which the abort was selected (i.e., the choice of retrograde or direct) and to the operation of the de-orbit logic. As a study effort, the logic was altered so that the form of the abort was forced to compare with the comparison trajectories. While this brought about excellent agreement, the difficulty in mechanizing these changes brought attention to the lack of flexibility. Attention given the problem of program control in the inside-the-sphere logic would considerably improve the simulation.

The modified logic exhibited a tendency to generate abort trajectories which impacted the lunar surface. While this tendency was not observed in the original logic, a change was made to apply a minimum altitude constraint. This was effected by controlling the de-orbit logic (or VSS for the midcourse mode) to insure non-impact.

The final area deserving additional attention is the de-orbit logic. While the original logic is seen to be trouble-free and compact, it is not clear that the minimum produced is optimum. During the simulation, there were indications that an occasional trajectory benefited by aborting prior to the opposition of the exit point. These cases violated the original logic when abort modes were forced which would not have been selected by the original logic.

Changes made to the original logic were minor, and generally consisted of replacing formulae which exhibited indeterminacy, or in using alterations designed to make violations of the logic easier. These violations were performed to study specific abort situation.

3.7 Precision Trajectory, Outside the Sphere

3.7.1 Description

The technique used outside the sphere to generate the precision trajectory consists of calibrating an analytic statement of the trajectory against an integration of the initial conditions of this trajectory. The mechanism is fairly simple, and is constructed so that a conic trajectory is produced which connects the abort position with some reentry position at the conclusion of the analytic portion of the program. This reentry position is selected to satisfy the constraints and optimization criteria placed on the problem.

The state vector at the abort position (post-abort) is integrated forward over a time corresponding to transit time from the analytic trajectory. A Lambert's problem is solved with the abort position vector, the terminal position vector from the integration, and the transit time. The initial velocity from the conic solution to Lambert's problem is differenced with the previous value to produce a correction to the initial velocity. The procedure is repeated until the terminal position from the integration is sufficiently close to the desired terminus from the original analytic solution.

3.7.2 Discussion

The procedure used here is three dimensional, and only the terminal (reentry) position is controlled. This forces the effects of perturbations to be evidenced in the terminal velocity. In the simulation this result is apparent, since neither the reentry flight-path angle nor the reentry speed agrees with the desired value. These effects are small (on the order of 0.1°), and no effort has been made to develop a more sophisticated model. Such a model might consist of the calibration of the entire analytic model, driving iteration, rather than the Lambert's solution. Such a search could be made six dimensional.

An infrequent occurrence has been a failure to converge. This situation was recognized in the original (MIT) logic, and a fix was specified. This fix consisted of solving the problem in reverse so that the initial, rather than the final, position was satisfied. While this is a reasonable solution, it was felt desirable in this simulation to include a guidance "targeting" scheme as a part of the iterative solution. This precluded the use of the specified fix.

As described in the section concerned with the steering logic, the target parameters are functions of the elements of the post-abort trajectory. Since these are readily obtained from the trajectory decision logic, an option was provided to include a simulation of the guided (finite) thrusting interval. This option may be exercised in one of three ways: the iteration may be done entirely with impulsive simulation of the thrusting, the iteration performed impulsively and the converged solution repeated with the finite burn, or each iteration may be made with finite burns. The last method has the advantage that the final trajectory is adequate in the presence of the finite burn within the restriction of the formulation. Additionally, it has been found that the procedure does not appreciably slow the rate of convergence.

One problem encountered with this targeting technique occurs in abort from near-reentry altitudes. In this instance, the time required for the burn may exceed the transit time on the impulsive conic to reentry. When this situation is encountered, the simulation cannot compensate; thus, no convergence is achieved.

3.8 Precision Trajectory, Inside the Sphere

3.8.1 Description

In contrast to the solution used outside the sphere, the inside-sphere logic uses a linear partials search. This is accomplished by solving from the inside-the-sphere conic for the rates of velocity with position at the exit point. These solutions are determined by successive perturbations of the nominal exit position with Lambert's problem solved each time (abort position, perturbed exit position, and transit time). A similar set of sensitivities is derived from the equation set used to determine the earth-phase conic. When the sensitivities have been developed, the nominal abort conditions (post-abort) are integrated forward to a time corresponding to exit from the sphere for the analytic solution. The reentry conditions are integrated in reverse to this same time, and the error in position and velocity between the two conics is computed. The sensitivity matrices are used to drive these errors to small values in an iterative loop.

3.8.2 Discussion

The technique used here has been found to be rapid in convergence for the first several iterations. The original logic allowed a total of four iterations, without regard to the errors remaining at the end of the fourth pass. Some instances were observed in which these errors were large, and the logic was modified to allow an additional four iterations. The increase in accuracy was small over the additional iterations.

Additional study is necessary in this area to adequately improve the method.

It should be pointed out that the method used inside the sphere, unlike the solution outside the sphere, is six dimensional.

3.9 Circumlunar

3.9.1 Description

This logic, like the inside-the-sphere logic, achieves a patch by use of linear sensitivities. The parameter used for optimization is the transit time to the first entry to the MSA. The mechanism is as follows: a transit time to the sphere is assumed, an entrance point is assumed, and Lambert's problem is solved between the two positions. The velocity resulting at the sphere is transformed to the moon phase and propagated to the exit from the sphere. The entrance position is perturbed, and the sensitivities of the exit position with the entrance position are computed. In an initialization procedure, these partials are used to drive the exit point to a point 45° behind the earth-moon line in the plane of the moon's motion, and the earth-phase conic is solved exactly as in the inside-the-sphere logic. The value for VSS on the earth-phase portion is taken from the moon-phase conic (transformed earth phase). This procedure results in conics which match in position at the exit from the sphere, have the same energy, but whose velocities at this point are separated by some angle. The entrance position is again perturbed, this time resulting in partials relating to motion of the velocity vectors from the two conics. These sensitivities are used to drive the angular separation to a small value.

The optimization logic is quite similar to that used inside the sphere, except that transit time to the sphere is used for optimization. The primary assumption made is that minimum time trajectories will result from maximum reentry velocity trajectories. Thus, if the mode is time-critical, the transit time to the sphere is adjusted until the reentry speed is equal to the maximum value. If this solution does not violate the constraints placed on the minimum lunar altitude or the maximum velocity available for abort, the solution is accepted. If either constraint is violated, an attempt is made to satisfy the constraints by moving the minimum amount away from the maximum reentry speed conditions. If the mode is fuel critical, successive solutions are made, using transit time to the sphere as a variable, until a minimum required velocity condition is reached. The constraints on reentry velocity and lunar altitude are treated as in the time critical case. For the landing site mode no attempt at optimization is made. As in the inside-the-sphere logic, if no solution is found initially, the earth-phase transit time is incremented by 24 hours in an attempt to reach a solution. If a constraint is violated on the first attempt, the same transit time increment is used.

3.9.2 Discussion

Many alternatives were investigated in selecting a patching technique for the circumlunar mode. The one selected was the only one found which converged consistently in each of the abort situations tested. In addition, it converges rapidly and is a fairly small logic package.

The optimization logic is one area obviously in need of improvement. This logic, particularly for the fuel-critical mode, requires what seems to be an excessive number of iterations. It is also possible that there may be simultaneous consideration of the various constraints and optimization parameters. Of the entire collection of logic in the simulation, this is the area most requiring further investigation.

3.10 Precision Trajectory, Circumlunar

3.10.1 Description

This routine was designed to share the logic used in solving the precise trajectory from inside the sphere. The single major modification is the manner in which the rates of change of exit velocity with exit position are determined. Since no closed solution exists for the statement of exit position, due to the required coordinate transformation at the entry, an analogous problem to Lambert's could not be solved. Instead, the components of initial velocity on the post-abort trajectory were perturbed individually, and these perturbed conics were propagated to the exit time for the nominal trajectory. These trajectories then furnished the rates of change of position and velocity at the exit with the initial post-abort velocity. These two sets of partials were combined to produce the derivatives of velocity at the exit with position at the exit. Once these derivatives were established, the inside-the-sphere routine was used to compute the necessary change in the exit position in order to "patch" the integrated segments of the trajectory. The initial velocity corresponding to this new position was approximated by use of the sensitivity matrix relating post-abort velocity with exit position. The procedure was repeated until the errors in position and velocity at the sphere were small.

3.10.2 Discussion

This routine has been found to be trouble-free and relatively efficient. An investigation was made into the improvement in the rate of convergence afforded by multiple solutions of the sensitivity matrices. The rate was not appreciably increased, and the present formulation computes these quantities only once.

3.11 Water Landing

3.11.1 Description

This logic does not solve specific trajectory problems, but is a control logic written around the other modes. The purpose is to define the time or fuel optimum trajectory which impacts on water. The mechanism uses a set of tables giving the boundaries of the land masses. These tables consist of ordered pairs of latitude and longitude. The tables are ordered so that successive pairs in the table define adjacent points on the land boundary. At present, the land area is represented by two land masses defined by a very few boundary points.

In this mode, the desired return will be either time or fuel critical, and the trajectory may be outside the sphere, inside the sphere, or circumlunar. In any event, the optimum conic (time or fuel critical) is generated, and the resulting landing site is checked to determine if the impact was on a land mass. Since several regions of longitude contain no land areas, the longitude of the return site is first tested to determine if it lies in one of these areas. If it does, the optimum solution is accepted. If not, the table of boundary points is entered and searched until a latitude pair is found which bounds the impact latitude. These latitudes and the corresponding longitudes are stored, and the search resumed to find the next pair of latitudes bounding the return latitude. When two such pairs are found, an interpolation is performed to produce the longitudes corresponding to the latitude of the return. If the longitude of the return is not contained in the interval between these two longitudes, the data is discarded, and the search is continued for an additional set which bound the return latitude. This is continued until it is determined that the impact was on land, or until the table is exhausted. If the table is exhausted, the procedure is repeated for the remainder of the land masses. If no land impact is found, the optimum trajectory solution is accepted.

If it is determined that the impact was on land, the logic returns to the trajectory determination logic, in the landing-site mode, and finds the analytic solution for each of the boundary points in the table corresponding to the land mass on which impact occurred. These solutions are then searched to find the appropriate minimum.

3.11.2 Discussion

The underlying assumption in this logic is that if land impact should occur, the most desirable water site will occur on the boundary of the land mass which contained the optimum return. This implies that the problem does not have relative minima such that a desirable return is located further from the optimum return than the boundaries. While this has not been observed, the problem merits further study.

It is also felt that to be useful, the land boundaries need to be more precisely defined by using additional points in the tables. In that case, a more sophisticated search along the boundaries would be feasible.

3.12 Abort Steering Law

3.12.1 Description

The steering model used in this program was taken from Reference 2. It is the simplest of the modes given in Reference 2, since steering is not affected by the time derivative of the required velocity. In this model, a required velocity which satisfies a set of parameters is computed for each position during the integration. The thrust vector is aligned along this direction, and integration continues until the velocity is equal to the computed, required velocity.

The target parameters are p, the semi-latus rectum; e, the eccentricity; i, the inclination; and two flags defining the direction of the radial and tangential components of velocity. As explained in the precision trajectory sections, an option is provided to determine these parameters during the iteration so that no errors result in the simulation of the finite burn.

Also included in the simulation are a rudimentary set of navigation equations taken from Reference 2. These consist, in essence, of a trapezoidal integration of a spherical gravitational acceleration and the acceleration due to thrust. An attempt was made to simulate the action of the accelerometers by approximating the change in velocity due to thrust. In the simulation, these navigation equations are used to furnish the state vector to the guidance model, while the standard trajectory simulation integrates the total acceleration. An additional option is the capability to input initial errors into the navigation equations in order to perform error analyses.

3.12.2 Discussion

The sole problem encountered in the guidance simulation involved a case which resulted in a failure of the guidance to produce a steering function. This occurs when the position vector is larger than the apogee distance computed from the target parameters, p and e. It is felt that this occurrence will be infrequent, and no corrective measures were applied.

4. OVERLAY STRUCTURE

The function of this section is to define the linkage to the overlay structure of the program. Overlay became necessary as the program capabilities increased. The structure is defined to provide a minimum of tape interface, since the present 7094-II stand alone software utilizes tape overlay. The overlay structure is defined in two sub-sections:

4.1 <u>Linkage Directory</u> - Giving subroutine names within a prescribed link.

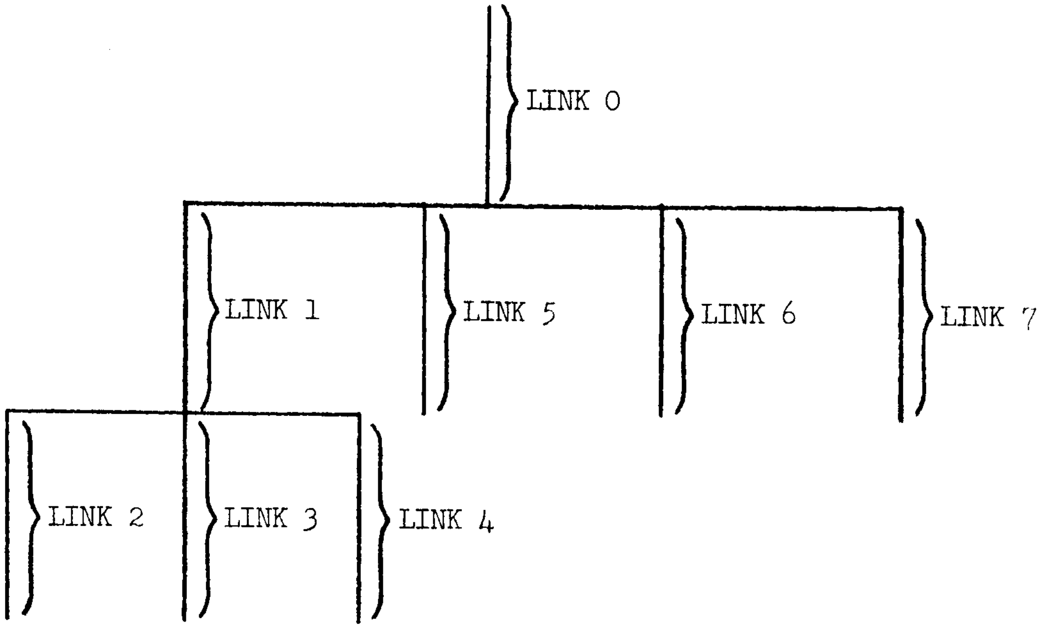
LINK 0

ALPAG0
BL0CK
CINT
CNVRT
DERIV
ENCKE
FC0MP
FSFB
JPLEPH
LAMBS
LATL0N
LSCR
MAIN
M0P
MTRXMP
NEWT
0SCUL
P0LAR
PRINTN
RASCGR
REENTY
REST0R
RKINT
STEP
SUBSAT
SUMR
TB0DY
TERMIN
UN11
VCMSC
VECT
WLSCN

4.1 <u>Linkage Directory</u> - continued

LINK 1	ØRIGIN A	ANALYT
LINK 2	ØRIGIN B	TCFC
LINK 3	ØRIGIN B	ØØUTS
LINK 4	ØRIGIN B	CIRCUM
LINK 5	ØRIGIN A	INMØ
LINK 6	ØRIGIN A	INITAL INV3X3 NAVIER PEICØM PMATC PRINTT PTCIN TCUT THR1 TPRINT
LINK 7	ØRIGIN A	PRINTI PWLØAD SYMBØL

4.2 Overlay Linkage Map - Showing the various levels of the links and the function of each.



Link	Functional Definition
LINK 0	Basic analytic and integration control; Encke free-flight control and computation; outside the sphere midcourse landing site computation.
LINK 1	Analytic control.
LINK 2	Outside the sphere midcourse time critical and fuel critical analytic computations.
LINK 3	Outside the sphere orbital landing site analytic computations.
LINK 4	Circumlunar analytic computations.

4.2 Overlay Linkage Map - continued

Link	Functional Definition
LINK 5	Inside-the-sphere analytic computations.
LINK 6	Thrusting routines for Encke; inside-the-sphere control and final integrated trajectory computation routines.
LINK 7	Case initialization routines.

5. INPUT

This section of the document will be devoted to defining the necessary inputs to ATAP. The inputs will be considered in two categories:

1. Standard inputs to the MSC-Encke Lunar Trajectory program.
2. New inputs required to take advantage of the abort features of the program.

5.1 Standard Inputs

The standard inputs (category 1) will be discussed only in terms of the changes to the existing MSC documentation concerning inputs to the program. The major differences are as follows:

INJECT - The ATAP program will only accept values of 11 or 21 as inputs. (i.e., only x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$, either geocentric or selenocentric, are acceptable inputs for the initial state vector).

The variety of special stops, such as GAMETH, are not recognized by ATAP. The program controls stops only through use of TMAX and RMINE.

RMINE - Should always be set to 1.01910943 earth radii.

5.2 New Inputs

The new input parameters (category 2) are defined in Table I. Specific headings and sub-headings in the table are defined below.

5.2 New Inputs - continued

Card Format Information:

PARAMETER NAME - Up to six alpha-numeric characters representing the name of the parameter being input. Columns 1 - 6 on the data card.

PSEUDO OP. - Describes to the input loader the format of the parameter, columns 16 - 72 of the data card, being loaded (BCD - alpha-numeric; OCT - octal; DEC - decimal).

DEC. PT. - Defines if decimal point is required for the given parameter.

R - decimal point required
NR - decimal point not required

PARAM UNITS - Defines the units expected by the program for this parameter.

MAX ENTRIES THIS NAME - Defines the maximum allowable entries which can be input to the program under the given name.

MODE ASSOCIATION - Defines how each of the new input parameters are associated with the operational modes of the program. The user may scan the columns for required or optional inputs to the mode which he intends to execute.

ST - Standard trajectory or non-iterative type of run.

MODE ASSOCIATION - continued

TC - Time critical mode desired.

FC - Fuel critical mode desired.

LS - Landing site mode desired.

R/Ø - R = required input for the mode;

Ø = optional input for the mode.

PARAMETER DESCRIPTION - Description of the parameter being input. In the event the program expects one of several values for this parameter, these values along with their description will also be presented.

Appendix A will present sample input lists for execution of the various modes of operation of the program.

CARD FORMAT INFORMATION				PARAM. UNITS	MAX. ENTRIES THIS NAME	MODE ASSOCIATION								PARAMETER DESCRIPTION
PARAMETER NAME COLS. 1-6	PSEUDO OP. COLS. 8-10	DEC. PT.				ST		TC		FC		LC		
		R	NR			R	0	R	0	R	0	R	0	
NAVFL	DEC		X		1		X		X		X		X	Flag to indicate use of navigation equations: = 0 do not use navigation equations = 1 use navigation equations
DUR	DEC	X		ER	1		X		X		X		X	1. u Component Error — Errors in the orbit plane components of the state vector at the abort time (UP=DOWN=CROSS). Used by the navigation equations initializing routine.
DVR	DEC	X		ER	1		X		X		X		X	2. v " "
DWR	DEC	X		ER	1		X		X		X		X	3. w " "
DDUR	DEC	X		ER/HR	1		X		X		X		X	4. $\dot{u}$ " "
DDVR	DEC	X		ER/HR	1		X		X		X		X	5. $\dot{v}$ " "
DDWR	DEC	X		ER/HR	1		X		X		X		X	6. $\dot{w}$ " "
SQS	DEC	X			1		X							1. Indicator defining the sgn (sign) of the radial velocity at the abort point = + 1. or = - 1.
PDES	DEC	X		ER	1		X							2. Desired semi-latus rectum.
EDES	DEC	X			1		X							3. Desired eccentricity. — This set of parameters is input in the event the user wishes to run a standard trajectory and define his own target parameters.
CINC	DEC	X		DEG.	1		X							4. Desired inclination.
SGM	DEC	X			1		X							5. Indicator defining the sgn (sign) of the component of velocity at abort in the direction of $\bar{H} \times \bar{R}$, where $\bar{H}$ is the angular momentum vector and R is the position vector at abort. = + 1. or = - 1.
IAMODE	DEC	X			1			X		X		X		= 0 Standard Trajectory(ST) = 1 Time Critical (TC) = 2 Fuel Critical (FC) = 3 Landing Site (LS) Defines mode of program operation.

CARD FORMAT INFORMATION				PARAM. UNITS	MAX. ENTRIES THIS NAME	MODE ASSOCIATION								PARAMETER DESCRIPTION
PARAMETER NAME COLS. 1-6	PSEUDO OP. COLS. 8-10	DEC. PT.				ST		TC		FC		LC		
		R	NR			R	Ø	R	Ø	R	Ø	R	Ø	
AVFUEL	DEC	X		ER/HR	1	X		X		X		X		Maximum ΔV available for abort maneuver. For fuel critical modes, this parameter must be set equal to 0 initially.
URMAX	DEC	X		ER/HR	1			X		X		X		1. Maximum re-entry velocity Defines desired re-entry parameters.
CØGR	DEC	X				X		X		X		X		2. Contangent of re-entry flight path angle
RR	DEC	X		ER	1	X		X		X		X		3. Magnitude of re-entry radius vector
NLS	DEC		X		1							X		Number of landing sites to be considered in LS mode NLS ≤ 4.
ALAT	DEC	X		DEG	4							X		Latitudes of the NLS possible landing sites.
ALØN	DEC	X		DEG	4							X		Longitudes of the NLS possible landing sites (measured positive east).
BURNFL	DEC	X			1			X		X		X		Flag to control type of burn to be executed during iterative phase of the program. It also controls the print during the burn cycles: = -1 This is a non-iterative run = 0 Do impulsive burns without print = 1 Do impulsive burns with print = 2 Do finite burns without print = 3 Do finite burn with print
DELTI	DEC	X		HRS	1				X		X		X	Minimum elapsed time from epoch to abort (built in as .01666666 hrs.).
H2ØFG	DEC		X		1				X		X		X	Flag to indicate if water landing required: = 0 No water landing constraint = 1 Water landing constraint imposed
CFLAG	DEC		X		1				X		X		X	Flag to indicate use of circumlunar option: = 0 No circumlunar = 1 Circumlunar
RPMIN	DEC	X		ER	1				X		X		X	Minimum pericynthian radius (moon phase).

6. OUTPUT

The function of the output section will be to present all of the new print blocks which may appear during the running of ATAP. The sub-sections are organized in the order in which the print blocks may appear during a given run. The exception to this is the last section which gives all the error messages that may appear. Accompanying each block print will be a list describing each parameter of the blocks. The description will contain the symbol, as it appears in the block; verbal description of the parameter, and the units associated with the parameter. Parameter definitions for identical print blocks (only title may have changed) will make reference to the first occurrence of the print blocks in the sub-sections.

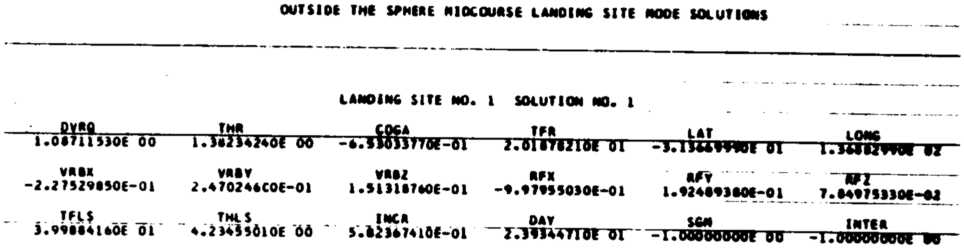
The output sub-sections are organized as follows:

6.1 Intermediate Solutions
6.2 Final Solution
6.3 Landing Site Limits - Outside The Sphere
6.4 Iteration Summaries
6.5 Target Parameter Definition
6.6 Thrust-Phase Print
6.7 Error Messages

6.1 Intermediate Solutions

The following block prints define the conic solutions of the landing site mode problem for each of the landing sites in question. Each solution for a given landing site will produce this print. If multiple solutions exist for a given landing site, the program will automatically pick the minimum fuel solution. When multiple landing sites are involved, the program will then pick the minimum time solution from the possible minimum fuel trajectories.

6.1.1 Outside-The-Sphere Midcourse Landing-Site Mode Solutions



```
                       OUTSIDE THE SPHERE MIDCOURSE LANDING SITE MODE SOLUTIONS

                                 LANDING SITE NO. 1  SOLUTION NO. 1

      DVRQ              THR              COGA              TFR               LAT              LONG
 1.08711530E 00   1.38234240E 00  -6.55033770E-01   2.01878210E 01  -3.13649990E 01   1.36882990E 02

      VRBX              VRBY              VRBZ              RFX               RFY              RFZ
-2.27529850E-01   2.47024600E-01   1.51318760E-01  -9.97955030E-01   1.92489380E-01   7.84975330E-02

      TFLS              THLS              INCA              DAY               SGM              INTER
 3.99884160E 01   4.23455010E 00   5.82367410E-01   2.39344710E 01  -1.00000000E 00  -1.00000000E 00
```

Symbol	Description	Units
DVRQ	Computed velocity change required to reach the landing site.	er/hr
THR	Re-entry range angle.	radians
COGA	Cotangent of the flight-path angle at the abort point.	
TFR	Time of flight from the abort time to re-entry.	hrs
LAT	Latitude of the landing site.	deg
LONG	Longitude of the landing site.	deg
VRBX VRBY VRBZ	Required velocity at burn termination.	er/hr
RFX RFY RFZ	Desired position vector at re-entry.	er
TFLS	Time of flight from the abort time to the landing site.	hrs

6.1.1 Outside-The-Sphere Midcourse Landing-Site Mode Solutions - continued

Symbol	Description	Units
THLS	The central angle from the abort position landing site.	radians
INCR	Desired return inclination.	radians
DAY	Number of earth rotations. One rotation equals 23.934471 hours.	hrs
SGM	Designator of the two return planes.	none
INTER	Designator of the two possible plane intersections.	none

6.1.2 Inside-The-Sphere Landing-Site Mode Solution

```
                         INSIDE THE SPHERE LANDING SITE MODE SOLUTION
     DVMO             THR              COGA             TFR              LAT              LONG
1.23463280E 00   1.93498090E 00  -3.48484050E 00   6.09509330E 01  -3.13669990E 01   1.36885990E 02
     VMBX             VRBY             VMBZ             RFX              RFY              RFZ
3.38116480E-01  -2.59160630E-01  -3.77710200E-02   7.72715200E-01  -6.62936040E-01  -5.07027010E-02
     TFLS             THLS             INCR             DAY              SGM              INTER
8.86674940E 01   4.72994380E 00   6.16478010E-01   2.39344710E 01  -1.00000000E 00   1.00000000E 00
```

See parameter descriptions above.

6.1.3 Outside-The-Sphere Orbital Landing-Site Mode Solutions

```
                    OUTSIDE THE SPHERE ORBITAL LANDING SITE MODE SOLUTIONS
                              LANDING SITE NO. 2  SOLUTION NO. 1
     LAT              LONG             DAY              INCR             SGM              INTER
2.11169990E 01   2.00332990E 02   0.               4.03471170E-01  -1.00000000E 00   1.00000000E 00
     TLS              TFL              COGXR            CAOXR            THLS             TFX
1.66228599E 00   4.54256330E-01   2.81796110E-02   1.70664970E 00   2.23024850E 00   1.26056380E 00
     DVR
1.65845870E 00
     VXRX             VXRY             VXRZ             RFX              RFY              RFZ
2.32802180E 00   3.16714960E 00   7.16656570E-01   4.54315190E-01   8.80814100E-01   2.38520540E-01
```

LAT	The latitude of the desired landing site.	deg
LONG	The longitude of the desired landing site.	deg
DAY	Number of earth rotations. One rotation equals 23.934471 hours.	hrs
INCR	The desired return inclination.	radians

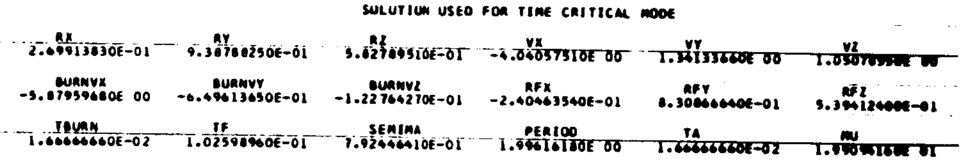
6.1.3 Outside-The-Sphere Orbital Landing-Site Mode Solutions - continued

Symbol	Description	Units
SGM	Designator of the two return planes.	none
INTER	Designator of the two possible plane intersections.	none
TLS	Time of flight to the landing site measured from the initial time.	hrs
TFC	Time of flight from the intersection of the planes to re-entry.	hrs
CØGXR	Cotangent of the required flight-path angle at the intersection of the planes.	none
CAØRR	Difference between the atmospheric flight range angle and THLS.	radians
THLS	The angle between the intersection of the pre/post abort planes and the landing site.	radians
TFX	The time of flight to the intersection of the planes.	hrs
DVR	The computed velocity increment required to reach the landing site.	er/hr
VXRX VXRY VXRZ	The required velocity at burn termination.	er/hr
RFX RFY RFZ	The desired position vector at re-entry.	er

6.2 Final Solution

The following block prints define parameters of the final accepted conic solution. These prints are mode dependent and will appear just prior to the iteration summary prints. Included are prints for outside the sphere, inside the sphere, and circumlunar trajectories.

6.2.1 Time-Critical Mode



```
                                   SULUTIUN USED FOR TIME CRITICAL MODE

      RX                RY                RZ                VX                VY                VZ
 2.69913830E-01    9.38780250E-01    5.82789510E-01   -4.04057510E 00    1.34133660E 00    1.05078990E 00
     BURNVX            BURNVY            BURNVZ             RFX               RFY               RFZ
-5.87959680E 00   -6.49613650E-01   -1.22764270E-01   -2.40463540E-01    8.30866640E-01    5.39412400E-01
      TBURN             TF              SEMIMA            PERIOD             TA                MU
 1.66666660E-02    1.02598960E-01    7.92446410E-01    1.99616180E 00    1.66666660E-02    1.99094160E 01
```

Symbol	Description	Units
RX RY RZ	Position of the vehicle at the abort time.	er
BURNVX BURNVY BURNVZ	Required velocity at burn termination.	er/hr
TBURN	Time to initiate thrust.	hrs
TF	Total time of flight from the initial time.	hrs
SEMIMA	Reciprocal of the semi-major axis of the pre-abort trajectory.	1/er
VX VY VZ	Velocity of the vehicle at the abort time.	er/hr
RFX RFY RFZ	Desired position vector at re-entry.	er
PERIOD	Period of the pre-abort trajectory.	hrs
TA	Abort time measured from the initial time.	hrs
MU	Gravitational parameter of the central	er^3/hr^2

6.2.2 Fuel-Critical Mode

```
                              SOLUTION USED FOR FUEL CRITICAL MODE

     RX               RY               RZ               VX               VY               VZ
1.99579660E 01   1.03184060E 00   1.63626610E 00  -1.18906000E 00  -2.07651390E-01  -7.35126400E-02

   BURNVX           BURNVY           BURNVZ           RFX              RFY              RFZ
-1.20185280E 00   2.48079370E-01  -1.49410670E-01  -8.53714050E-01   5.32198950E-01  -1.64512600E-01

   TBURN             TF              SEMIMA           PERIOD            TA               MU
0.               1.09993290E 01   2.62911510E-02   3.30321000E 02   0.               1.99094160E 01
```

See above for parameter definitions.

6.2.3 Outside The Sphere Orbital Landing-Site Mode

```
                  SOLUTION USED FOR OUTSIDE THE SPHERE ORBITAL LANDING SITE MODE

     RX               RY               RZ               VX               VY               VZ
-2.05830330E 00  -2.28207350E-01  -4.52690890E-02   1.47521100E-01  -2.12887150E 00  -1.36002380E 00

   BURNVX           BURNVY           BURNVZ           RFX              RFY              RFZ
2.32802180E 00   3.16714960E 00   7.16656570E-01   4.54315190E-01   6.80814100E-01   2.36520540E-01

   TBURN             TF              SEMIMA           PERIOD            TA               MU
1.27723050E 00   1.73148680E 00   6.43892950E-01   2.72539890E 00   1.66666660E-02   1.99094160E 01
```

See above for parameter definitions.

6.2.4 Outside-The-Sphere Midcourse Landing-Site Mode

```
                 SOLUTION USED FOR OUTSIDE THE SPHERE MIDCOURSE LANDING SITE MODE

     RX               RY               RZ               VX               VY               VZ
1.99579660E 01   1.03184060E 00   1.63626610E 00  -1.18906000E 00  -2.07651390E-01  -7.35126400E-02

   BURNVX           BURNVY           BURNVZ           RFX              RFY              RFZ
-6.50100810E-01   2.36617170E-01  -2.05248220E-01  -9.15260590E-01   3.43749950E-01  -2.88556940E-01

   TBURN             TF              SEMIMA           PERIOD            TA               MU
0.               1.43857120E 01   2.62911510E-02   3.30321000E 02   0.               1.99094160E 01
```

See above for parameter definitions.

6.2.5 Inside-The-Sphere Solution

```
                              SUMMARY OF INSIDE THE SPHERE'S SOLUTION

     RL(1)          RL(2)          RL(3)          RL(4)          VOL(1)         VOL(2)         VOL(3)         VOL(4)
-2.9370540E-01 -3.5497583E-02 -1.0766916E-02  2.4580547E-01 -4.0501373E-01  1.1706680E 00  6.2874798E-01  1.3891810E 00

     VL(1)          VL(2)          VL(3)          VL(4)          RS(1)          RS(2)          RS(3)          RS(4)
 1.7430640E-01  9.4785122E-01  1.0370454E 00  1.4157217E 00 -4.8319009E 01  1.9919487E 01  1.3932543E 01  5.4089078E 01

     VS(1)          VS(2)          VS(3)          VS(4)          RR(1)          RR(2)          RR(3)          RR(4)
 4.0210607E-01 -2.7207675E-01 -6.2216900E-02  4.6947633E-01  7.7893083E-01 -6.5520772E-01 -5.5753144E-02  1.0193816E 00

     VRC(1)         VRC(2)         VRC(3)         VRC(4)         DVR            TL             TF             TFE
 2.6035547E 00  4.4047049E 00 -3.5192570E 00  6.2100799E 00  7.4294408E-01  2.0792200E 00  5.0386167E 01  5.0386167E 01
```

Symbol	Description	Units
$\overline{RL}$	The position vector, relative to the moon, at the time of burn initiation.	er
$\overline{VL}$	The required velocity, relative to the moon, at the abort time.	er/hr
$\overline{VS}$	The velocity vector, relative to the earth, at the lunar sphere of action.	er/hr
$\overline{VRC}$	The required velocity vector, relative to the earth, at re-entry.	er/hr
$\overline{V0L}$	The velocity vector, relative to the moon, at the abort time before the abort.	er/hr
$\overline{RS}$	The position vector, relative to the earth, at the lunar sphere of action.	er
$\overline{RR}$	The desired re-entry vector relative to the earth.	er
DVR	The required velocity increment from pre-abort to post-abort at the abort time.	er/hr
TL	Time of burn initiation measured from the initial time.	hrs
TF	The total time of flight from the initial time to re-entry.	hrs
TFE	The time of flight from the lunar sphere of action to re-entry.	hrs

6.2.6 Circumlunar Solutions

```
                                          CIRCUMLUNAR SOLUTION - SUMMARY PRINT
     RL(1)           RL(2)           RL(3)             RL          RSM(1)          RSM(2)          RSM(3)             RSM
3.6147020E 01 -2.2583878E 01 -1.3347224E 01  4.4663038E 01 -8.7702706E 00 -4.4685745E-01 -9.3155479E-01  8.8309186E 00

     VL(1)           VL(2)           VL(3)             VL            LAT             LON            INCR            INTER
4.4017399E-01 -3.9380329E-01 -2.2546800E-01  6.3219458E-01 -0.0000000E-20 -0.0000000E-20  5.7204892E-01  1.0000000E 00

     RR(1)           RR(2)           RR(3)             RR           VR(1)           VR(2)           VR(3)              VR
-5.6171017F-01  8.3785615E-01  1.4703241E-01  1.0193821E 00 -3.7452753E 00 -3.8519516E 00  3.1338191E 00  6.2197620E 00

     RS(1)           RS(2)           RS(3)             RS           VS(1)           VS(2)           VS(3)              VS
4.1191890E 01 -2.9234004E 01 -1.8130955E 01  5.3666846E 01 -4.0914649E-01  4.1907938E-01  1.5072373E-01  6.0476939E-01

     RM(1)           RM(2)           RM(3)             RM           VM(1)           VM(2)           VM(3)              VM
4.9962161E 01 -2.8787146E 01 -1.7199400E 01  6.0172557E 01  3.4716325E-01  4.1570255E-01  2.0970784E-01  5.8078250E-01

    RM1(1)          RM1(2)          RM1(3)            RM1          VM1(1)          VM1(2)          VM1(3)             VM1
4.1483463E 01 -3.7052852E 01 -2.1310106E 01  5.9564353E 01  4.3905076E-01  3.4997380E-01  1.7104851E-01  5.8694533E-01

      TFH             TA            DELT           TIME              TL             IFE              TS             VSS
4.1093866E 01  0.             1.9591185E 01  2.1502683E 01 -0.0000000E-20  5.2106547E 01 -0.0000000E-20  1.8370505E-02

      SGM            HVR              UR
1.0000000E 00  2.5676913E-01  6.2197863E 00
```

Symbol	Description	Units
RL	The position vector relative to the moon at time of burn initiation.	er
RSM	Position relative to the moon at the lunar sphere of influence.	er
VL	Velocity relative to the moon at time of burn initiation.	er/hr
LAT	Latitude of the landing site.	deg
LØN	Longitude of the landing site.	deg
INCR	Desired inclination of return trajectory.	radians
INTER	Designator of the preselected intersection of the landing site with the return plane.	
RR	Desired position vector at re-entry.	er
VR	The required velocity at re-entry.	er
RS	Position at the lunar sphere of influence relative to the earth.	er
VS	Velocity at the lunar sphere of influence relative to the earth.	er/hr

6.2.6 Circumlunar Solutions - continued

Symbol	Description	Units
RM	Moon's position at time TA + DELT + TIME.	er
VM	Moon's velocity at time TA + DELT + TIME.	er/hr
RM1	Moon's position at time TA + DELT.	er
VM1	Moon's velocity at time TA + DELT.	er/hr
TFH	Time from RL to RSM.	hr
TA	Time of abort measured from initial time.	hr
DELT	Time from abort to first pierce point at lunar sphere of influence.	hr
TIME	Time required to go from entry to exit in the lunar sphere of influence.	hr
TL	Time of burn initiation.	hr
TFE	Time of flight from RS to RR.	hr
TS	Time of arrival at the lunar sphere of influence.	hr
VSS	Square of the velocity divided by μ_E relative to the earth at the lunar sphere of influence.	1/er
SGM	Designator of the preselected return plane.	
DVR	The required change in velocity.	er/hr
UR	The magnitude of the required re-entry velocity.	er/hr

6.3 Landing Site Limits - Outside The Sphere

The following block prints define the landing sites corresponding to the minimum and maximum re-entry range angles for the time critical/fuel critical modes. These prints are applicable only to outside the sphere solutions.

6.3.1 Fuel Critical Mode

```
                    LANDING SITE LIMITS FUEL CRITICAL MODE
      MINLAT            MINLON             MAXLAT            MAXLON
  -9.5620081E-02    -4.9840292E 00     7.4244544E-02    -4.2705436E 00
```

Symbol	Description	Units
MINLAT	Latitude of the landing site corresponding to the minimum re-entry range angle.	radians
MINLON	Longitude of the landing site corresponding to the minimum re-entry range angle.	radians
MAXLAT	Latitude of the landing site corresponding to the maximum re-entry range angle.	radians
MAXLON	Longitude of the landing site corresponding to the maximum re-entry range angle.	radians

6.3.2 Time-Critical Mode

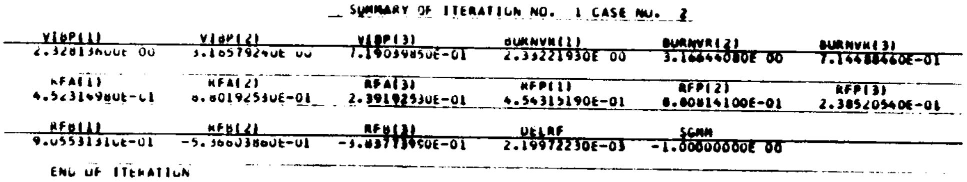
```
                    LANDING SITE LIMITS TIME CRITICAL MODE
      MINLAT            MINLON             MAXLAT            MAXLON
   4.2468633E-01    -5.3516527E 00    -4.6005845E-02    -3.8559375E 00
```

See parameter definitions above.

6.4 Iteration Summaries

The following block prints describe the intermediate results of each iteration cycle.

6.4.1 Outside-The-Sphere Iteration Summary



```
                               SUMMARY OF ITERATION NO.  1 CASE NO.  2

    VIBP(1)          VIBP(2)          VIBP(3)          BURNVR(1)        BURNVR(2)        BURNVR(3)
  2.32813600E 00   3.16579240E 00   7.19039850E-01   2.33221930E 00   3.16644080E 00   7.14488460E-01

    RFA(1)           RFA(2)           RFA(3)           RFP(1)           RFP(2)           RFP(3)
  4.52314980E-01   8.80192530E-01   2.39192530E-01   4.54315190E-01   8.80814100E-01   2.38520540E-01

    RFB(1)           RFB(2)           RFB(3)           DELRF            SGMM
  9.05531310E-01  -5.36603880E-01  -3.83773950E-01   2.19972230E-03  -1.00000000E 00

    END OF ITERATION
```

Symbol	Description	Units
VIBP	The Lambert's velocity at the abort point for the desired transit time between the abort position and re-entry.	er/hr
$\mathrm{BURNV}\overline{\mathrm{R}}$	The n^{th} value of the required velocity at burn termination.	er/hr
$\mathrm{RF}\overline{\mathrm{A}}$	The computed position vector at re-entry.	er
$\mathrm{RF}\overline{\mathrm{P}}$	The desired position vector at re-entry.	er
RFB	The computed position vector at burn initiation.	er
DELRF	The magnitude of the vector difference of the computed and the desired re-entry position vectors. Convergence occurs when this parameter is less than .25 miles.	er
SGMM	The indicator of the transfer angle. SGMM = 1, $\theta \geq 180^\circ$ SGMM = -1, $\theta < 180^\circ$	

6.4.2 Inside-The-Sphere/Circumlunar Iteration Summary

```
                              SUMMARY OF ITERATION NO. 4 INSIDE THE SPHERE
     RL(1)           RL(2)           RL(3)           RL(4)           VLC(1)          VLC(2)          VLC(3)          VLC(4)
-2.9370540E-01 -3.3497583E-02 -1.0766916E-02  2.9580547E-01  1.7797926E-01  9.6305846E-01  1.0367796E 00  1.4157217E 00
     RSM(1)          RSM(2)          RSM(3)          RSM(4)          VSM(1)          VSM(2)          VSM(3)          VSM(4)
 7.5476559E 00  3.7066579E 00  3.3930612E 00  9.0674884E 00 -5.7289400E-01 -2.3943070E-01 -2.1318226E-01 -6.5649164E-01
     RR(1)           RR(2)           RR(3)           RR(4)           VRC(1)          VRC(2)          VRC(3)          VRC(4)
 7.7328252E-01 -6.6141649E-01 -6.5083949E-02  1.0193816E 00  2.6174123E 00  4.4059703E 00 -3.5075896E 00  6.2100799E 00
     RS(1)           RS(2)           RS(3)           RS(4)           VS(1)           VS(2)           VS(3)           VS(4)
-4.8197105E 01  2.0113836E 01  1.4091081E 01  5.4093307E 01  4.1758593E-01 -2.6086569E-01 -5.2341172E-02  4.9514494E-01
    DELR(1)         DELR(2)         DELR(3)         DELR(4)         DELV(1)         DELV(2)         DELV(3)         DELV(4)
-4.7130585E-03  2.9492378E-04  2.7283430E-03  5.4537836E-03  1.1073798E-04 -9.2238188E-06 -2.0094216E-05  1.1292368E-04
      TL              TFM             TS              TA              TFE
 2.0792200E 00  1.2618354E 01  1.4698211E 01  7.3228573E 01  5.8530959E 01
```

Symbol	Description	Units
$R\bar{L}$	The position vector relative to the moon at the time of burn initiation.	er
$RS\bar{M}$	The position vector relative to the moon at the lunar sphere of action.	er
$R\bar{R}$	The desired re-entry vector relative to the earth.	er
$R\bar{S}$	The position vector relative to the earth at the lunar sphere of action.	er
$DEL\bar{R}$	The vector difference of the two computed position vectors at the lunar sphere of action.	er
$DEL\bar{V}$	The vector difference of the two computed velocity vectors at the lunar sphere of action.	er/hr
$VL\bar{C}$	Velocity vector relative to the moon at the time of burn initiation.	er/hr
$VS\bar{M}$	The velocity vector relative to the moon at the lunar sphere of action.	er/hr
$VR\bar{C}$	The required velocity at re-entry relative to the earth.	er/hr
$V\bar{S}$	The velocity vector relative to the earth at the lunar sphere of action.	er/hr

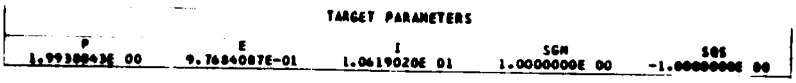
6.4.2 Inside-The-Sphere/Circumlunar Iteration Summary - continued

Symbol	Description	Units
TL	Time of burn initiation measured from the initial time.	hrs
TFH	Time-from-burn initiation to the lunar sphere of action.	hrs
TS	Time at the lunar sphere of action.	
TR	Time of flight from the initial time to re-entry.	hrs
TFE	Time of flight from the lunar sphere of action to re-entry.	hrs

6.5 Target Parameter Definition

This block print will appear whenever finite burns are to be executed by the program during an iterative type run. These parameters define the target for the burn model guidance equations.

6.5.1 Target Parameters



```
                              TARGET PARAMETERS
       P              E               I              SGM             SQS
 1.99380843E 00  9.76840087E-01  1.06190200E 01  1.00000000E 00  -1.00000000E 00
```

Symbol	Description	Units
P	The semi-latus rectum of the post-abort trajectory.	er
E	The eccentricity of the post-abort trajectory.	
I	The inclination of the post-abort trajectory relative to the earth's equator.	deg
SGM	Indicator defining the (sign) of the component of velocity at abort in the direction of $\bar{h} \times \bar{R}$.	
SQS	Indicator defining the (sign) of the radial velocity at the abort.	

6.6 Thrust-Phase Print

The following block prints define the output of the navigation equations simulation and of the thrust acceleration computation routines. They appear at each print cycle of the thrusting phase.

6.6.1 Navigation Simulation Print

```
NAVIGATION ERROR PARAMETERS
     RSN    1.99546580E 01  1.03133980E 00  1.63604900E 00  2.00481600E 01
     VSN   -1.19075950E 00 -1.52494590E-01 -8.27201570E-02
     CGSN  -4.93030720E-02 -2.54821900E-03 -4.04232540E-03    SSG    -4.92741400E-02 -2.54749020E-03 -4.04800270E-03
     DVSAN -7.93149390E-05  2.80095430E-03 -4.66939640E-04    DVSIN  -8.61585130E-05  2.80060090E-03 -4.67501570E-04
```

Symbol	Description	Units
$\mathrm{RS\bar{N}}$	The position vector determined by the integration of the navigation equations.	er
$\mathrm{VS\bar{N}}$	The velocity vector determined by the integration of the navigation equations.	er/hr
$\mathrm{CGS\bar{N}}$	Two-body accelerations used in the integration of the navigation equations.	er/hr^2
$\mathrm{DVSA\bar{N}}$	Analytic velocity increment.	er/hr
$\mathrm{SS\bar{G}}$	Summation of the perturbation accelerations.	er/hr^2
$\mathrm{DVSI\bar{N}}$	Integrated velocity increment.	er/hr

6.6.2 Guidance Equations Print

```
BURN PARAMETERS
     VRDES  -1.20292840E 00  2.40305010E-01 -1.49623830E-01  1.23738400E 00
     VD     -1.49450640E-05  5.45350830E-04 -9.07443460E-05  5.53051020E-04     ATM     2.50900780E 01
```

$\mathrm{VRDE\bar{S}}$	The desired velocity at burn termination.	er/hr
$\mathrm{V\bar{D}}$	The velocity to be gained.	er/hr
ATM	The magnitude of the thrust acceleration.	er/hr^2

6.7 Error Messages

The following represents error messages which may appear in the course of a given run.

6.7.1 No Solution - Outside The Sphere Orbital Landing Site Mode

```
                          OUTSIDE THE SPHERE ORBITAL LANDING SITE MODE SOLUTIONS
                             NO SOLUTION FOR LATITUDE= -5.4745741E-01   LONGITUDE=  2.3890590E 00
NO LANDING SITE FOUND OUTSIDE THE SPHERE ORBITAL.
     END OF CASE NO.  1
```

When running the landing site mode (IAMØDE = 1), outside the sphere, if no solution for a particular landing site can be found, the program prints the latitude and longitude of that landing site in radians and tries to find a solution for the next specified landing site. If no solution can be found for any specified landing site, the program prints the message, "No Landing Site Found Outside The Sphere...," and goes on to the next case.

6.7.2 No Solution - Inside The Sphere

```
NO SOLUTION INSIDE THE SPHERE.
END OF CASE NO.  2
```

If a solution cannot be found when inside the lunar sphere of action, the program prints, "No Solution Inside The Sphere," and goes on to the next case.

6.7.3 Insufficient Fuel

```
THE AVAILABLE FUEL IS LESS THAN THE MINIMUM REQUIRED. THE FOLLOWING SOLUTION USES THE MINIMUM FUEL POSSIBLE.
```

When running the time critical mode (IAMØDE = 2), outside the sphere. if the available fuel (AVFUEL) is less than the minimum required to find a solution, the above comment is printed and the program computes the minimum fuel solution.

6.7.4 Optimum Trajectory Impacts On Land

```
OPTIMUM TRAJECTORY IMPACTS ON LAND

                                   LAT               LON                LAND MASS
                              -2.96145695E 01   1.11581446E 02              1
```

When a water landing is requested and the nominal trajectory fails to impact on water, the above message appears. It defines the latitude and longitude of the nominal impact point and the land mass containing the impact point. The program will proceed to find the relative optimum trajectory using the boundary points of the specified land mass as target points.

7. SUBROUTINE SPECIFICATION

The following section will define the subroutines which have been generated under this task. These subroutines extend the capabilities of the MSC Lunar Trajectory program to determine abort trajectories from any point, after translunar injection, on an Apollo type trajectory. It is the intent of this section to give as much information about these subroutines so that the user may fully understand their capability. Each subroutine is defined by three sections:

1. Basic Description - giving subroutine name, purpose, name common blocks used, subroutines called for, and approximate storage.
2. Input/Output Interface
3. Flowcharts - giving basic flow and equations.

The subroutine descriptions are presented on the following pages being listed in alphabetical order.

SUBROUTINE: ALPAG0

PURPOSE: To compute α_{go}, the right ascension of Greenwich.

CALLING SEQUENCE: CALL ALPAG0 (JD, RAGM)

NAME COMMON USED: None

SUBROUTINES REQUIRED: None

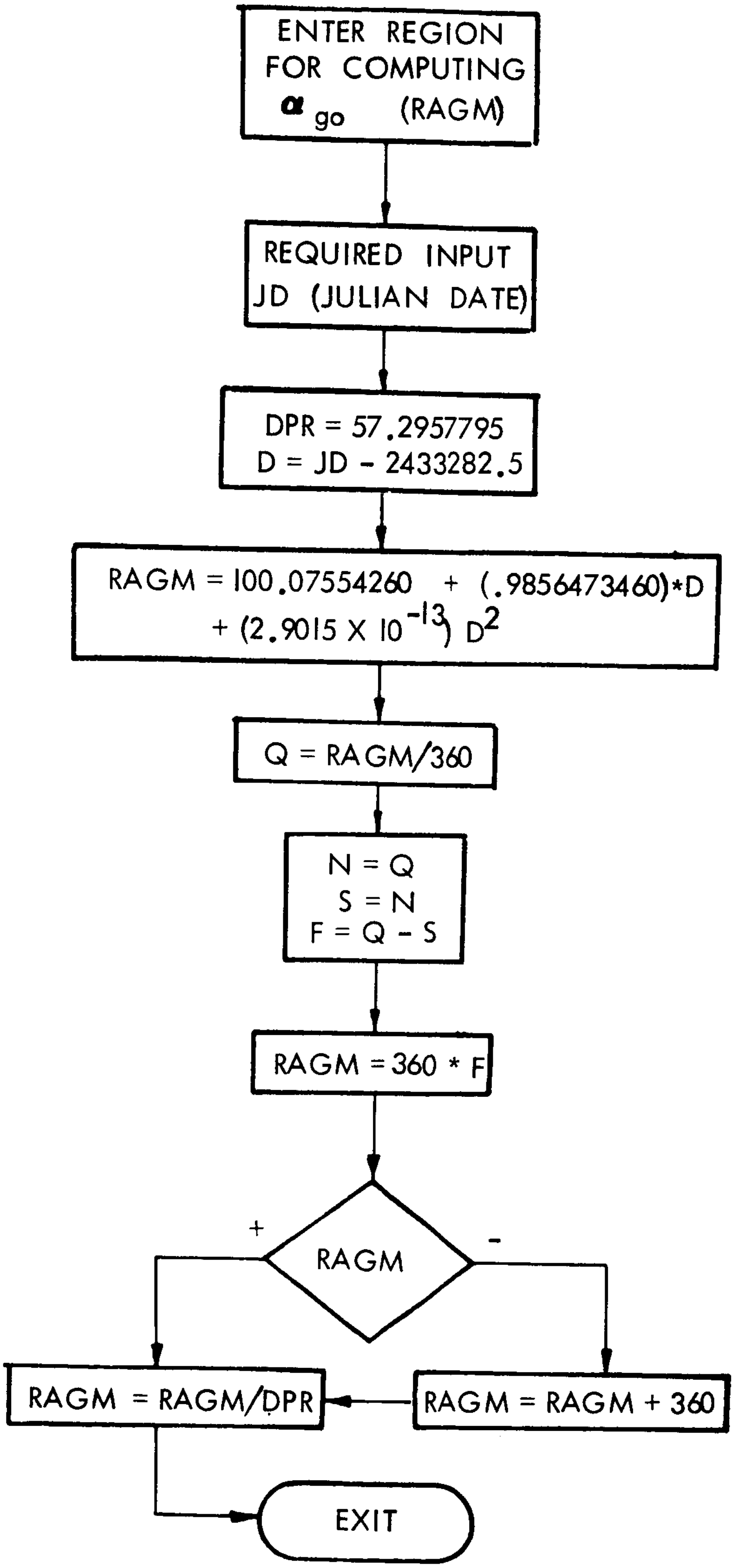
FUNCTIONS REQUIRED: None

APPROXIMATE STORAGE: 121

SUBROUTINE:

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I		JD	1	JD		Julian Date
Ø		RAGM	1	α_{go}	rad	Right ascension of Greenwich at 0^h day of epoch.


ENTER REGION FOR COMPUTING α_{go} (RAGM)
REQUIRED INPUT JD (JULIAN DATE)
DPR = 57.2957795
D = JD - 2433282.5
RAGM = 100.07554260 + (.9856473460)*D + $(2.9015 \times 10^{-13})\ D^2$
Q = RAGM/360
N = Q
S = N
F = Q - S
RAGM = 360 * F
+
RAGM
-
RAGM = RAGM/DPR
RAGM = RAGM + 360
EXIT

SUBROUTINE: ANALYT

PURPOSE: To control the overall flow of the abort trajectory determination logic.

CALLING SEQUENCE: CALL ANALYT

NAME COMMON USED:
INTGR
C0NST
INDS
AINPUT
BURNPR
RVM00N
INM0C
BLANK
0TPT

SUBROUTINES REQUIRED: VCMSC, TCFC, LSCR, 00UTS, JPLEPH, RASCGR, CIRCUM

FUNCTIONS REQUIRED: ABS, SQRT

APPROXIMATE STORAGE: 655

SUBROUTINE: ANALYT

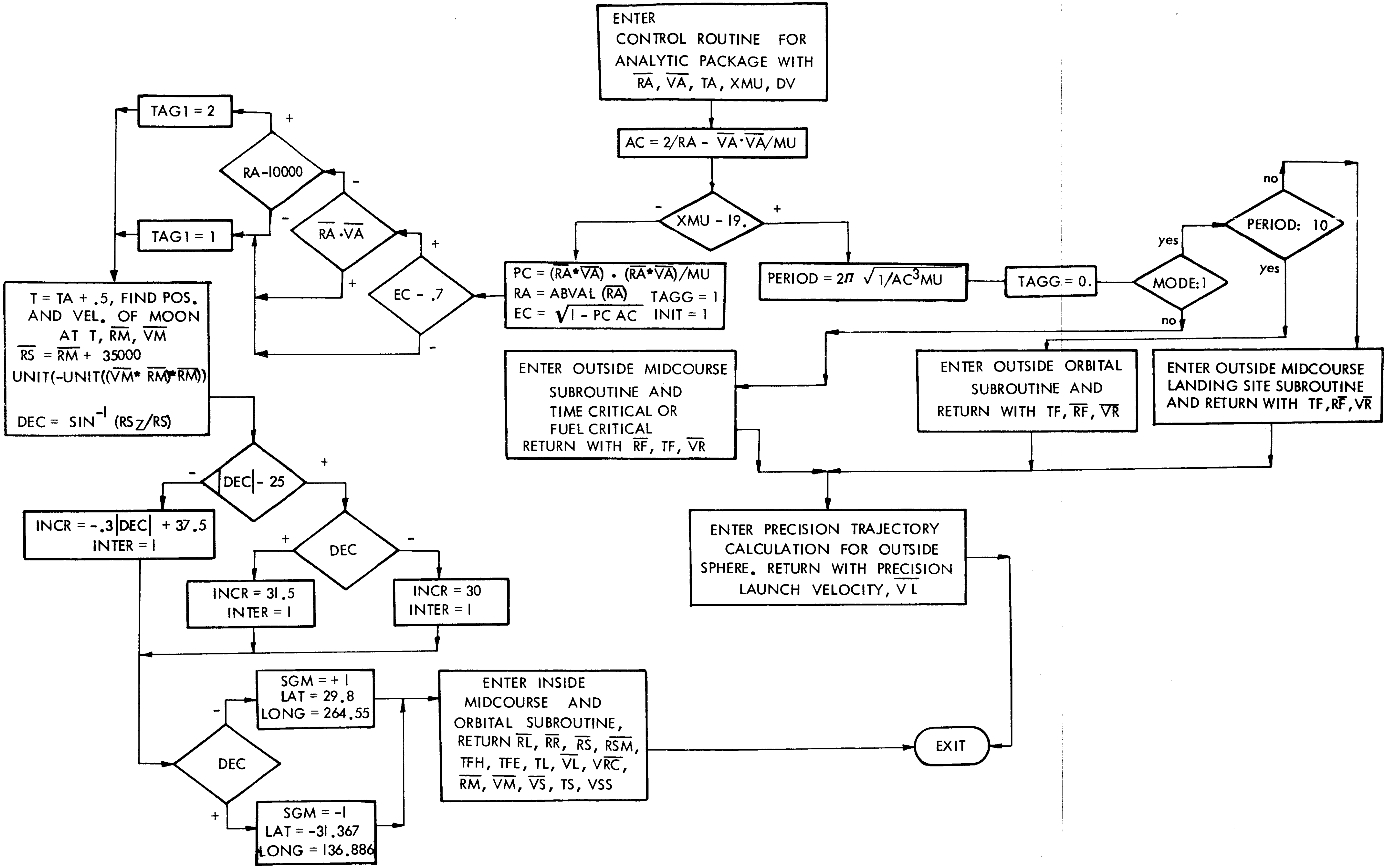
INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	INTGR	TA	1		hrs	Time of abort measured from initial time.
I	INTGR	R	6	$\bar{R}$	er	Position of the spacecraft at time TA.
I	INTGR	V	6	$\bar{V}$	er/hr	Velocity of the spacecraft at time TA.
I	CØNST	USSTER	1		$\frac{\text{statute mi.}}{\text{er}}$	Conversion factor: 3963.20799
I	INDS	XMU	1	μ	er^3/hr^2	Gravitational parameter of the central body.
I	CØNST	TWØPI	1	2π		6.283185307
I	CØNST	RAD	1		deg/rad	57.29577951
I	AINPUT	MØDE	1			MØDE = 1, landing site. MØDE = 2, time critical. MØDE = 3, fuel critical.
Ø	INTGR	TF	1	T_F	hrs	Time of flight measured from initial time to re-entry.
Ø	INTGR	RFA	6	$\bar{R}_R$	er	Desired position vector at re-entry.
Ø	INTGR	TBURN	1	T_B	hrs	Time of burn initiation measured from initial time.
Ø	BURNPR	BURNVR	3	$\bar{V}_B$	er/hr	Velocity required at end of burn.

SUBROUTINE: ANALYT (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
Ø		SEMIMA	1	$1/a$	(1/er)	Reciprocal of the semi-major axis of the pre-abort trajectory.
Ø		PER	1	P	hrs	Period of the pre-abort trajectory.
Ø	AINPUT	TAGG	1			For nominal operation in outside the sphere modes: TAGG = 0 Inside the sphere: TAGG ≠ 0
Ø	AINPUT	INØSØF	1			= 0, if no solution has been computed. = 1, if a solution has been computed.
I	AINPUT	CFLAG	1			0, no circumlunar logic. 1, do circumlunar logic.
Ø	AINPUT	INSFG	1			= 1, if the abort time is inside the lunar sphere of action.
Ø	INMØC	INCR	1	i_R	rad	Return inclination.
Ø	INMØC	INTER	1		± 1	Designator of the return plane intersection with the landing site.
Ø	INMØC	SGM	1		± 1	Designator of the return plane.
Ø	ØTPT	DVR	1	ΔV_r	er/hr	The required velocity change for the abort trajectory.


ENTER CONTROL ROUTINE FOR ANALYTIC PACKAGE WITH $\overline{RA}$, $\overline{VA}$, TA, XMU, DV
AC = 2/RA - $\overline{VA}\cdot\overline{VA}$/MU
XMU - 19.
-
+
PC = ($\overline{RA}$*$\overline{VA}$) • ($\overline{RA}$*$\overline{VA}$)/MU
RA = ABVAL ($\overline{RA}$)
EC = $\sqrt{1 - PC\,AC}$
TAGG = 1
INIT = 1
EC - .7
+
-
$\overline{RA}\cdot\overline{VA}$
-
+
RA-10000
+
-
TAG1 = 2
TAG1 = 1
T = TA + .5, FIND POS. AND VEL. OF MOON AT T, $\overline{RM}$, $\overline{VM}$
$\overline{RS}$ = $\overline{RM}$ + 35000 UNIT(-UNIT(($\overline{VM}$* $\overline{RM}$)*$\overline{RM}$))
DEC = $\sin^{-1}$ (RS_Z/RS)
\|DEC\| - 25
-
+
INCR = -.3\|DEC\| + 37.5
INTER = 1
DEC
+
-
INCR = 31.5
INTER = 1
INCR = 30
INTER = 1
DEC
-
+
SGM = + 1
LAT = 29.8
LONG = 264.55
SGM = -1
LAT = -31.367
LONG = 136.886
ENTER INSIDE MIDCOURSE AND ORBITAL SUBROUTINE, RETURN $\overline{RL}$, $\overline{RR}$, $\overline{RS}$, $\overline{RSM}$, TFH, TFE, TL, $\overline{VL}$, $\overline{VRC}$, $\overline{RM}$, $\overline{VM}$, $\overline{VS}$, TS, VSS
EXIT
PERIOD = $2\pi\sqrt{1/AC^3MU}$
TAGG = 0.
MODE:1
yes
no
PERIOD: 10
no
yes
ENTER OUTSIDE MIDCOURSE SUBROUTINE AND TIME CRITICAL OR FUEL CRITICAL RETURN WITH $\overline{RF}$, TF, $\overline{VR}$
ENTER OUTSIDE ORBITAL SUBROUTINE AND RETURN WITH TF, $\overline{RF}$, $\overline{VR}$
ENTER OUTSIDE MIDCOURSE LANDING SITE SUBROUTINE AND RETURN WITH TF, $\overline{RF}$, $\overline{VR}$
ENTER PRECISION TRAJECTORY CALCULATION FOR OUTSIDE SPHERE. RETURN WITH PRECISION LAUNCH VELOCITY, $\overline{VL}$

SUBROUTINE: CIRCUM

PURPOSE: To generate the abort trajectory which enters the moon's sphere of influence, passes around the moon, and returns to the earth with acceptable re-entry conditions.

CALLING SEQUENCE: CALL CIRCUM

NAME COMMON USED:
INPUT
AINPUT
C0NST
INDS
BURNPR
RVM00N
INTGR
INM0C
INTGRK

SUBROUTINES REQUIRED: JPLEPH, LAMBS, LSCR, VCMSC

FUNCTIONS REQUIRED: ARC0S, ARSIN, ATAN2, C0S, SIN, SQRT, ABS

APPROXIMATE STORAGE: 2964

SUBROUTINE: CIRCUM

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	AINPUT	MØDE	1			MØDE = 1, landing site. MØDE = 2, time critical. MØDE = 3. fuel critical.
I	AINPUT	DV	1	ΔV	er/hr	The maximum allowable change in velocity.
I	AINPUT	RR	1	$\bar{R}_R$	er	Magnitude of the re-entry position vector.
I	AINPUT	RPMIN	1	R_{PMIN}	er	Minimum allowable lunar pericynthian altitude.
I	AINPUT	URMAX	1	U_{RMAX}	er/hr	Maximum allowable re-entry velocity magnitude.
I	INTGR	TA	1	T_A	hr	Time of abort measured from initial time.
I	INTGR	RØ	6	$\bar{R}$	er	Position of the vehicle at time TA (ECI).
I	INTGR	VØ	6	$\bar{V}$	er/hr	Velocity of the vehicle at time TA (ECI).
I	CØNST	EMU	1	μ_E	er^3/hr^2	Gravitational parameter of the earth: 19.9094165
I	CØNST	PMU	1	μ_M	er^3/hr^2	Gravitational parameter of the moon: .244883757
I	CØNST	USSTER	1		$\frac{\text{statute mi.}}{\text{er}}$	Conversion factor: 3963.20799
I	CØNST	RADIAN	1		deg/rad	Conversion factor: 57.2957795

SUBROUTINE: CIRCUM (continued)

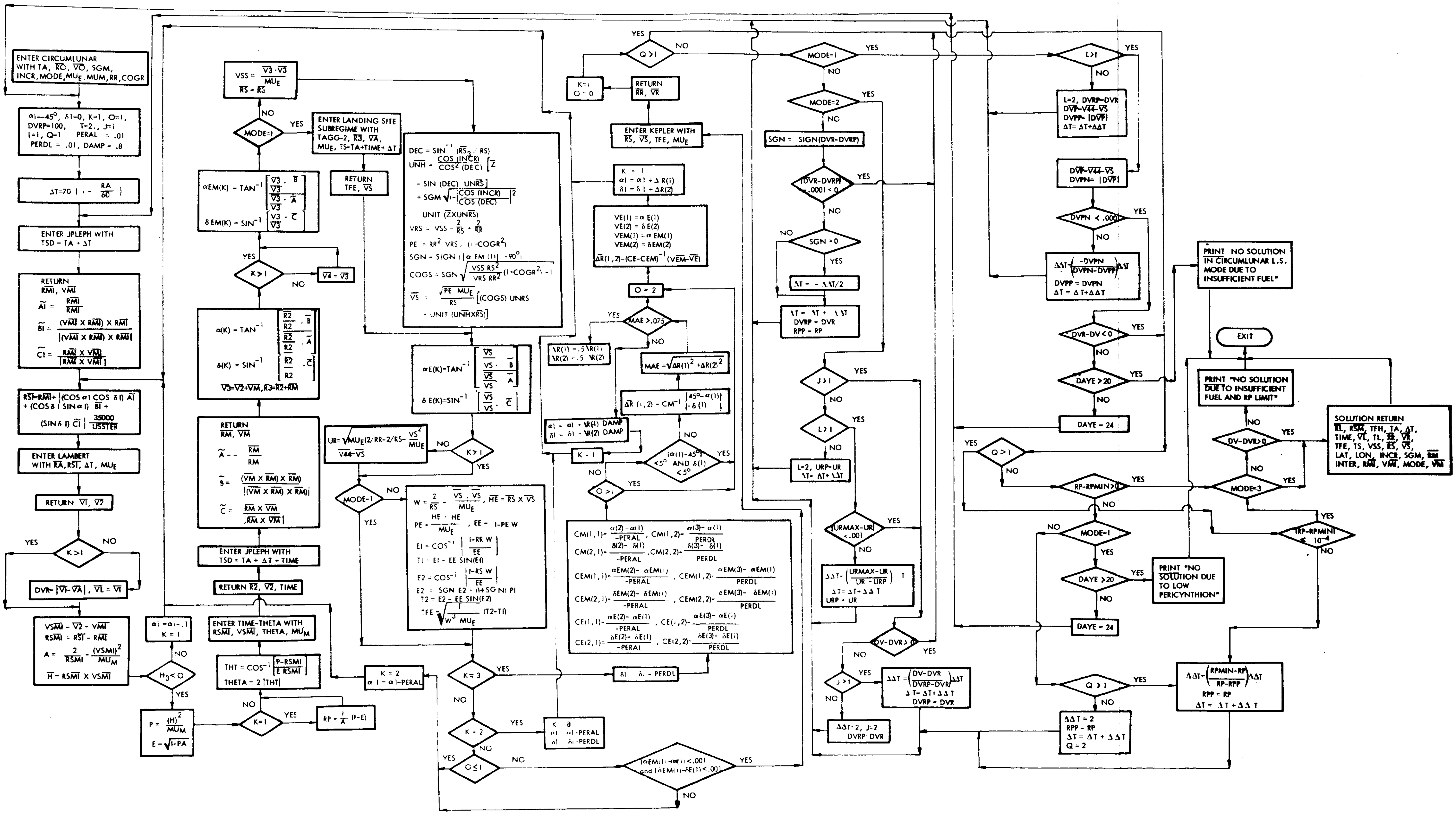
INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	CØNST	SGMM	1		± 1	SGMM = + 1 for $\theta > 180^\circ$ SGMM = - 1 for $\theta < 180^\circ$
I	INMØC	INCR	1	i_R	rad	Desired inclination of the return trajectory.
I	INMØC	INTER	1		± 1	Designator of the preselected intersection of the landing site with the return plane.
I	INMØC	SGM	1		± 1	Designator of the preselected return plane.
Ø	INMØC	RL	4	$\bar{R}_L$	er	The position vector relative to the earth at time of burn initiation.
Ø	INMØC	RSM	4	$\bar{R}_{SM}$	er	Position relative to the moon at lunar sphere of action (outgoing).
Ø	INMØC	VL	4	$\bar{V}_L$	er/hr	Velocity relative to the moon at time of burn initiation.
Ø	INMØC	RRV	4	$\bar{R}_R$	er	Desired re-entry position vector.
Ø	INMØC	VR	4	$\bar{V}_R$	er/hr	The required velocity at re-entry.
Ø	INMØC	RS	4	$\bar{R}_S$	er	Position at the shift relative to the earth (outgoing).
Ø	INMØC	VS	4	$\bar{V}_S$	er/hr	Velocity at the shift relative to the earth (outgoing).
Ø	INMØC	TFH	1	T_{FH}	hr	Time from R_L to R_{SM}.

SUBROUTINE: CIRCUM (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
0	INM0C	DELT	1	ΔT	hr	Time from abort to first pierce point at lunar sphere of influence.
0	INTGRK	TIME	1	TIME	hr	Time required to go from entry to exit in the lunar sphere of influence.
0	INM0C	TL	1	T_L	hr	Time of burn initiation.
0	INM0C	TFE	1	T_{FE}	hr	Time of flight from $\bar{R}_S$ to $\bar{R}_R$.
0	INM0C	TS	1	T_S	hr	Time of arrival at the lunar sphere of influence (outgoing).
0	INM0C	VSS	1	V_{SS}	1/er	Square of the velocity divided by μ_E relative to the earth at the lunar sphere of influence.
0		DVR	1	ΔV_R	er/hr	The required change in velocity to achieve the abort trajectory.
0		UR	1	U_R	er/hr	The required re-entry velocity.
0	RVM00N	RM	6	$\bar{R}_M$	er	Moon's position at time TA + ΔT + TIME.
0	RVM00N	VM	6	$\bar{V}_M$	er/hr	Moon's velocity at time TA + ΔT + TIME.
0	INM0C	RM1	6	$\bar{R}_{M1}$	er	Moon's position at time TA + ΔT.
0	INM0C	VM1	6	$\bar{V}_{M1}$	er/hr	Moon's velocity at time TA + ΔT.



ENTER CIRCUMLUNAR WITH TA, $\overline{RO}$, $\overline{VO}$, SGM, INCR, MODE, MU_E, MUM, RR, COGR
$\alpha i = -45^\circ$, $\delta 1 = 0$, K=1, O=1, DVRP=100, T=2., J=1, L=1, Q=1, PERAL = .01, PERDL = .01, DAMP = .8
$\Delta T = 70\,(1 - \frac{RA}{60})$
ENTER JPLEPH WITH TSD = TA + ΔT
RETURN $\overline{RMI}$, $\overline{VMI}$
$\tilde{AI} = \frac{\overline{RMI}}{RMI}$
$\tilde{BI} = \frac{(\overline{VMI} \times \overline{RMI}) \times \overline{RMI}}{|(\overline{VMI} \times \overline{RMI}) \times \overline{RMI}|}$
$\tilde{CI} = \frac{\overline{RMI} \times \overline{VMI}}{|\overline{RMI} \times \overline{VMI}|}$
$\overline{RSI} = \overline{RMI} + [(\cos\alpha 1 \cos\delta 1)\,\tilde{AI} + (\cos\delta 1 \sin\alpha 1)\,\tilde{BI} + (\sin\delta 1)\,\tilde{CI}]\,\frac{35000}{USSTER}$
ENTER LAMBERT WITH $\overline{RA}$, $\overline{RSI}$, ΔT, MU_E
RETURN $\overline{VI}$, $\overline{V2}$
K > 1
YES
NO
DVR = $|\overline{VI} - \overline{VA}|$, $\overline{VL} = \overline{VI}$
$\overline{VSMI} = \overline{V2} - \overline{VMI}$
$\overline{RSMI} = \overline{RSI} - \overline{RMI}$
$A = \frac{2}{RSMI} - \frac{(VSMI)^2}{MU_M}$
$\overline{H} = \overline{RSMI} \times \overline{VSMI}$
$H_3 < 0$
YES
NO
$\alpha i = \alpha i - .1$
K = 1
$P = \frac{(H)^2}{MU_M}$
$E = \sqrt{1 - PA}$
K=1
YES
NO
$RP = \frac{1}{A}(1-E)$
$VSS = \frac{\overline{V3} \cdot \overline{V3}}{MU_E}$
$\overline{RS} = \overline{R3}$
MODE=1
NO
YES
ENTER LANDING SITE SUBREGIME WITH TAGG=2, $\overline{R3}$, $\overline{VA}$, MU_E, TS=TA+TIME+ΔT
RETURN TFE, $\overline{VS}$
$\alpha EM(K) = \tan^{-1}\left[\frac{\overline{V3}\cdot\tilde{B}}{V3} \Big/ \frac{\overline{V3}\cdot\tilde{A}}{V3}\right]$
$\delta EM(K) = \sin^{-1}\left[\frac{\overline{V3}\cdot\tilde{C}}{V3}\right]$
K > 1
YES
NO
$\overline{V4} = \overline{V3}$
$\alpha(K) = \tan^{-1}\left[\frac{\overline{R2}\cdot\tilde{B}}{R2} \Big/ \frac{\overline{R2}\cdot\tilde{A}}{R2}\right]$
$\delta(K) = \sin^{-1}\left[\frac{\overline{R2}\cdot\tilde{C}}{R2}\right]$
$\overline{V3} = \overline{V2} + \overline{VM}$, $\overline{R3} = \overline{R2} + \overline{RM}$
RETURN $\overline{RM}$, $\overline{VM}$
$\tilde{A} = \frac{\overline{RM}}{RM}$
$\tilde{B} = \frac{(\overline{VM} \times \overline{RM}) \times \overline{RM}}{|(\overline{VM} \times \overline{RM}) \times \overline{RM}|}$
$\tilde{C} = \frac{\overline{RM} \times \overline{VM}}{|\overline{RM} \times \overline{VM}|}$
ENTER JPLEPH WITH TSD = TA + ΔT + TIME
RETURN $\overline{R2}$, $\overline{V2}$, TIME
ENTER TIME-THETA WITH $\overline{RSMI}$, $\overline{VSMI}$, THETA, MU_M
$THT = \cos^{-1}\left|\frac{P - RSMI}{E\ RSMI}\right|$
THETA = 2 |THT|
K = 2
α 1 = α 1 - PERAL
$DEC = \sin^{-1}(\overline{RS}_3 / RS)$
$\overline{UNH} = \frac{\cos(INCR)}{\cos^2(DEC)}\left[\tilde{Z} - \sin(DEC)\ \overline{UNRS}\right] + SGM\sqrt{1 - \left[\frac{\cos(INCR)}{\cos(DEC)}\right]^2}\ \mathrm{UNIT}(\tilde{Z} \times \overline{UNRS})$
$VRS = VSS - \frac{2}{RS} + \frac{2}{RR}$
$PE = RR^2\ VRS\ (1 - COGR^2)$
$SGN = SIGN\,(|\alpha EM(1)| - 90^\circ)$
$COGS = SGN\sqrt{\frac{VSS\ RS^2}{VRS\ RR^2}(1 - COGR^2) - 1}$
$\overline{VS} = \frac{\sqrt{PE\ MU_E}}{RS}\left[(COGS)\ \overline{UNRS} + \mathrm{UNIT}(\overline{UNH} \times \overline{RS})\right]$
$\alpha E(K) = \tan^{-1}\left[\frac{\overline{VS}\cdot\tilde{B}}{VS} \Big/ \frac{\overline{VS}\cdot\tilde{A}}{VS}\right]$
$\delta E(K) = \sin^{-1}\left[\frac{\overline{VS}\cdot\tilde{C}}{VS}\right]$
$UR = \sqrt{MU_E(2/RR - 2/RS - \frac{VS^2}{MU_E})}$
$\overline{V44} = \overline{VS}$
K > 1
NO
YES
MODE=1
NO
YES
$W = \frac{2}{RS} - \frac{\overline{VS}\cdot\overline{VS}}{MU_E}$, $\overline{HE} = \overline{RS} \times \overline{VS}$
$PE = \frac{HE \cdot HE}{MU_E}$, $EE = 1 - PE\ W$
$E1 = \cos^{-1}\left|\frac{1 - RR\ W}{EE}\right|$
T1 = E1 - EE SIN(E1)
$E2 = \cos^{-1}\left|\frac{1 - RS\ W}{EE}\right|$
E2 = SGN E2 + (1+SGN) PI
T2 = E2 - EE SIN(E2)
$TFE = \sqrt{\frac{1}{W^3\ MU_E}}\ (T2 - T1)$
K = 3
YES
NO
K = 2
YES
NO
K = 3
α1 = α1 - PERAL
δ1 = δ1 - PERDL
C ≤ 1
YES
NO
$|\alpha EM(1) - \alpha E(1)| < .001$ and $|\delta EM(1) - \delta E(1)| < .001$
YES
NO
δ1 = δ1 - PERDL
Q > 1
YES
NO
K = 1
O = 0
RETURN RR, $\overline{VR}$
ENTER KEPLER WITH $\overline{RS}$, $\overline{VS}$, TFE, MU_E
K = 1
α1 = α1 + ΔR(1)
δ1 = δ1 + ΔR(2)
VE(1) = α E(1)
VE(2) = δ E(2)
VEM(1) = α EM(1)
VEM(2) = δ EM(2)
$\overline{\Delta R}(1,2) = (CE - CEM)^{-1}\,(\overline{VEM} - \overline{VE})$
O = 2
MAE > .075
YES
NO
ΔR(1) = .5 ΔR(1)
ΔR(2) = .5 ΔR(2)
$MAE = \sqrt{\Delta R(1)^2 + \Delta R(2)^2}$
$\overline{\Delta R}(1,2) = CM^{-1}\begin{Bmatrix}45^\circ - \alpha(1) \\ -\delta(1)\end{Bmatrix}$
α1 = α1 + ΔR(1) DAMP
δ1 = δ1 + ΔR(2) DAMP
K = 1
$|\alpha(1) - 45^\circ| < 5^\circ$ AND $\delta(1) < 5^\circ$
YES
NO
O > 1
YES
NO
$CM(1,1) = \frac{\alpha(2) - \alpha(1)}{-PERAL}$, $CM(1,2) = \frac{\alpha(3) - \alpha(1)}{PERDL}$
$CM(2,1) = \frac{\delta(2) - \delta(1)}{-PERAL}$, $CM(2,2) = \frac{\delta(3) - \delta(1)}{PERDL}$
$CEM(1,1) = \frac{\alpha EM(2) - \alpha EM(1)}{-PERAL}$, $CEM(1,2) = \frac{\alpha EM(3) - \alpha EM(1)}{PERDL}$
$CEM(2,1) = \frac{\delta EM(2) - \delta EM(1)}{-PERAL}$, $CEM(2,2) = \frac{\delta EM(3) - \delta EM(1)}{PERDL}$
$CE(1,1) = \frac{\alpha E(2) - \alpha E(1)}{-PERAL}$, $CE(1,2) = \frac{\alpha E(3) - \alpha E(1)}{PERDL}$
$CE(2,1) = \frac{\delta E(2) - \delta E(1)}{-PERAL}$, $CE(2,2) = \frac{\delta E(3) - \delta E(1)}{PERDL}$
MODE=1
YES
NO
MODE=2
YES
NO
SGN = SIGN(DVR-DVRP)
|DVR-DVRP| - .0001 < 0
YES
NO
SGN > 0
YES
NO
ΔT = - ΔT/2
ΔT = ΔT + ΔT
DVRP = DVR
RPP = RP
J > 1
YES
NO
L > 1
YES
NO
L=2, URP=UR
ΔT = ΔT + ΔT
|URMAX-UR| < .001
YES
NO
$\Delta\Delta T = \left(\frac{URMAX - UR}{UR - URP}\right) T$
ΔT = ΔT + ΔΔT
URP = UR
DV-DVR > 0
YES
NO
J > 1
YES
NO
$\Delta\Delta T = \left(\frac{DV - DVR}{DVRP - DVR}\right)\Delta\Delta T$
ΔT = ΔT + ΔΔT
DVRP = DVR
ΔΔT = 2, J=2
DVRP = DVR
L > 1
YES
NO
L=2, DVRP=DVR
$\overline{DVP} = \overline{V44} - \overline{VS}$
DVPP = |$\overline{DVP}$|
ΔT = ΔT + ΔΔT
$\overline{DVP} = \overline{V44} - \overline{VS}$
DVPN = |$\overline{DVP}$|
DVPN < .0001
YES
NO
$\Delta\Delta T = \left(\frac{-DVPN}{DVPN - DVPP}\right)\Delta\Delta T$
DVPP = DVPN
ΔT = ΔT + ΔΔT
DVR-DV < 0
YES
NO
DAYE > 20
YES
NO
DAYE = 24
PRINT "NO SOLUTION IN CIRCUMLUNAR L.S. MODE DUE TO INSUFFICIENT FUEL"
EXIT
PRINT "NO SOLUTION DUE TO INSUFFICIENT FUEL AND RP LIMIT"
NO
DV-DVR > 0
YES
NO
MODE=3
YES
SOLUTION RETURN $\overline{RL}$, $\overline{RSM}$, TFH, TA, ΔT, TIME, $\overline{VL}$, TL, $\overline{RR}$, $\overline{VR}$, TFE, TS, VSS, $\overline{RS}$, $\overline{VS}$, LAT, LON, INCR, SGM, $\overline{RM}$ INTER, $\overline{RMI}$, $\overline{VMI}$, MODE, $\overline{VM}$
Q > 1
YES
NO
RP-RPMIN > 0
YES
NO
$|RP - RPMIN| < 10^{-4}$
YES
NO
MODE=1
YES
NO
DAYE > 20
YES
NO
PRINT "NO SOLUTION DUE TO LOW PERICYNTHION"
DAYE = 24
Q > 1
YES
NO
$\Delta\Delta T = \left(\frac{RPMIN - RP}{RP - RPP}\right)\Delta\Delta T$
RPP = RP
ΔT = ΔT + ΔΔT
ΔΔT = 2
RPP = RP
ΔT = ΔT + ΔΔT
Q = 2

SUBROUTINE: ENCKE*

PURPOSE: To supply the control logic for the execution of the trajectory program.

CALLING SEQUENCE: CALL ENCKE (INDIC)

NAME COMMON USED*:
BURNPR
NAVERR
AINPUT
BLANK

SUBROUTINES REQUIRED*: PRINTI

FUNCTIONS REQUIRED: SQRT, ABS

APPROXIMATE STORAGE: 903

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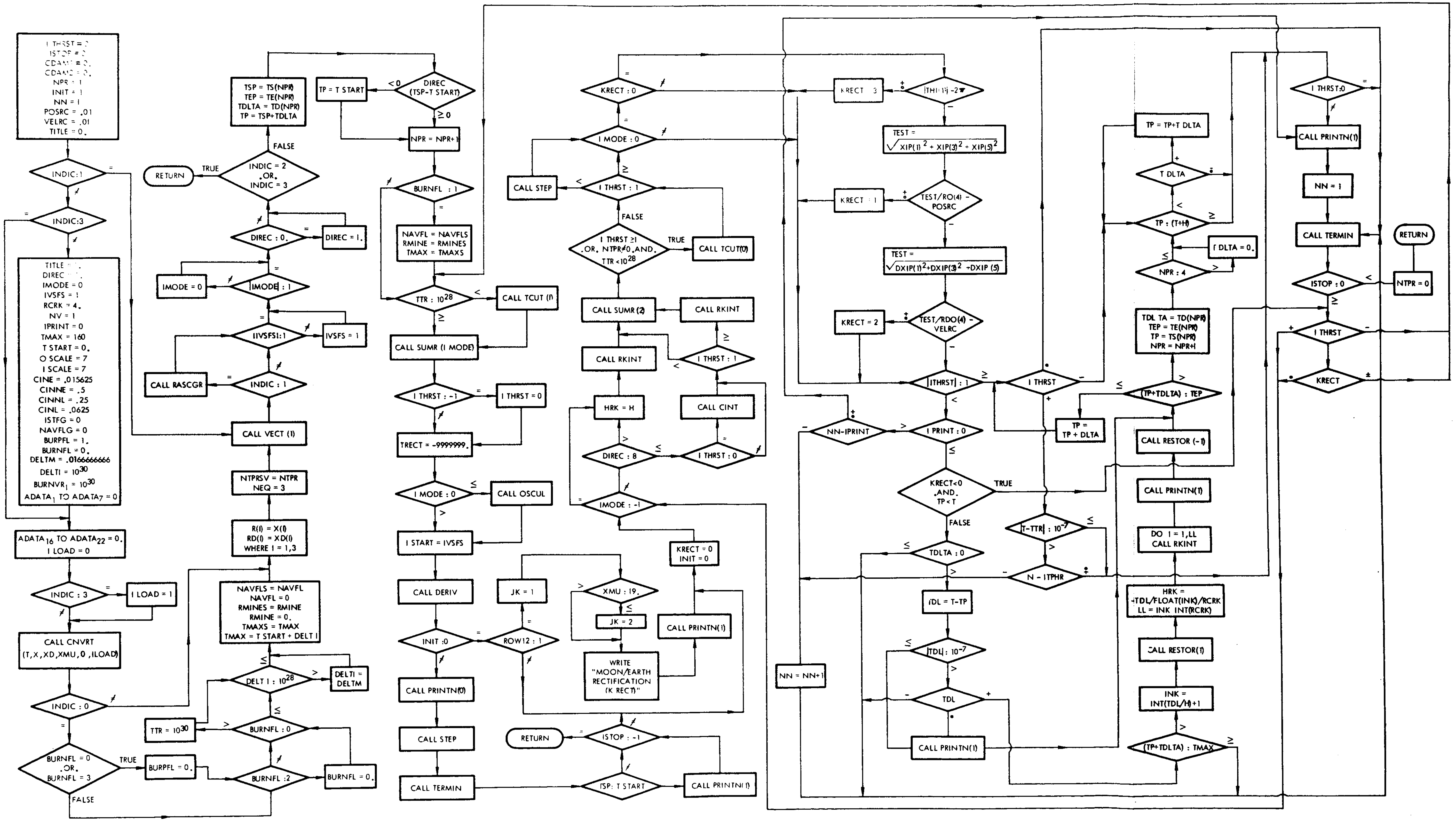
*Additional input/output of the ENCKE subroutine.

SUBROUTINE: ENCKE*

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	AINPUT	NAVFL	1			Input flag: = 1, compute navigation errors during thrust. = 0, do not compute navigation errors.
I	AINPUT	INSFG	1			= 0, for outside the sphere analytic modes. = 1, for inside the sphere analytic modes.
I	BURNPR	BURNVR	3	V_r	er/hr	The velocity required at burn termination of an impulsive burn.
I	BURNPR	BURNFL	1			= -1, non-iterative run. = 0, impulsive burn, no burn print. = 2, impulsive burn, burn print. = 3, integrated burn, no burn print. = 4, integrated burn, burn print.
I	BURNPR	DELTI	1	ΔT	hrs	Minimum time from epoch to abort. = .016666666 unless input.
O	BURNPR	NTPRSV	1			The input value of the number of thrust periods.

*Additional input/output of the ENCKE subroutine.


I THRST = 0
ISTOP = 0
CDAM1 = 0.
CDAM2 = 0.
NPR = 1
INIT = 1
NN = 1
POSRC = .01
VELRC = .01
TITLE = 0.
INDIC:1
INDIC:3
TITLE = 1.
DIREC = 1.
IMODE = 0
IVSFS = 1
RCRK = 4.
NV = 1
IPRINT = 0
TMAX = 160
T START = 0.
O SCALE = 7
I SCALE = 7
CINE = .015625
CINNE = .5
CINNL = .25
CINL = .0625
ISTFG = 0
NAVFLG = 0
BURPFL = 1.
BURNFL = 0.
DELTM = .0166666666
DELTI = 10^30
BURNVR1 = 10^30
ADATA1 TO ADATA7 = 0
ADATA16 TO ADATA22 = 0.
I LOAD = 0
INDIC : 3
I LOAD = 1
CALL CNVRT (T,X,XD,XMU,0 ,ILOAD)
INDIC : 0
BURNFL = 0 .OR. BURNFL = 3
TRUE
FALSE
BURPFL = 0.
RETURN
TRUE
INDIC = 2 .OR. INDIC = 3
FALSE
TSP = TS(NPR)
TEP = TE(NPR)
TDLTA = TD(NPR)
TP = TSP+TDLTA
DIREC : 0.
DIREC = 1.
IMODE = 0
IMODE : 1
IIVSFSI:1
IVSFS = 1
CALL RASCGR
INDIC : 1
CALL VECT (1)
NTPRSV = NTPR
NEQ = 3
R(I) = X(I)
RD(I) = XD(I)
WHERE I = 1,3
NAVFLS = NAVFL
NAVFL = 0
RMINES = RMINE
RMINE = 0.
TMAXS = TMAX
TMAX = T START + DELT I
DELT I : 10^28
DELTI = DELTM
TTR = 10^30
BURNFL : 0
BURNFL :2
BURNFL = 0.
TP = T START
DIREC (TSP-T START)
NPR = NPR+1
BURNFL : 1
NAVFL = NAVFLS
RMINE = RMINES
TMAX = TMAXS
TTR : 10^28
CALL TCUT (I)
CALL SUMR (I MODE)
I THRST : -1
I THRST = 0
TRECT = -9999999.
I MODE : 0
CALL OSCUL
I START = IVSFS
CALL DERIV
INIT :0
ROW12 : 1
JK = 1
CALL PRINTN(0)
CALL STEP
CALL TERMIN
KRECT : 0
I MODE : 0
CALL STEP
I THRST : 1
FALSE
I THRST ≥1 .OR. NTPR≠0 .AND. TTR <10^28
TRUE
CALL TCUT(0)
CALL SUMR (2)
CALL RKINT
CALL RKINT
I THRST : 1
HRK = H
CALL CINT
DIREC : 8
I THRST : 0
IMODE : -1
KRECT = 0
INIT = 0
XMU : 19.
JK = 2
CALL PRINTN(1)
WRITE "MOON/EARTH RECTIFICATION (K RECT)"
RETURN
ISTOP : -1
TSP: T START
CALL PRINTN(1)
KRECT 3
|THI(1)| -2π
TEST = √(XIP(1)^2 + XIP(3)^2 + XIP(5)^2)
KRECT = 1
TEST/RO(4) - POSRC
TEST = √(DXIP(1)^2+DXIP(3)^2 +DXIP (5))
KRECT = 2
TEST/RDO(4) - VELRC
|ITHRST| : 1
NN-IPRINT
I PRINT : 0
KRECT<0 .AND. TP<T
TRUE
FALSE
TDLTA : 0
IDL = T-TP
|TDL| : 10^-7
TDL
CALL PRINTN(1)
NN = NN+1
I THRST
TP = TP + DLTA
|T-TTR| : 10^-7
N - ITPHR
TP = TP+T DLTA
T DLTA
TP : (T+H)
T DLTA = 0.
NPR : 4
TDL TA = TD(NPR)
TEP = TE(NPR)
TP = TS(NPR)
NPR = NPR+1
(TP+TDLTA) : TEP
CALL RESTOR (-1)
CALL PRINTN(1)
DO I = 1,LL
CALL RKINT
HRK = -TDL/FLOAT(INK)/RCRK
LL = INK INT(RCRK)
CALL RESTOR(1)
INK = INT(TDL/H)+1
(TP+TDLTA) : TMAX
I THRST:0
CALL PRINTN(1)
NN = 1
CALL TERMIN
RETURN
ISTOP : 0
NTPR = 0
I THRST
KRECT

SUBROUTINE:	INITAL
PURPOSE:	To initialize navigation equation parameters. Execution of the subroutine occurs before integration begins.
CALLING SEQUENCE:	CALL INITAL (DELTAT, VSIN)
NAME COMMON USED:	VEH AINPUT VEHICL INDS NAVERR
SUBROUTINES REQUIRED:	VCMSC
FUNCTIONS REQUIRED:	None
APPROXIMATE STORAGE:	160

SUBROUTINE: INITAL

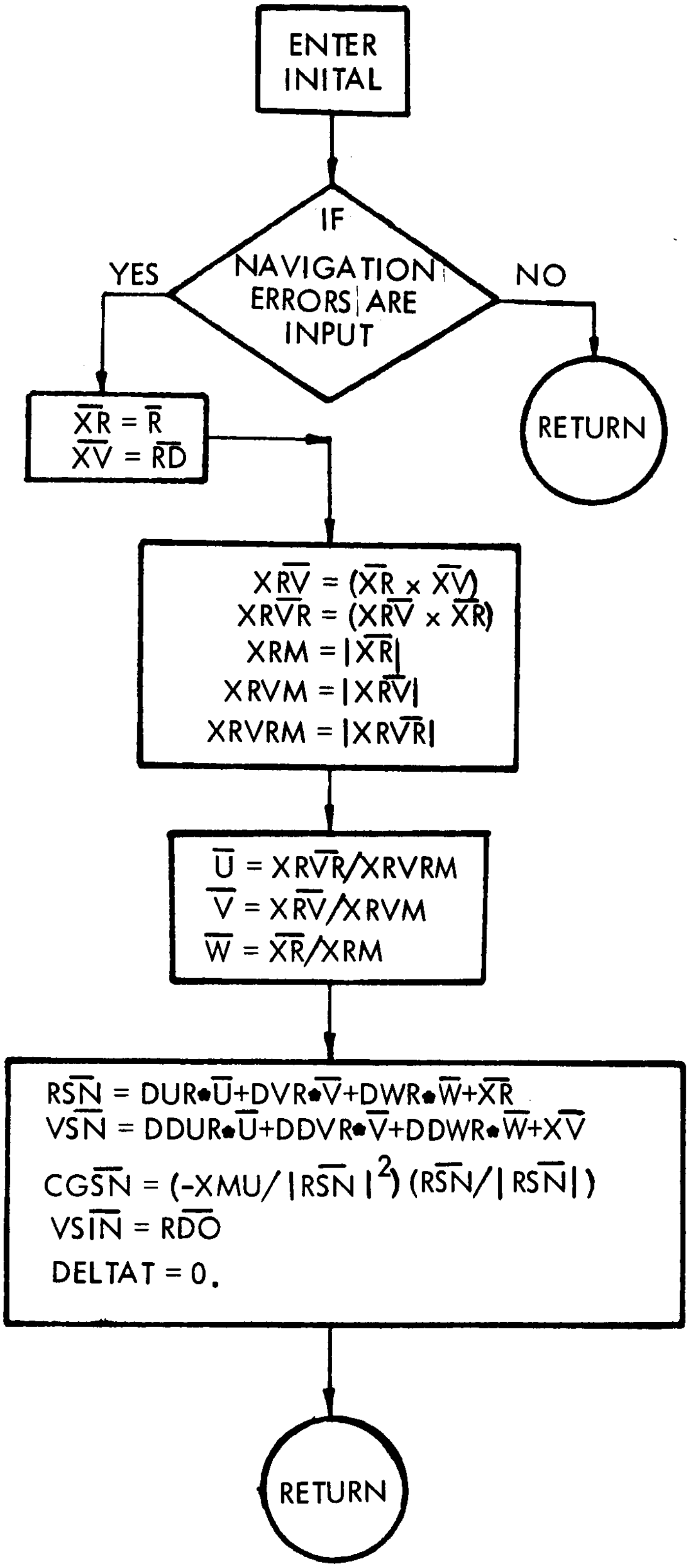
INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	AINPUT	NAVFL	1			Input flag to use navigation equations.
I	AINPUT	DUR	1	ΔU_R	er	Input position error navigation equations.
I	AINPUT	DVR	1	ΔV_R	er	Input position error navigation equations.
I	AINPUT	DWR	1	ΔW_R	er	Input position error navigation equations.
I	AINPUT	DDUR	1	$\Delta \dot{U}_R$	er/hr	Input velocity error navigation equations.
I	AINPUT	DDVR	1	$\Delta \dot{V}_R$	er/hr	Input velocity error navigation equations.
I	AINPUT	DDWR	1	$\Delta \dot{W}_R$	er/hr	Input velocity error navigation equations.
0	AINPUT	RSN	4	$\bar{R}_N$	er	Position vector for navigation equations.
0	AINPUT	VSN	3	$\bar{V}_N$	er/hr	Velocity vector for navigation equations.
I	INDS	XMU	1	μ	er^3/hr^2	Gravitational parameter of the central body.
0	NAVERR	CGSN	3	G_N	er/hr^2	Gravitational acceleration for the navigation equations.
0	NAVERR	ISTFG	1			= 1 use navigation equations.

SUBROUTINE: INITAL (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	VEH	R	12	$\bar{R}$	er	Double precision position vector.
I	VEH	RD	12	$\dot{\bar{R}}$	er/hr	Double precision velocity vector.
I	VEHICL	RD0	12	$\dot{\bar{R}}$	er/hr	Single precision velocity vector.
0		DELTAT	1	ΔT	hrs	Time increment.
0		VSIN	3	$\bar{V}_{IN}$	er/hr	Integrated navigation equations velocity.


ENTER INITAL
IF NAVIGATION ERRORS ARE INPUT
YES
NO
RETURN
$\overline{XR} = \overline{R}$
$\overline{XV} = \overline{RD}$
$X\overline{RV} = (\overline{XR} \times \overline{XV})$
$XRV\overline{R} = (X\overline{RV} \times \overline{XR})$
$XRM = |\overline{XR}|$
$XRVM = |X\overline{RV}|$
$XRVRM = |XRV\overline{R}|$
$\overline{U} = XRV\overline{R}/XRVRM$
$\overline{V} = X\overline{RV}/XRVM$
$\overline{W} = \overline{XR}/XRM$
$RS\overline{N} = DUR \bullet \overline{U} + DVR \bullet \overline{V} + DWR \bullet \overline{W} + \overline{XR}$
$VS\overline{N} = DDUR \bullet \overline{U} + DDVR \bullet \overline{V} + DDWR \bullet \overline{W} + X\overline{V}$
$CGS\overline{N} = (-XMU/|RS\overline{N}|^2)(RS\overline{N}/|RS\overline{N}|)$
$VS\overline{IN} = RD\overline{O}$
DELTAT = 0.
RETURN

SUBROUTINE: INMØ

PURPOSE: To patch two conics, one relative to the earth and one relative to the moon, at the lunar sphere of influence to produce a return trajectory to the earth. The conics generated satisfy the constraints imposed by the designated mode. This regime of operation is used only when the spacecraft is within the moon's sphere of influence.

CALLING SEQUENCE: CALL INMØ (LAT, LØNG, TAG2)

NAME COMMON USED:
INTGR
AINPUT
CØNST
VEH
INPUT
BURNPR
INDS
INTGRK
RVMØØN
INMØC
DINTGR
IØUT

SUBROUTINES REQUIRED: ENCKE, JPLEPH, LAMBS, LSCR, RASCGR, VCMSC, LATLØN

FUNCTIONS REQUIRED: CØS, SIN, SQRT, ABS

APPROXIMATE STORAGE: 3169

SUBROUTINE: INMØ

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	INTGR	RØ	6	$\bar{R}_o$	er	Position of spacecraft at time TA with respect to the earth.
I	INTGR	VØ	6	$\bar{V}_o$	er/hr	Velocity at time TA.
I	INTGR	TA	1	T_A	hr	Time of abort initiation measured from initial time.
I	AINPUT	DV	1	ΔV	er/hr	The maximum allowable change in velocity.
I		LAT	1	LAT	deg	Latitude of the preselected landing site.
I		LØNG	1	LØNG	deg	Longitude of the preselected landing site.
I	AINPUT	MØDE	1			MØDE = 1, landing site. MØDE = 2, time critical. MØDE = 3, fuel critical.
I	INMØC	INCR	1	i_r	rad	Return inclination.
I	INMØC	SGM	1		± 1	Designator of the return plane.
I	INMØC	INTER	1		± 1	Designator of the return plane intersection with the landing site.
I	CØNST	EMU	1	μ_E	er^3/hr^2	Gravitational parameter of the earth: 19.9094165
I	CØNST	PMU	1	μ_M	er^3/hr^2	Gravitational parameter of the moon: .244883757

SUBROUTINE: INMØ (continued)

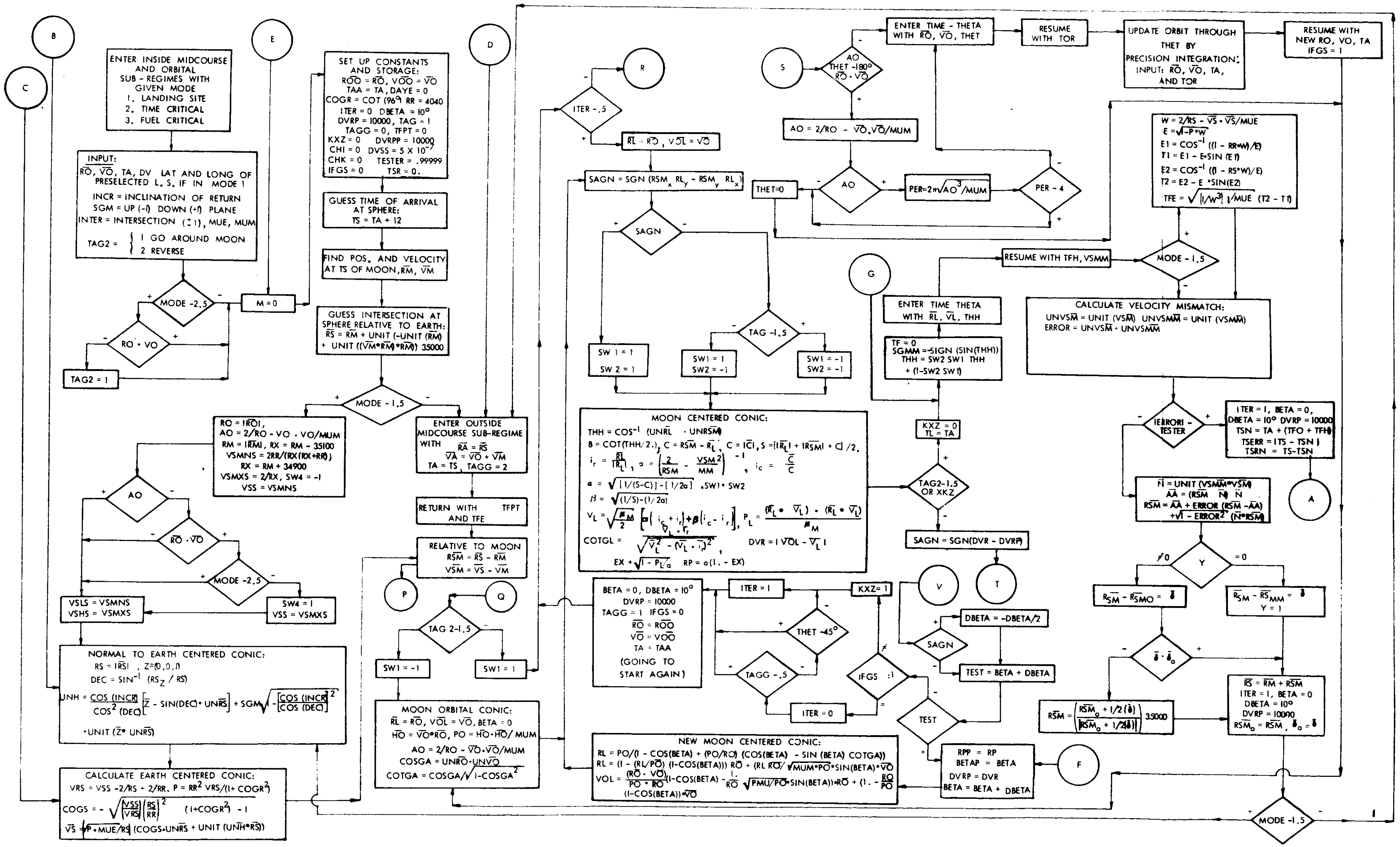
INPUT AND OUTPUT:

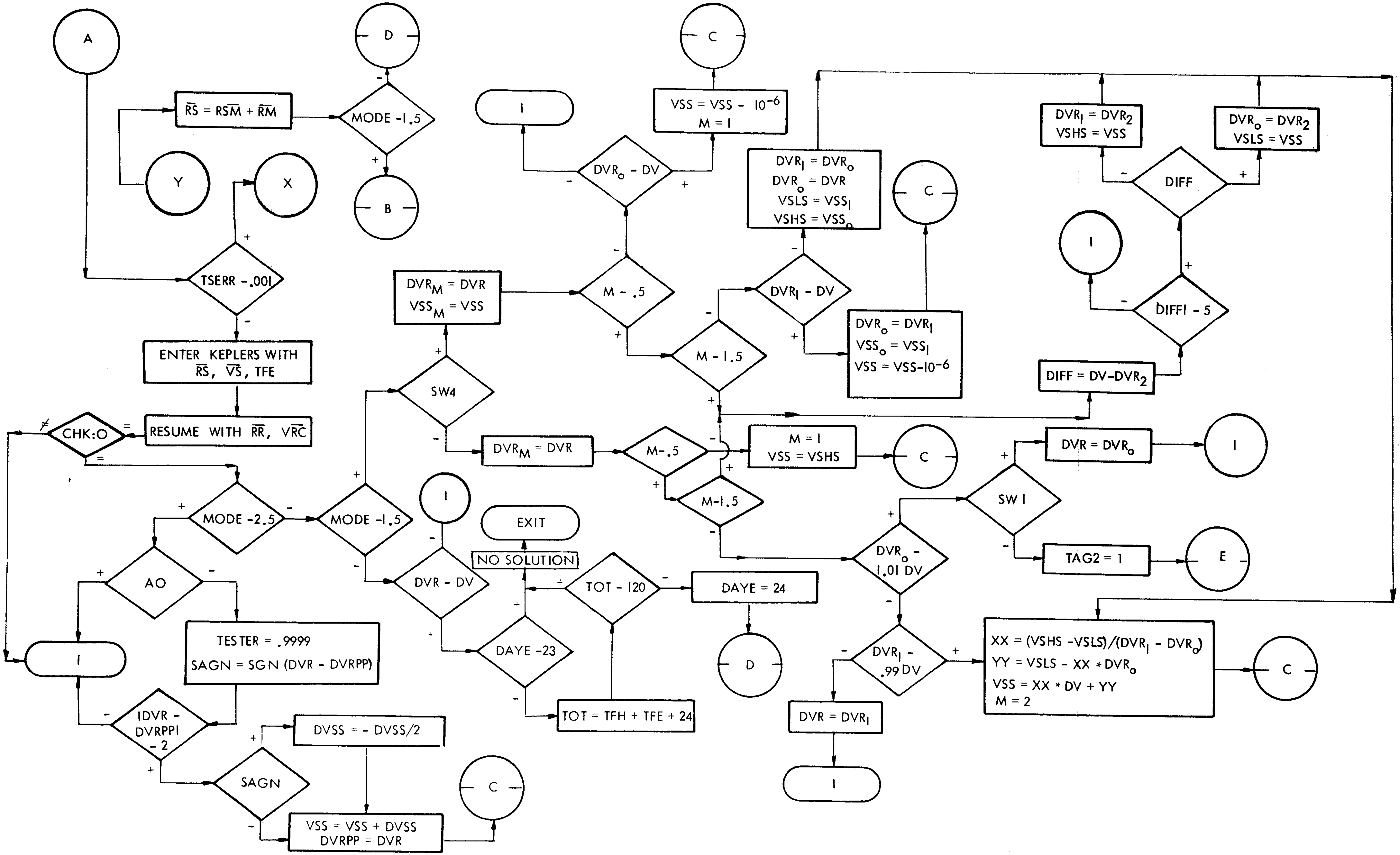
I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I		TAG2	1			TAG2 = 1, go around moon. TAG2 = 2, reverse.
I	AINPUT	RR	1	$\lvert\bar{R}_R\rvert$	er	Magnitude of the re-entry position vector.
I	AINPUT	CØGR	1	ctn γ_R		Cotangent of the re-entry flight path angle. cot (96°)
I	AINPUT	RPMIN	1	R_{PMIN}	er	Minimum allowable altitude at lunar pericynthian.
I	AINPUT	IWATFG	1			Land mass number = 0 if nominal trajectory impacts on water.
Ø	INMØC	RL	4	$\bar{R}_L$	er	Position relative to the moon at time of burn initiation.
Ø	INMØC	RSM	4	$\bar{R}_{SM}$	er	Position relative to the moon at lunar sphere of influence.
Ø	INMØC	TFH	1	T_{FH}	hr	Time from $\bar{R}_L$ to $\bar{R}_{SM}$.
Ø	INMØC	TL	1	T_L	hr	Time of burn initiation.
Ø	INMØC	RRB	4	$\bar{R}_R$	er	Desired position vector at re-entry.
Ø	INMØC	VSS	1	V_{SS}	1/er	Square of the velocity divided by μ_E relative to the earth at the lunar sphere of influence.
Ø	INMØC	TFE	1	T_{FE}	hr	Time of flight from $\bar{R}_S$ to $\bar{R}_R$.

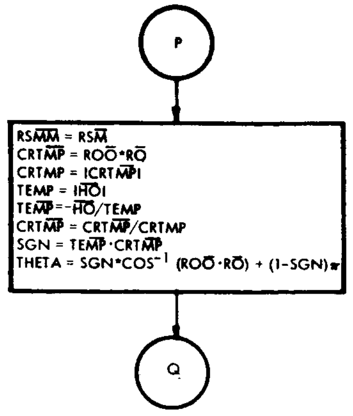
SUBROUTINE: INM0 (continued)

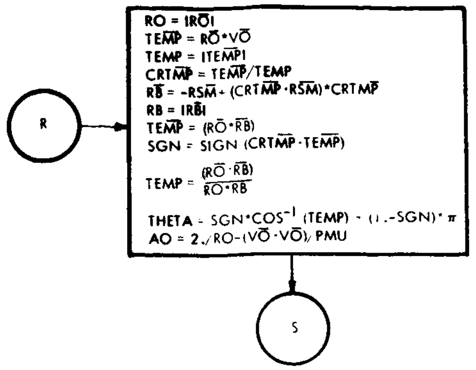
INPUT AND OUTPUT:

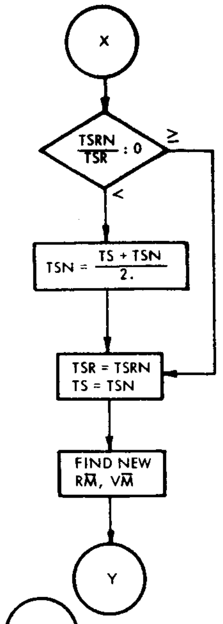
I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
0	INM0C	TS	1	T_S	hr	Time of arrival at the lunar sphere of influence.
0	BURNPR	BURNVR	3	$\bar{V}_B$	er/hr	Velocity at the end of burn.
0	INTGRK	TIME	1	TIME	hr	Time required to go from entry to exit in the lunar sphere of influence.
0		DVR	1	ΔV_R	er/hr	The required change in velocity to achieve the abort trajectory.
0	INTGR	TF	1	T_F	hr	Total time of flight.

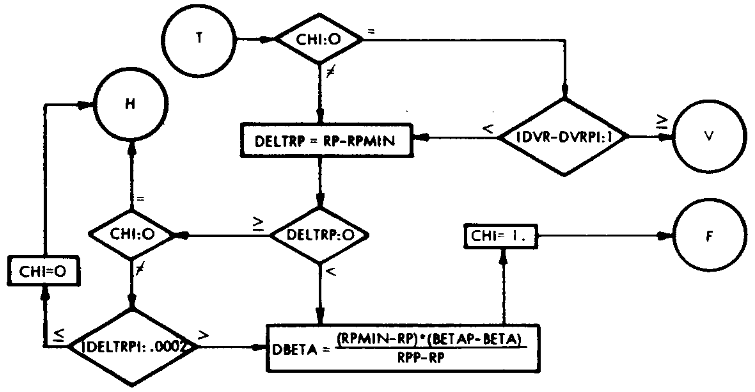

B
C
E
D
ENTER INSIDE MIDCOURSE AND ORBITAL SUB - REGIMES WITH GIVEN MODE
1. LANDING SITE
2. TIME CRITICAL
3. FUEL CRITICAL
INPUT:
RO, VO, TA, DV LAT AND LONG OF PRESELECTED L. S. IF IN MODE 1
INCR = INCLINATION OF RETURN
SGM = UP (-1) DOWN (+1) PLANE
INTER = INTERSECTION (±1), MUE, MUM
TAG2 = { 1 GO AROUND MOON / 2 REVERSE
MODE -2.5
+
-
RO · VO
TAG2 = 1
M = 0
SET UP CONSTANTS AND STORAGE:
ROO = RO, VOO = VO
TAA = TA, DAYE = 0
COGR = COT (96°) RR = 4040
ITER = 0 DBETA = 10°
DVRP = 10000, TAG = 1
TAGG = 0, TFPT = 0
KXZ = 0 DVRPP = 10000
CHI = 0 DVSS = 5 X 10^-7
CHK = 0 TESTER = .99999
IFGS = 0 TSR = 0.
GUESS TIME OF ARRIVAL AT SPHERE: TS = TA + 12
FIND POS. AND VELOCITY AT TS OF MOON, RM, VM
GUESS INTERSECTION AT SPHERE RELATIVE TO EARTH:
RS = RM + UNIT (-UNIT (RM) + UNIT ((VM*RM)*RM)) 35000
MODE - 1.5
RO = |RO|,
AO = 2/RO - VO · VO/MUM
RM = |RM|, RX = RM - 35100
VSMNS = 2RR/(RX(RX+RR))
RX = RM + 34900
VSMXS = 2/RX, SW4 = -1
VSS = VSMNS
AO
RO · VO
MODE -2.5
VSLS = VSMNS
VSHS = VSMXS
SW4 = 1
VSS = VSMXS
NORMAL TO EARTH CENTERED CONIC:
RS = |RS| , Z=(0,0,1)
DEC = SIN^-1 (RS_Z / RS)
UNH = COS (INCR)/COS^2 (DEC) [Z - SIN(DEC)* UNRS] + SGM √(1 - [COS (INCR)/COS (DEC)]^2) *UNIT (Z* UNRS)
CALCULATE EARTH CENTERED CONIC:
VRS = VSS -2/RS + 2/RR, P = RR^2 VRS/(1+ COGR^2)
COGS = - √((VSS/VRS)(RS/RR)^2 (1+COGR^2) - 1)
VS = √(P * MUE/RS) (COGS·UNRS + UNIT (UNH*RS))
ENTER OUTSIDE MIDCOURSE SUB-REGIME WITH RA = RS, VA = VO + VM, TA = TS, TAGG = 2
RETURN WITH TFPT AND TFE
RELATIVE TO MOON
RSM = RS - RM
VSM = VS - VM
P
Q
TAG 2-1.5
SW1 = -1
SW1 = 1
MOON ORBITAL CONIC:
RL = RO, VOL = VO, BETA = 0
HO = VO*RO, PO = HO·HO/ MUM
AO = 2/RO - VO·VO/MUM
COSGA = UNRO·UNVO
COTGA = COSGA/√(1-COSGA^2)
R
ITER -.5
RL = RO , VOL = VO
SAGN = SGN (RSM_x RL_y - RSM_y RL_x)
SAGN
TAG -1.5
SW 1 = 1
SW 2 = 1
SW1 = 1
SW2 = -1
SW1 = -1
SW2 = -1
MOON CENTERED CONIC:
THH = COS^-1 (UNRL · UNRSM)
B = COT(THH/2.), C = RSM - RL, C = |C|, S = (|RL| + |RSM| + C) /2.
i_r = RL/|RL|, a = (2/RSM - VSM^2/MM)^-1, i_c = C/C
α = √([1/(S-C)] - [1/2a]) *SW1* SW2
β = √((1/S)-(1/2a))
V_L = √(μ_M/2) [α(i_c + i_r) + β(i_c - i_r)], P_L = ((R_L · V_L) · (R_L · V_L))/μ_M
COTGL = V_L · r_r / √(V_L^2 - (V_L · i_r)^2),
DVR = | VOL - V_L |
EX + √(1 - P_L/a)   RP = a(1. - EX)
BETA = 0, DBETA = 10°
DVRP = 10000
TAGG = 1 IFGS = 0
RO = ROO
VO = VOO
TA = TAA
(GOING TO START AGAIN)
ITER = 1
KXZ= 1
THET -45°
TAGG -.5
IFGS :1
≠
=
ITER = 0
NEW MOON CENTERED CONIC:
RL = PO/(1 - COS(BETA) + (PO/RO) (COS(BETA) - SIN (BETA) COTGA))
RL = (1 - (RL/PO) (1-COS(BETA))) RO + (RL RO/ √(MUM*PO)*SIN(BETA)*VO
VOL = (RO · VO)/(PO * RO) (1-COS(BETA) - 1./RO √(PMU/PO)*SIN(BETA))*RO + (1. - RO/PO (1-COS(BETA))*VO
S
AO THET -180° RO · VO
ENTER TIME - THETA WITH RO, VO, THET
RESUME WITH TOR
UPDATE ORBIT THROUGH THET BY PRECISION INTEGRATION: INPUT: RO, VO, TA, AND TOR
RESUME WITH NEW RO, VO, TA IFGS = 1
AO = 2/RO - VO.VO/MUM
THET=0
AO
PER=2π√(AO^3/MUM)
PER - 4
W = 2/RS - VS · VS/MUE
E = √(1-P*W)
E1 = COS^-1 ((1 - RR*W)/E)
T1 = E1 - E*SIN (E1)
E2 = COS^-1 ((1 - RS*W)/E)
T2 = E2 - E *SIN(E2)
TFE = √(|1/W^3|) 1/MUE (T2 - T1)
G
RESUME WITH TFH, VSMM
MODE - 1.5
ENTER TIME THETA WITH RL, VL, THH
TF = 0
SGMM = -SIGN (SIN(THH))
THH = SW2 SW1 THH + (1-SW2 SW1)
CALCULATE VELOCITY MISMATCH:
UNVSM = UNIT (VSM) UNVSMM = UNIT (VSMM)
ERROR = UNVSM · UNVSMM
KXZ = 0
TL = TA
TAG2-1.5 OR XKZ
SAGN = SGN(DVR - DVRP)
V
T
DBETA = -DBETA/2
SAGN
TEST = BETA + DBETA
TEST
RPP = RP
BETAP = BETA
DVRP = DVR
BETA = BETA + DBETA
F
|ERROR| - TESTER
ITER = 1, BETA = 0,
DBETA = 10° DVRP = 10000
TSN = TA + (TFO + TFH)
TSERR = |TS - TSN|
TSRN = TS-TSN
A
N = UNIT (VSMM*VSM)
AA = (RSM · N) N
RSM = AA + ERROR (RSM -AA) +√(1 - ERROR^2) (N*RSM)
Y
≠0
=0
RSM - RSMO = δ
RSM - RS_MM = δ
Y = 1
δ · δ_o
RSM = ((RSM_o + 1/2 (δ))/|RSM_o + 1/2(δ)|) 35000
RS = RM + RSM
ITER = 1, BETA = 0
DBETA = 10°
DVRP = 10000
RSM_o = RSM , δ_o = δ
MODE -1.5
1

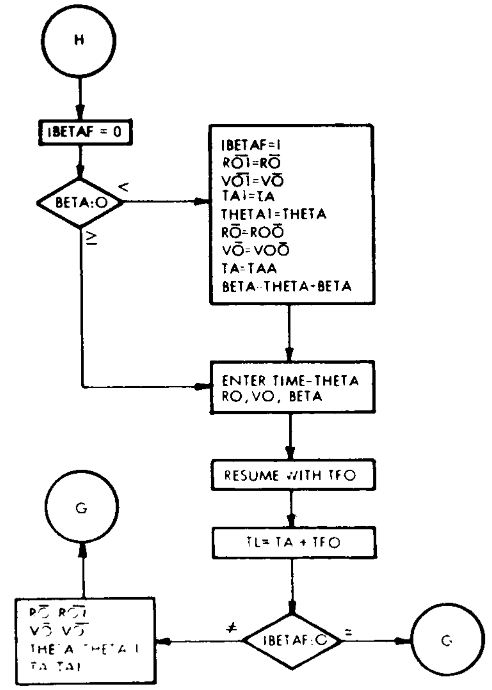

A
D
C
$\overline{RS} = RS\overline{M} + \overline{RM}$
MODE -1.5
-
+
I
DVR$_o$ - DV
VSS = VSS - 10^{-6}
M = 1
DVR$_I$ = DVR$_2$
VSHS = VSS
DVR$_o$ = DVR$_2$
VSLS = VSS
Y
X
B
DVR$_I$ = DVR$_o$
DVR$_o$ = DVR
VSLS = VSS$_I$
VSHS = VSS$_o$
C
DIFF
I
TSERR -.001
DVR$_M$ = DVR
VSS$_M$ = VSS
M - .5
DVR$_I$ - DV
DVR$_o$ = DVR$_I$
VSS$_o$ = VSS$_I$
VSS = VSS-10^{-6}
DIFFI - 5
ENTER KEPLERS WITH
$\overline{RS}$, $\overline{VS}$, TFE
M - 1.5
SW4
DIFF = DV-DVR$_2$
≠
CHK:O
=
RESUME WITH $\overline{RR}$, $V\overline{RC}$
DVR$_M$ = DVR
M-.5
M = 1
VSS = VSHS
C
DVR = DVR$_o$
I
M-1.5
SW I
MODE -2.5
MODE -1.5
I
EXIT
NO SOLUTION
TAG2 = 1
E
AO
DVR - DV
TOT - 120
DAYE = 24
DVR$_o$ -
1.01 DV
TESTER = .9999
SAGN = SGN (DVR - DVRPP)
DAYE -23
D
DVR$_I$ -
.99 DV
XX = (VSHS -VSLS)/(DVR$_I$ - DVR$_o$)
YY = VSLS - XX * DVR$_o$
VSS = XX * DV + YY
M = 2
C
I
IDVR -
DVRPPI
- 2
TOT = TFH + TFE + 24
DVR = DVR$_I$
DVSS = - DVSS/2
SAGN
C
VSS = VSS + DVSS
DVRPP = DVR
I

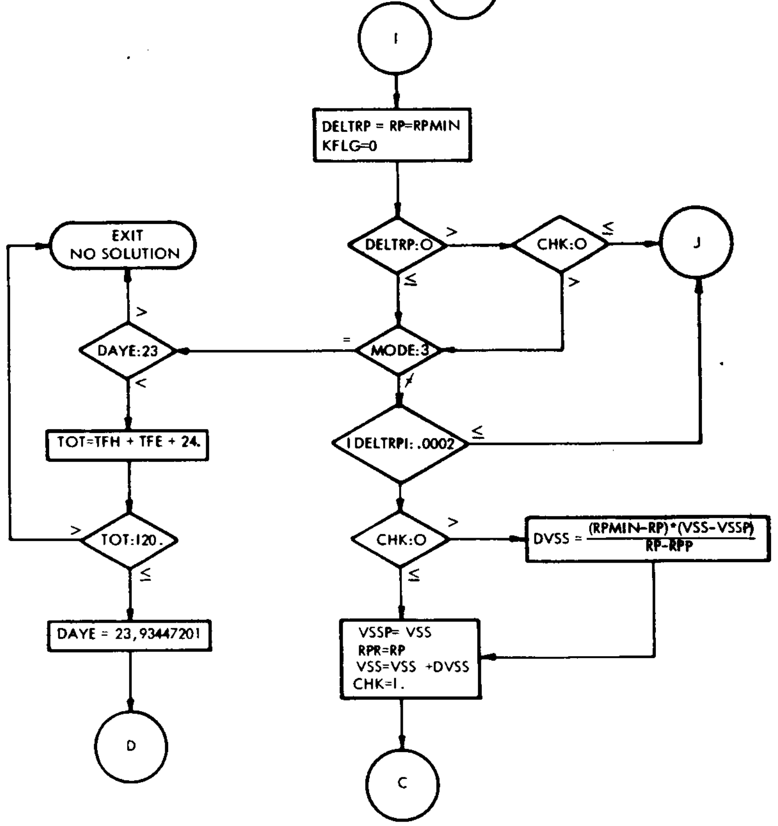

P
RSMM = RSM
CRTMP = ROO*RO
CRTMP = ICRTMPI
TEMP = IHOI
TEMP = -HO/TEMP
CRTMP = CRTMP/CRTMP
SGN = TEMP·CRTMP
THETA = SGN*COS-1 (ROO·RO) + (1-SGN)π
Q

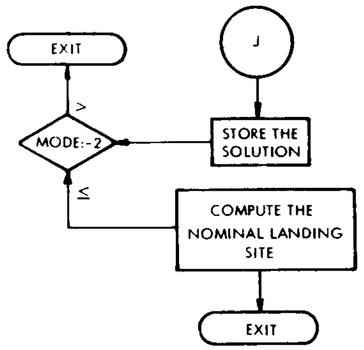

R
RO = IROI
TEMP = RO*VO
TEMP = ITEMPI
CRTMP = TEMP/TEMP
RB = -RSM+ (CRTMP·RSM)*CRTMP
RB = IRBI
TEMP = (RO*RB)
SGN = SIGN (CRTMP·TEMP)
TEMP = (RO·RB) / RO*RB
THETA = SGN*COS-1 (TEMP) + (1.-SGN)*π
AO = 2./RO-(VO·VO)/PMU
S


X
TSRN / TSR : 0
≥
<
TSN = TS + TSN / 2.
TSR = TSRN
TS = TSN
FIND NEW
RM, VM
Y


T
CHI:O
=
≠
V
<
IDVR-DVRPI:1
≥
DELTRP = RP-RPMIN
H
=
CHI:O
≥
DELTRP:O
CHI= 1.
F
CHI=O
≠
<
≤
IDELTRPI: .0002
>
DBETA = (RPMIN-RP)*(BETAP-BETA) / RPP-RP


H
IBETAF = 0
BETA:O
<
≥
IBETAF=1
RO1=RO
VO1=VO
TA1=TA
THETA1=THETA
RO=ROO
VO=VOO
TA=TAA
BETA=THETA-BETA
ENTER TIME-THETA
RO, VO, BETA
RESUME WITH TFO
TL= TA + TFO
G
≠
IBETAF:O
=
G
RO RO1
VO VO1
THETA THETA1
TA TA1


I
DELTRP = RP-RPMIN
KFLG=0
EXIT
NO SOLUTION
DELTRP:O
>
CHK:O
≤
J
≤
>
>
DAYE:23
=
MODE:3
<
≠
TOT=TFH + TFE + 24.
IDELTRPI: .0002
≤
>
TOT:120.
≤
CHK:O
>
DVSS = (RPMIN-RP)*(VSS-VSSP) / RP-RPP
≤
DAYE = 23.93447201
VSSP= VSS
RPR=RP
VSS=VSS +DVSS
CHK=1.
D
C


EXIT
J
>
MODE:-2
STORE THE
SOLUTION
≤
COMPUTE THE
NOMINAL LANDING
SITE
EXIT

SUBROUTINE: INV3X3

PURPOSE: To invert A (3x3) matrix.

CALLING SEQUENCE: CALL INV3X3 (A, B, DT)

NAME COMMON USED:

FUNCTIONS REQUIRED: None

APPROXIMATE STORAGE: 210

SUBROUTINE: INV3X3

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I		A	9 (3,3)	A		Input matrix.
O		B	9 (3,3)	A^{-1}		Output matrix.
O		DT	1	A		Determination of A. = 0, A is singular.

SUBROUTINE: LAMBS

PURPOSE: To solve the two-body problem for initial velocity given two position vectors and the transit time; final position given the initial position and velocity and the transit time; or transit time given the initial position and velocity and the transfer angle.

CALLING SEQUENCE: CALL LAMBS (V1B, V2B, LKT)

NAME COMMON USED: INTGR
INTGRK
C0NST
INDS

SUBROUTINES REQUIRED: VCMSC

FUNCTIONS REQUIRED: DABS, DC0S, DSIN, DSQRT

APPROXIMATE STORAGE: 1013

SUBROUTINE: LAMBS

INPUT AND OUTPUT: LAMBERT'S EQUATIONS

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I		LKT	1		1	Entry flag for Lambert solution: = 1
I	INTGR	R1B	6	$\bar{R}_1$	er	Initial position vector.
I	INTGR	R2B	6	$\bar{R}_2$	er	Final position vector.
I	INTGR	T	1	T_F	hrs	Transit time.
I	INDS	XMU	1	μ	er^3/hr^2	Gravitational parameter of the central body.
I	CONST	PI	1	π		3.141592654
I	CONST	SGMM	1		± 1	SGMM = +1 for $\theta > 180^\circ$ SGMM = -1 for $\theta < 180^\circ$ where θ is the transfer angle
O		V1B	6	$\bar{V}_1$	er/hr	Initial velocity.

SUBROUTINE: LAMBS (continued)

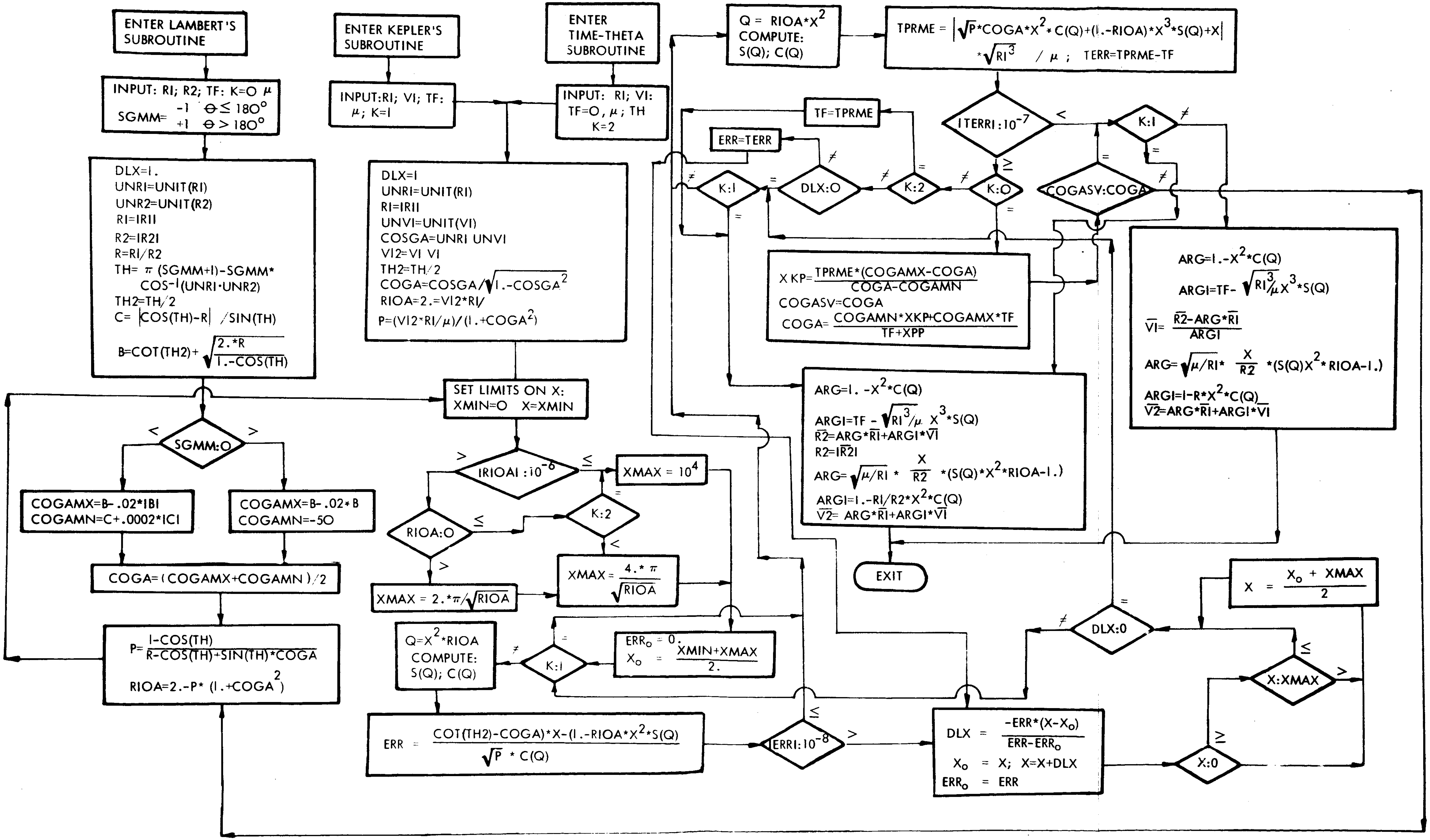
INPUT AND OUTPUT: KEPLER'S EQUATIONS

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I		LKT	1		2	Entry flag for Kepler solution: = 2
I	INTGR	R1B	6	$\bar{R}_1$	er	Initial position vector.
I		V1B	6	$\bar{V}_1$	er/hr	Initial velocity vector.
I	INTGR	T	1	T_F	hrs	Transit time.
I	INDS	XMU	1	μ	er^3/hr^2	Gravitational parameter of the central body.
I	CØNST	PI	1	π		3.141592654
Ø	INTGR	R2B	6	$\bar{R}_2$	er	Final position vector.
Ø		V2B	6	$\bar{V}_2$	er/hr	Final velocity vector.

SUBROUTINE: LAMBS (continued)

INPUT AND OUTPUT: TIME-THETA

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I		LKT	1		3	Entry flag for Time-Theta solution: = 3
I	INTGR	R1B	6	$\bar{R}_1$	er	Initial position vector.
I		V1B	6	$\bar{V}_1$	er/hr	Initial velocity vector.
I	INTGRK	THETA	1	θ	rad	Transfer angle.
I	INTGR	T	1	T	hrs	Transit time must be set to 0.
I	INDS	XMU	1	μ	er^3/hr^2	Gravitational parameter of the central body.
I	C0NST	PI	1	π		3.141592654
0	INTGRK	T2	1	T_F	hrs	Transit time.

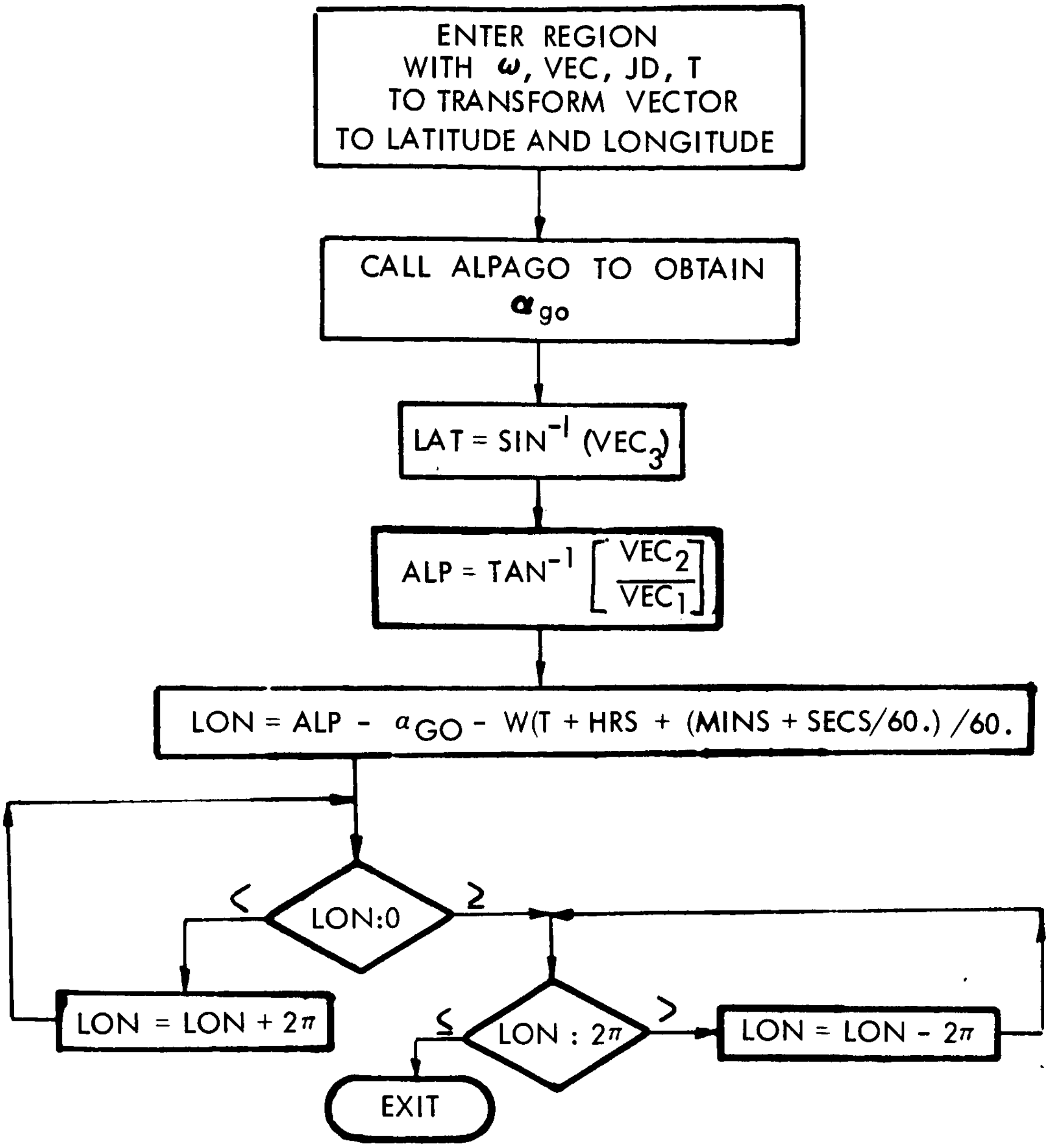

ENTER LAMBERT'S SUBROUTINE
INPUT: R1; R2; TF: K=0 μ
SGMM= -1 θ ≤ 180° ; +1 θ > 180°
DLX=1.
UNR1=UNIT(R1)
UNR2=UNIT(R2)
R1=lR1l
R2=lR2l
R=R1/R2
TH= π (SGMM+1)-SGMM* COS-1(UNR1·UNR2)
TH2=TH/2
C= lCOS(TH)-Rl /SIN(TH)
B=COT(TH2)+ √(2.*R / 1.-COS(TH))
SGMM:0
<
>
COGAMX=B-.02*lBl
COGAMN=C+.0002*lCl
COGAMX=B-.02*B
COGAMN=-50
COGA=(COGAMX+COGAMN)/2
P= 1-COS(TH) / R-COS(TH)+SIN(TH)*COGA
RIOA=2.-P* (1.+COGA²)
ENTER KEPLER'S SUBROUTINE
INPUT:R1; V1; TF: μ; K=1
DLX=1
UNR1=UNIT(R1)
R1=lR1l
UNV1=UNIT(V1)
COSGA=UNR1 UNV1
V12=V1 V1
TH2=TH/2
COGA=COSGA/√(1.-COSGA²)
RIOA=2.-V12*R1/
P=(V12*R1/μ)/(1.+COGA²)
ENTER TIME-THETA SUBROUTINE
INPUT: R1; V1: TF=0, μ; TH K=2
SET LIMITS ON X: XMIN=0 X=XMIN
lRIOAl :10⁻⁶
>
≤
XMAX = 10⁴
K:2
=
<
RIOA:0
≤
>
XMAX = 2.*π/√RIOA
XMAX = 4.*π / √RIOA
ERR₀ = 0.
X₀ = XMIN+XMAX / 2.
K:1
=
≠
Q=X²*RIOA
COMPUTE: S(Q); C(Q)
ERR = COT(TH2)-COGA)*X-(1.-RIOA*X²*S(Q) / √P * C(Q)
lERRl:10⁻⁸
≤
>
Q = RIOA*X²
COMPUTE: S(Q); C(Q)
TPRME = l√P*COGA*X²* C(Q)+(1.-RIOA)*X³*S(Q)+Xl *√R1³ / μ ; TERR=TPRME-TF
lTERRl:10⁻⁷
<
≥
K:1
≠
=
TF=TPRME
ERR=TERR
K:1
≠
=
DLX:0
≠
=
K:2
≠
=
K:0
≠
=
COGASV:COGA
=
≠
X KP= TPRME*(COGAMX-COGA) / COGA-COGAMN
COGASV=COGA
COGA= COGAMN*XKP+COGAMX*TF / TF+XPP
ARG=1. -X²*C(Q)
ARG1=TF - √(R1³/μ) X³*S(Q)
R2=ARG*R1+ARG1*V1
R2=lR2l
ARG=√(μ/R1) * X/R2 *(S(Q)*X²*RIOA-1.)
ARG1=1.-R1/R2*X²*C(Q)
V2= ARG*R1+ARG1*V1
EXIT
ARG=1.-X²*C(Q)
ARG1=TF- √(R1³/μ) X³*S(Q)
V1= R2-ARG*R1 / ARG1
ARG= √(μ/R1)* X/R2 *(S(Q)X²* RIOA-1.)
ARG1=1-R*X²*C(Q)
V2=ARG*R1+ARG1*V1
X = X₀ + XMAX / 2
DLX:0
≠
=
X:XMAX
≤
>
DLX = -ERR*(X-X₀) / ERR-ERR₀
X₀ = X; X=X+DLX
ERR₀ = ERR
X:0
≥

SUBROUTINE:	LATLØN
PURPOSE:	To transform coordinates to latitude and longitude.
CALLING SEQUENCE:	CALL LATLØN (VEC, LAT, LØN, T)
NAME COMMON USED:	CØNST AINPUT
SUBROUTINES REQUIRED:	ALPAGØ, VCMSC
FUNCTIONS REQUIRED:	None
APPROXIMATE STORAGE:	75

SUBROUTINE: LATLØN

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I		VEC	6		er	The vector to be transformed to latitude and longitude.
I		T	1		hrs	Time - Hours from epoch time.
I	CØNST	ØMEGA	1	ω	rad/hr	Rotational rate of the earth.
I	AINPUT	JD	1	JD		Julian Date
Ø		LAT	1	LAT	rad	Latitude
Ø		LØNG	1	LØNG	rad	Longitude
I	CØNST	TWØPI	1			6.2831853071796
I	INPUT	HRS	1		hrs	Epoch Time - Hours
I	INPUT	XMINS	1		mins	Epoch Time - Minutes
I	INPUT	SECS	1		secs	Epoch Time - Seconds


ENTER REGION WITH ω, VEC, JD, T TO TRANSFORM VECTOR TO LATITUDE AND LONGITUDE
CALL ALPAGO TO OBTAIN αgo
LAT = SIN⁻¹ (VEC3)
ALP = TAN⁻¹ [VEC2 / VEC1]
LON = ALP - αGO - W(T + HRS + (MINS + SECS/60.) /60.
LON:0
<
≥
LON = LON + 2π
LON : 2π
≤
>
LON = LON - 2π
EXIT

SUBROUTINE:	LSCR
PURPOSE:	The purpose of this subroutine is to compute the conic abort trajectory which departs the pre-abort trajectory at the earliest opportunity. The abort trajectory returns to acceptable re-entry conditions and achieves a specified landing site within the re-entry ranging capabilities of the spacecraft.
CALLING SEQUENCE:	CALL LSCR
NAME COMMON USED:	INTGR AINPUT C0NST 0TPT BURNPR INTGRK INM0C WLSC0N INPUT
SUBROUTINES REQUIRED:	VCMSC, ALPAG0, REENTY, LAMBS
FUNCTIONS REQUIRED:	C0S, SIN, SQRT
APPROXIMATE STORAGE:	1201

SUBROUTINE: LSCR

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	INTGR	RAB	6	$\bar{R}$	er	Position of the vehicle at time TA.
I	INTGR	VAB	6	$\bar{V}$	er/hr	Velocity of the vehicle at time TA.
I	INTGR	TA	1	TA	hr	Time of abort measured from initial time.
I	AINPUT	DVMX	1	ΔV	er/hr	The maximum allowable change in velocity.
I	CØNST	EMU	1	μ	er^3/hr^2	Gravitational parameter of the earth.
I	CØNST	USSTER	1		$\frac{\text{statute mi.}}{\text{er}}$	Conversion factor: 3963.20799
I	CØNST	PI	1	π		3.141592654
I	CØNST	ØMEGA	1	ω	R/hr	Rotational rate of the earth.
I	AINPUT	MØDE	1			MØDE = 1, landing site. MØDE = 2, time critical. MØDE = 3, fuel critical.
I	AINPUT	RR	1	$\lvert\bar{R}_R\rvert$	er	Magnitude of the re-entry position vector.
I	AINPUT	NLS	1			Number of landing sites for which solutions are desired. ($NLS \leq 4$)
I	AINPUT	TAGG	1			For normal operation in outside the sphere modes. TAGG = 0

SUBROUTINE: LSCR (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	AINPUT	JD	1	JD		Julian Date
I	AINPUT	LAT	4	LAT	deg	Latitudes of the desired landing sites.
I	AINPUT	LØNG	4	LØNG	deg	Longitudes of the desired landing sites.
I	CØNST	RADIAN	1		deg/rad	57.2957795
Ø	ØTPT	DVRQ	1	ΔV_{RQ}	er/hr	Computed ΔV required for each solution.
Ø	ØTPT	THR	1	θ_R	rad	Re-entry range angle.
Ø	ØTPT	CØGA	1	ctn γ		Cotangent of the return conic flight path angle at position $\bar{R}$.
Ø	ØTPT	INTER	1		± 1	Designator of the two possible intersections of the landing site with the return plane.
Ø	INTGR	TF	1	T_F	hrs	Total time of flight from initial time of re-entry.
Ø	INTGR	TB	1	T_B	hrs	Time of burn initiation measured from initial time.
Ø	BURNPR	BURNVR	3	$\bar{V}_B$	er/hr	Velocity required at end of burn.
Ø	INTGR	RFA	6	$\bar{R}_R$	er	Desired position vector at re-entry.

SUBROUTINE: LSCR (continued)

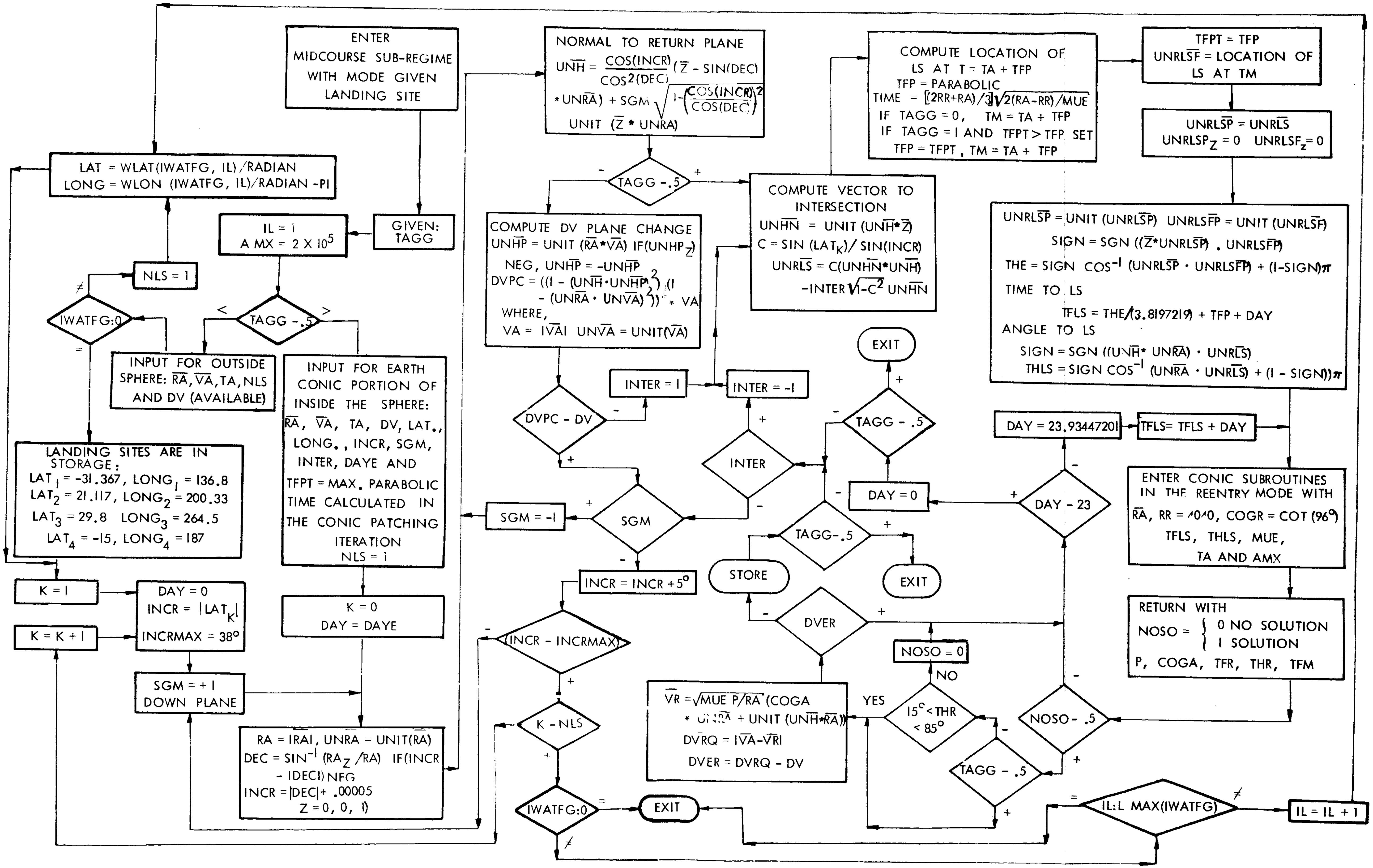
INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	AINPUT	Z	3			Unit vector (0,0,1).
Ø	AINPUT	INØSØF	1			= 0, if no solution has been computed. = 1, if a solution has been computed.
I	AINPUT	IWATFG	1			Land mass number = 0 if nominal trajectory impacts on water.
I	WLSCØN	LMAX	6			Maximum number of landing sites per land mass.
I	WLSCØN	WLAT	(6,20)	LAT	deg	Latitudes of the landing sites surrounding the land mass.
I	WLSCØN	WLØN	(6,20)	LØNG	deg	Longitudes of the landing sites surrounding the land mass.
I	INPUT	HRS	1		hrs	Epoch Time - Hours
I	INPUT	XMINS	1		mins	Epoch Time - Minutes
I	INPUT	SECS	1		secs	Epoch Time - Seconds

SUBROUTINE: LSCR (continued)

INPUT AND OUTPUT: For computing the earth conic portion of inside the sphere, the following additional input is required.

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	AINPUT	LAT	4	LAT	deg	Desired latitude of one pre-selected landing site.
I	AINPUT	LØNG	4	LØNG	deg	Desired longitude of one pre-selected landing site.
I	ØTPT	INCR	1	i_R	rad	Desired inclination of post abort trajectory.
I	ØTPT	INTER	1		± 1	Designator of the pre-selected intersection of the landing site with the return plane.
I	AINPUT	DAYE	1		hrs	Pre-selected value for day: DAYE = 0, or DAYE = 23.93447201
I	ØTPT	SGM	1		± 1	Designator of the pre-selected return plane.
I	AINPUT	TFPT	1	TF_P	hrs	Parabolic flight time calculated in the conic patching iteration.


ENTER MIDCOURSE SUB-REGIME WITH MODE GIVEN LANDING SITE
NORMAL TO RETURN PLANE
UNH̄ = COS(INCR)/COS²(DEC) (Z̄ - SIN(DEC) * UNRĀ) + SGM √(1-(COS(INCR)/COS(DEC))²) UNIT (Z̄ * UNRA)
COMPUTE LOCATION OF LS AT T = TA + TFP
TFP = PARABOLIC TIME = [(2RR+RA)/3]√(2(RA-RR)/MUE)
IF TAGG = 0, TM = TA + TFP
IF TAGG = 1 AND TFPT > TFP SET TFP = TFPT, TM = TA + TFP
TFPT = TFP
UNRLS̄F = LOCATION OF LS AT TM
UNRLS̄P = UNRLS̄
UNRLSP_Z = 0 UNRLSF_Z = 0
LAT = WLAT(IWATFG, IL)/RADIAN
LONG = WLON (IWATFG, IL)/RADIAN -PI
TAGG -.5
-
+
COMPUTE VECTOR TO INTERSECTION
UNH̄N = UNIT (UNH̄*Z̄)
C = SIN (LAT_K)/ SIN(INCR)
UNRL̄S = C(UNH̄N*UNH̄)
-INTER √(1-C²) UNH̄N
UNRLS̄P = UNIT (UNRLS̄P) UNRLSF̄P = UNIT (UNRLS̄F)
SIGN = SGN ((Z̄*UNRLS̄P) . UNRLSF̄P)
THE = SIGN COS⁻¹ (UNRLS̄P · UNRLSF̄P) + (1-SIGN)π
TIME TO LS
TFLS = THE/(3.8197219) + TFP + DAY
ANGLE TO LS
SIGN = SGN ((UN̄H* UNRĀ) · UNRL̄S)
THLS = SIGN COS⁻¹ (UNRĀ · UNRL̄S) + (1 - SIGN))π
IL = 1
A MX = 2 X 10⁵
GIVEN: TAGG
NLS = 1
≠
IWATFG:0
=
TAGG -.5
<
>
COMPUTE DV PLANE CHANGE
UNH̄P = UNIT (R̄A*V̄A) IF(UNHP_Z) NEG, UNH̄P = -UNH̄P
DVPC = ((1 - (UNH̄·UNH̄P)²) (1 - (UNRĀ · UNV̄A)²))^½ * VA
WHERE,
VA = |V̄A| UNV̄A = UNIT(V̄A)
EXIT
INPUT FOR OUTSIDE SPHERE: R̄A, V̄A, TA, NLS AND DV (AVAILABLE)
INPUT FOR EARTH CONIC PORTION OF INSIDE THE SPHERE: R̄A, V̄A, TA, DV, LAT., LONG., INCR, SGM, INTER, DAYE AND TFPT = MAX. PARABOLIC TIME CALCULATED IN THE CONIC PATCHING ITERATION
NLS = 1
INTER = 1
INTER = -1
+
DVPC - DV
-
+
INTER
+
-
TAGG - .5
-
+
DAY = 23.93447201
TFLS= TFLS + DAY
LANDING SITES ARE IN STORAGE:
LAT₁ = -31.367, LONG₁ = 136.8
LAT₂ = 21.117, LONG₂ = 200.33
LAT₃ = 29.8 LONG₃ = 264.5
LAT₄ = -15, LONG₄ = 187
SGM = -1
SGM
+
-
DAY = 0
DAY - 23
+
-
ENTER CONIC SUBROUTINES IN THE REENTRY MODE WITH R̄A, RR = 4040, COGR = COT (96°) TFLS, THLS, MUE, TA AND AMX
TAGG-.5
-
+
STORE
EXIT
K = 1
DAY = 0
INCR = |LAT_K|
INCRMAX = 38°
K = K + 1
K = 0
DAY = DAYE
INCR = INCR +5°
DVER
-
+
RETURN WITH
NOSO = { 0 NO SOLUTION / 1 SOLUTION
P, COGA, TFR, THR, TFM
INCR - INCRMAX
-
+
NOSO = 0
NO
YES
SGM = + 1 DOWN PLANE
V̄R = √(MUE P/RA) (COGA * UNRĀ + UNIT (UNH̄*R̄A))
DVRQ = |V̄A-V̄R|
DVER = DVRQ - DV
15° < THR < 85°
-
NOSO- .5
-
+
K -NLS
+
RA = |RA|, UNRA = UNIT(RA)
DEC = SIN⁻¹ (RA_Z /RA) IF(INCR - |DEC|) NEG
INCR = |DEC|+ .00005
Z = 0, 0, 1)
TAGG - .5
+
IWATFG:0
=
≠
EXIT
=
IL:L MAX(IWATFG)
≠
IL = IL + 1

SUBROUTINE: MAIN

PURPOSE: To control the flow of the combined analytic and integration routines. The routine also acts as the interation control logic for outside the lunar sphere of influence computations.

NAME COMMON USED:
VEH
INPUT
C0NST
BURNPR
TINPUT
AINPUT
INDS
INTGR
RVM00N
INM0C
BURNID

SUBROUTINES REQUIRED: VCMSC, ANALYT, ENCKE, LAMBS, PTCIN, INM0, WLSCN

FUNCTIONS REQUIRED: ABS

APPROXIMATE STORAGE: 664

SUBROUTINE: MAIN

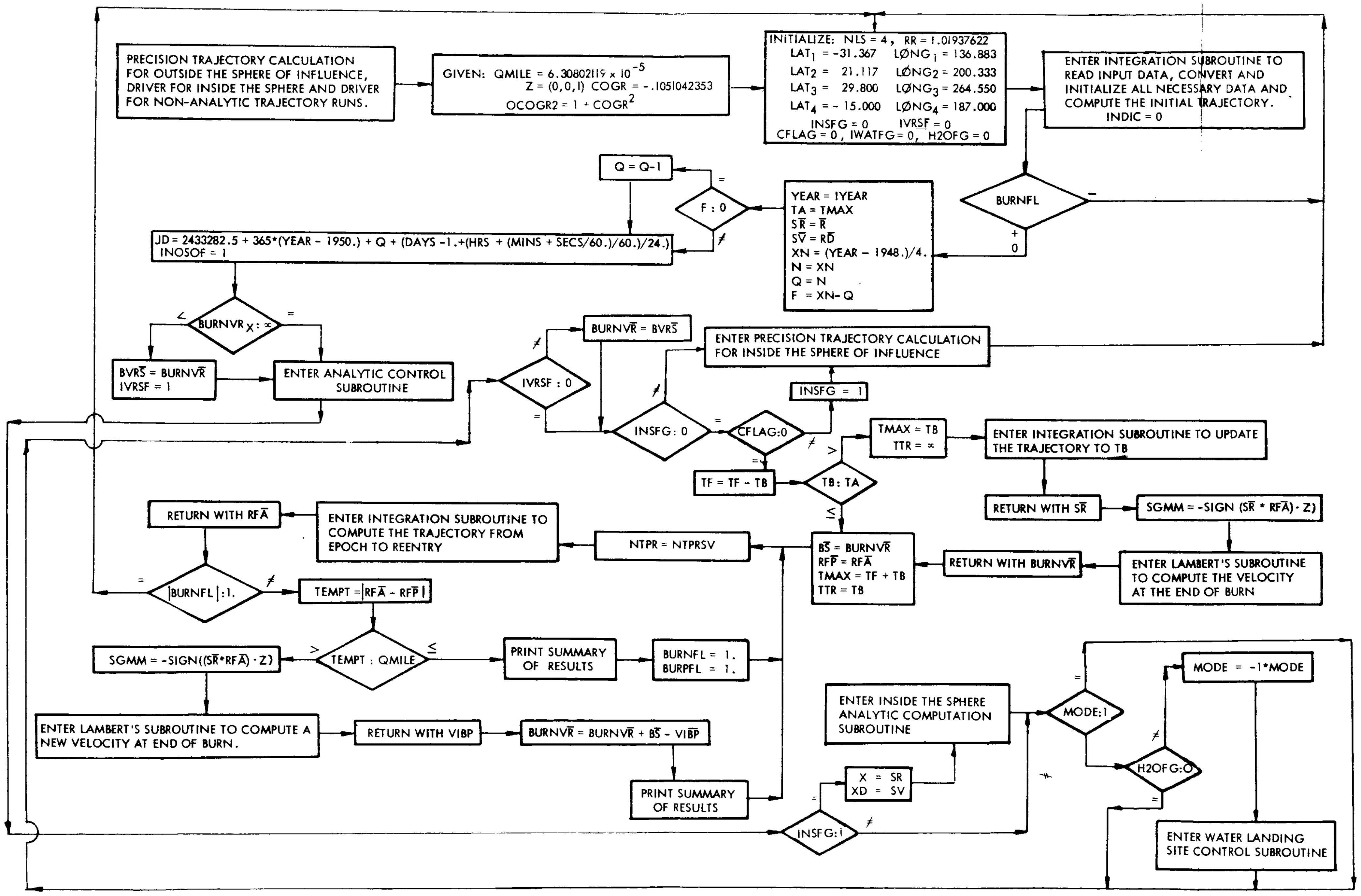
INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	BURNPR	BURNFL	1			-1, production with no analytic solution. 0, burn and print only on last pass.
						1, set internally to indicate last pass. 2, burn last pass, print every pass.
						3, burn every pass, print last pass. 4, burn every pass, print every pass.
I	BURNPR	DELTI	1	Δt_1	hrs	Minimum time allowable from initial time to beginning of abort procedures. .01666667 if not input.
I	AINPUT	ALAT	4	LAT	deg	Latitudes of the selected landing sites in the analytic package (landing site mode).
I	AINPUT	AL0NG	4	L0NG	deg	Longitudes of the selected landing sites in the analytic package (landing site mode).
I	AINPUT	C0GR	1	$\text{ctn}\,\gamma_R$		Cotangent of the re-entry flight path angle.
I	AINPUT	RR	1	$\lvert\bar{R}_R\rvert$	er	Magnitude of the re-entry position vector.
I	AINPUT	NLS	1			Number of landing sites ($NLS \leq 4$).
I	AINPUT	CFLAG	1			= 0, no circumlunar logic. = 1, do circumlunar logic.
I	AINPUT	H20FG	1			= 0, do not use the water landing logic. = 1, compute a water landing site.
I	INPUT	IYEAR	1		years	Epoch Time - Year

SUBROUTINE: MAIN (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	INPUT	DAYS	1		days	Epoch Time - Days from beginning of the year.
I	INPUT	HRS	1		hrs	Epoch Time - Hours
I	INPUT	MINS	1		minutes	Epoch Time - Minutes
I	INPUT	SECS	1		secs	Epoch Time - Seconds
O		VIBP	6	V_r	er/hr	The Lamberts velocity at the abort point for the desired transit time between the abort position and re-entry.
O	BURNPR	BURNVR	3	V_r	er/hr	The n^{th} value of the required velocity at burn termination.
O	INTGR	RFA	6	R_f	er	The computed position vector at re-entry.
O		RFP	6	R_r	er	The desired position vector at re-entry.
O	CONST	SGMM	1			The indicator of the transfer angle. SGMM = $1 \; \theta > 180^\circ$ SGMM = $-1 \; \theta < 180^\circ$
O		RFB	6	R_b	er	The computed position vector at burn initiation.
O		DELRF	1	ΔR_r	er	The magnitude of the vector difference of the computed and the desired re-entry position vectors. Convergence occurs
						when this parameter is less than .25 miles.


PRECISION TRAJECTORY CALCULATION FOR OUTSIDE THE SPHERE OF INFLUENCE, DRIVER FOR INSIDE THE SPHERE AND DRIVER FOR NON-ANALYTIC TRAJECTORY RUNS.
GIVEN: QMILE = 6.30802115 x 10^-5
Z = (0,0,1) COGR = -.1051042353
OCOGR2 = 1 + COGR^2
INITIALIZE: NLS = 4, RR = 1.01937622
LAT1 = -31.367 LØNG1 = 136.883
LAT2 = 21.117 LØNG2 = 200.333
LAT3 = 29.800 LØNG3 = 264.550
LAT4 = - 15.000 LØNG4 = 187.000
INSFG = 0 IVRSF = 0
CFLAG = 0, IWATFG = 0, H2OFG = 0
ENTER INTEGRATION SUBROUTINE TO READ INPUT DATA, CONVERT AND INITIALIZE ALL NECESSARY DATA AND COMPUTE THE INITIAL TRAJECTORY.
INDIC = 0
BURNFL
-
+
0
YEAR = IYEAR
TA = TMAX
SR̄ = R̄
SV̄ = RD̄
XN = (YEAR - 1948.)/4.
N = XN
Q = N
F = XN-Q
F : 0
=
≠
Q = Q-1
JD = 2433282.5 + 365*(YEAR - 1950.) + Q + (DAYS -1.+(HRS + (MINS + SECS/60.)/60.)/24.)
INOSOF = 1
BURNVR X : ∞
<
=
BVRS̄ = BURNVR̄
IVRSF = 1
ENTER ANALYTIC CONTROL SUBROUTINE
IVRSF : 0
≠
=
BURNVR̄ = BVRS̄
ENTER PRECISION TRAJECTORY CALCULATION FOR INSIDE THE SPHERE OF INFLUENCE
INSFG = 1
INSFG : 0
≠
=
CFLAG:0
≠
=
TMAX = TB
TTR = ∞
ENTER INTEGRATION SUBROUTINE TO UPDATE THE TRAJECTORY TO TB
RETURN WITH SR̄
SGMM = -SIGN (SR̄ * RFĀ) · Z)
TF = TF - TB
TB : TA
>
≤
ENTER LAMBERT'S SUBROUTINE TO COMPUTE THE VELOCITY AT THE END OF BURN
RETURN WITH BURNVR̄
BS̄ = BURNVR̄
RFP̄ = RFĀ
TMAX = TF + TB
TTR = TB
NTPR = NTPRSV
ENTER INTEGRATION SUBROUTINE TO COMPUTE THE TRAJECTORY FROM EPOCH TO REENTRY
RETURN WITH RFĀ
|BURNFL| :1.
=
≠
TEMPT = |RFĀ - RFP̄|
TEMPT : QMILE
>
≤
SGMM = -SIGN((SR̄*RFĀ) · Z)
PRINT SUMMARY OF RESULTS
BURNFL = 1.
BURPFL = 1.
ENTER LAMBERT'S SUBROUTINE TO COMPUTE A NEW VELOCITY AT END OF BURN.
RETURN WITH VIBP
BURNVR̄ = BURNVR̄ + BS̄ - VIBP̄
PRINT SUMMARY OF RESULTS
INSFG:1
=
≠
X = SR
XD = SV
ENTER INSIDE THE SPHERE ANALYTIC COMPUTATION SUBROUTINE
MODE:1
=
≠
H2OFG:0
=
MODE = -1*MODE
ENTER WATER LANDING SITE CONTROL SUBROUTINE

SUBROUTINE:	NAVIER
PURPOSE	To simulate the navigation equations used in the on-board computer to advance the state vector.
CALLING SEQUENCE:	CALL NAVIER (DELTAT, VSIN)
NAME COMMON USED:	PERTS VEHICL AUT0 INDS AINPUT NAVERR
SUBROUTINES REQUIRED:	VCMSC
FUNCTIONS REQUIRED:	None
APPROXIMATE STORAGE:	154

SUBROUTINE: NAVIER

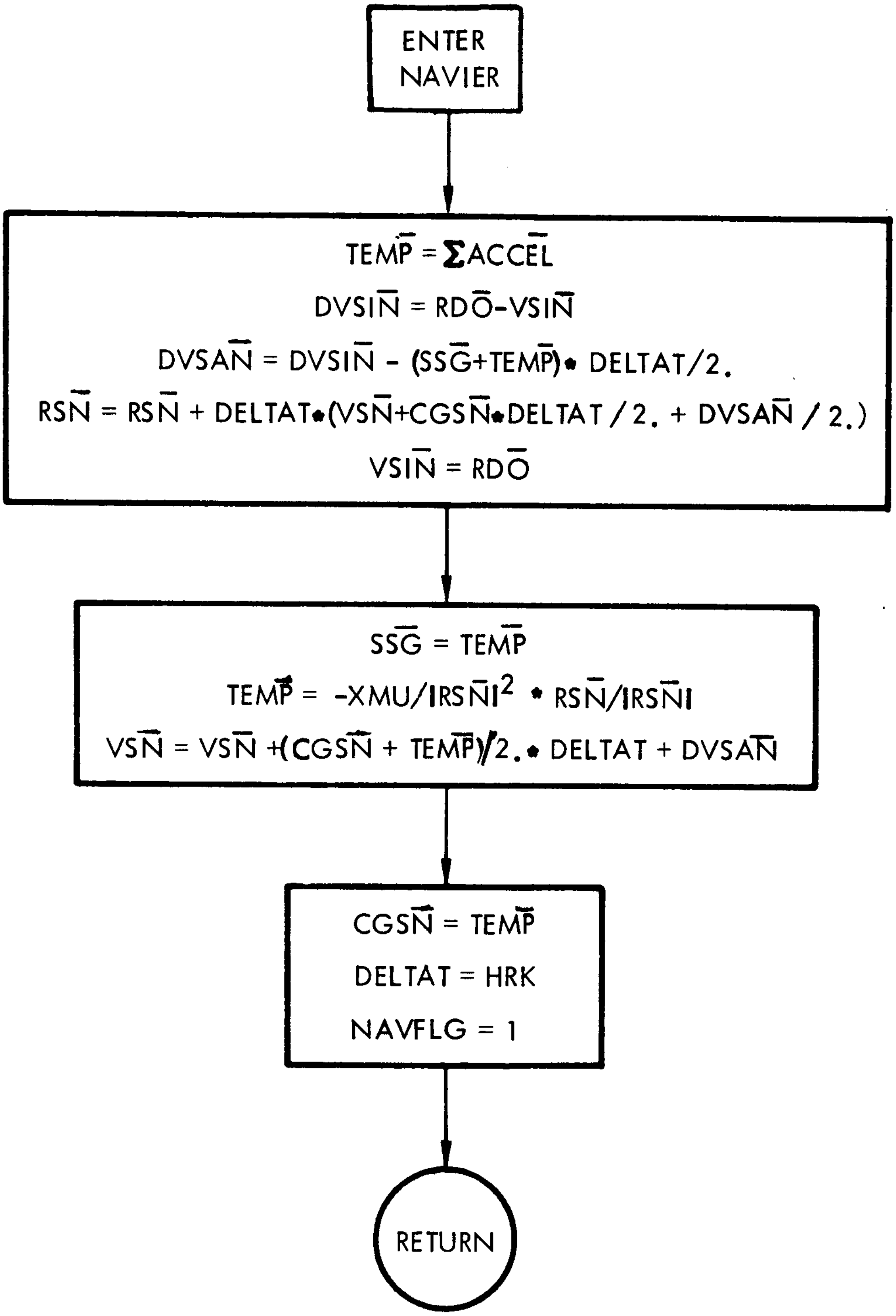
INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I/0	AINPUT	RSN	4	$\bar{R}_N$	er	Position vector for navigation equations.
I/0	AINPUT	VSN	3	$\bar{V}_N$	er/hr	Velocity vector for navigation equations.
I/0		DELTAT	1	ΔT	hrs	Time increment.
I/0		VSIN	3	$\bar{V}_{IN}$	er/hr	Integrated velocity used by the navigation equations.
I	PERTS	ACCEL	30		er/hr^2	The integrated perturbative accelerations (double precision).
0	NAVERR	DVSIN	3	$\Delta\bar{V}_{IN}$	er/hr	Integrated velocity increment.
0	NAVERR	DVSAN	3	$\Delta\bar{V}_{AN}$	er/hr	Analytic velocity increment.
I	VEHICL	RD0	12	V	er/hr	Single precision velocity vector.
I/0	NAVERR	SSG	3	Σ_G	er/hr^2	Summation of perturbation accelerations.
I/0	NAVERR	CGSN	3	G_N	er/hr^2	Approximation to the gravitational acceleration for the navigation equations.
I	INDS	XMU	1	μ	er^3/hr^2	Gravitational parameter of the central body.
I	AUT0	HRK	1	ΔT	hrs	Integration step size.

SUBROUTINE: NAVIER (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
0	NAVERR	NAVFLG	1			Navigation parameters have been computed.


ENTER NAVIER
$TEM\bar{P} = \Sigma ACCE\bar{L}$
$DVSI\bar{N} = RD\bar{O} - VSI\bar{N}$
$DVSA\bar{N} = DVSI\bar{N} - (SS\bar{G} + TEM\bar{P}) * DELTAT/2.$
$RS\bar{N} = RS\bar{N} + DELTAT * (VS\bar{N} + CGS\bar{N} * DELTAT/2. + DVSA\bar{N}/2.)$
$VSI\bar{N} = RD\bar{O}$
$SS\bar{G} = TEM\bar{P}$
$TEM\bar{P} = -XMU/|RS\bar{N}|^2 * RS\bar{N}/|RS\bar{N}|$
$VS\bar{N} = VS\bar{N} + (CGS\bar{N} + TEM\bar{P})/2. * DELTAT + DVSA\bar{N}$
$CGS\bar{N} = TEM\bar{P}$
DELTAT = HRK
NAVFLG = 1
RETURN

SUBROUTINE:	ØØUTS
PURPOSE:	To establish the conic trajectory which satisfies the re-entry constraints and allows the spacecraft to land at one of the pre-selected landing sites using less than the specified DV. More than one solution to the problem will be generated, although only the minimum time solution will be output for further computations.
CALLING SEQUENCE:	CALL ØØUTS
NAME COMMON USED:	INTGRK INTGR ØTPT BURNPR AINPUT CØNST WLSCØN INPUT BLANK
SUBROUTINES REQUIRED:	ALPAGØ, VCMSC
FUNCTIONS REQUIRED:	SIN, CØS, SQRT, ABS, ATAN
APPROXIMATE STORAGE:	1419

SUBROUTINE: 00UTS

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	INTGR	RA	6	$\bar{R}$	er	The position of the spacecraft at time TA.
I	INTGR	VA	6	$\bar{V}$	er/hr	The velocity of the spacecraft at time TA.
I	AINPUT	DV	1	ΔV	er/hr	The maximum change in velocity.
I	AINPUT	RR	1	$\lvert\bar{R}_R\rvert$	er	Magnitude of the re-entry position vector.
I	AINPUT	C0GR	1	$\text{ctn}\ \gamma_R$		Cotangent of the re-entry flight path angle.
I	INTGR	TA	1	TA	hr	Time of abort measured in hours from initial time.
I	C0NST	EMU	1	μ	er^3/hr^2	Gravitational parameter of the earth. 19.9094165
I	C0NST	RADIAN	1		deg/rad	57.29577951
I	AINPUT	M0DE	1			M0DE = 1, landing site. M0DE = 2, time critical. M0DE = 3, fuel critical.
I	AINPUT	TJD	1			Julian Date
I	C0NST	PI	1	π		3.141592654
I	AINPUT	LAT	4	LAT	deg	Latitudes of desired landing sites.

SUBROUTINE: ØØUTS (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	AINPUT	LØNG	4	LØNG	deg	Longitudes of desired landing sites.
I	AINPUT	NLS	1			Number of desired landing sites. (≤ 4).
Ø	INTGR	TF	1	TF	hrs	Total time of flight from initial time to re-entry.
Ø	INTGR	RFA	6	$\bar{R}_R$	er	Desired position vector at re-entry.
Ø	INTGR	TTR	1	T_B	hr	Time of burn initiation measured from initial time.
Ø	BURNPR	BURNVR	3	V_R	er/hr	Velocity required at end of burn.
Ø	ØTPT	WLAT	1		rad	Working storage for the latitude of each landing site.
Ø	ØTPT	WLØNG	1		rad	Working storage for the longitude of each landing site.
Ø	ØTPT	DAY	1		hr	DAY = 0 or DAY = 23.93447201
Ø	ØTPT	INCR	1	i_R	rad	Desired return inclination.
Ø	ØTPT	SGM	1		± 1	Designator of the two return planes.
Ø	ØTPT	INTER	1		± 1	Designator of the two possible intersections of the orbital plane with the $\overline{\text{UNH}}$ plane.

SUBROUTINE: ØØUTS (continued)

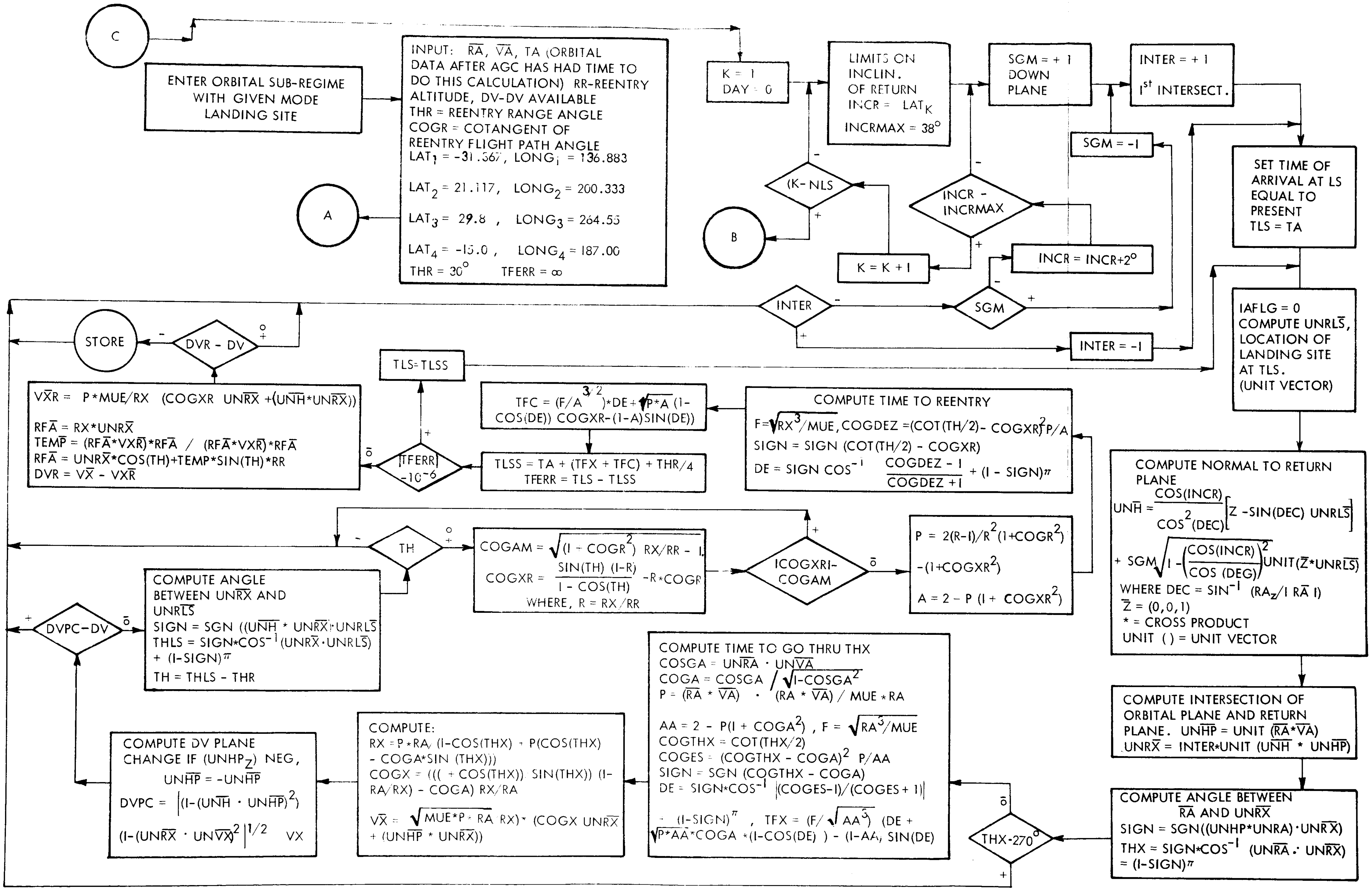
INPUT AND OUTPUT:

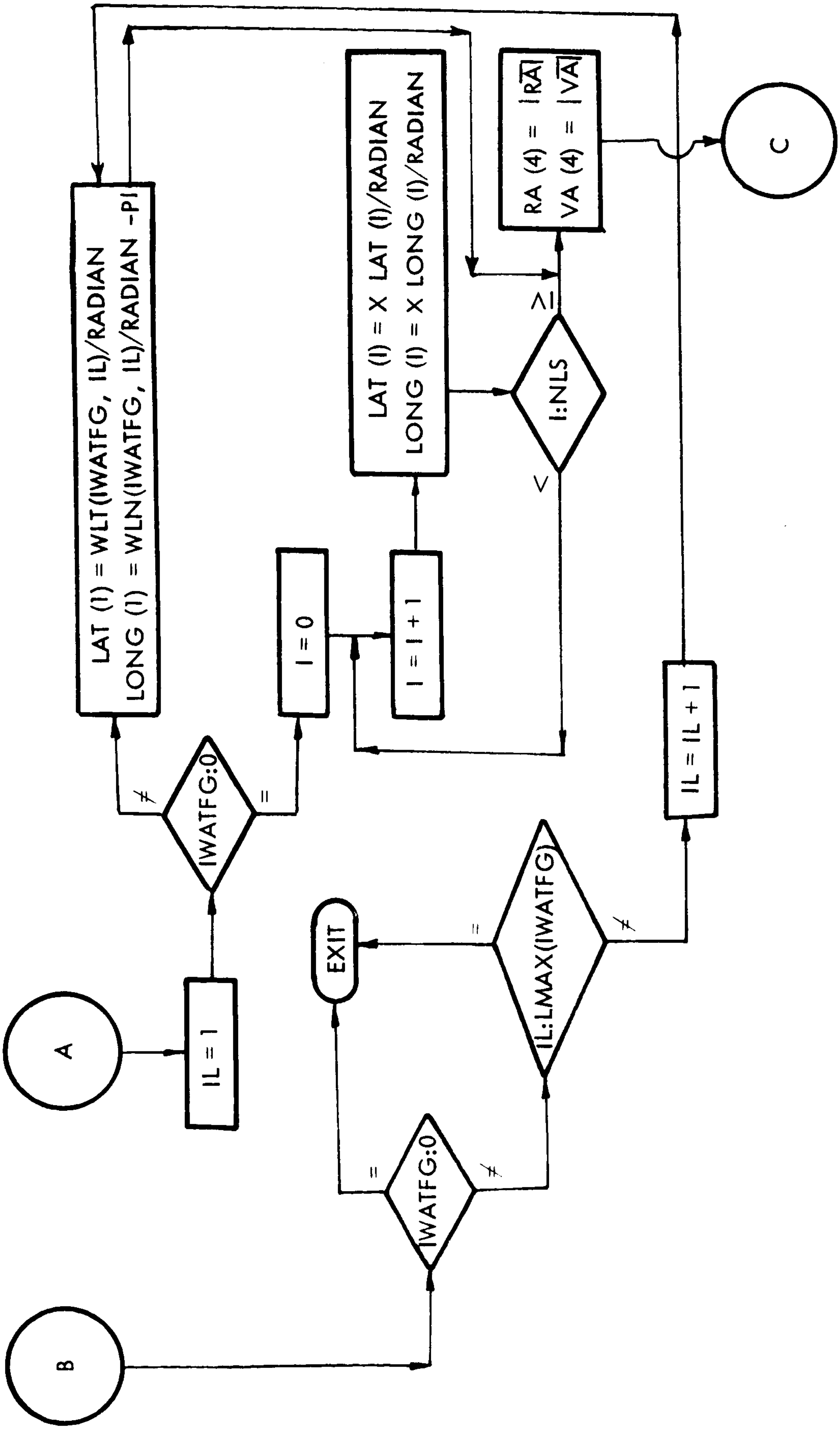
I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
Ø	ØTPT	TLS	1	TLS	hrs	Time of arrival at the landing site measured from initial time.
Ø	ØTPT	TFC	1	TFC	hrs	Time of flight from the intersection of the pre-post abort orbit planes to re-entry.
Ø	ØTPT	CØGXR	1	ctn γ_{XR}		Cotangent of the required flight path angle at the intersection of the planes.
Ø	ØTPT	CAØRR	1	θ	rad	THLS minus re-entry range angle.
Ø	ØTPT	THLS	1	θ_{LS}	rad	Angle between the intersection of the planes and the landing site.
Ø	ØTPT	TFX	1	TFX	hrs	Time of flight to the intersection of the planes.
Ø	ØTPT	DVR	1	ΔV_R	er/hr	Computed ΔV required for each solution.
I	AINPUT	UNZB	3	$\bar{Z}$		Unit vector (0,0,1).
Ø	AINPUT	INØSØF	1			= 0, no solution has been computed. = 1, a solution has been computed.
I	AINPUT	IWATFG	1			Land mass number = 0 if nominal trajectory impacts on water.
I	AINPUT	ØCØGR2	1			$\left[1. + COGR^2\right]$
I	WLSCØN	LMAX	6			Maximum number of landing sites per land mass.

SUBROUTINE: OOUTS (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	WLSCON	WLT	(6,20)	LAT	deg	Latitudes of the landing sites surrounding the land masses.
I	WLSCON	WLN	(6,20)	LONG	deg	Longitudes of the landing sites surrounding the land masses.
I	INPUT	HRS	1		hrs	Epoch Time - Hours
I	INPUT	XMINS	1		mins	Epoch Time - Minutes
I	INPUT	SECS	1		secs	Epoch Time - Seconds


C
ENTER ORBITAL SUB-REGIME WITH GIVEN MODE LANDING SITE
INPUT: RA, VA, TA (ORBITAL DATA AFTER AGC HAS HAD TIME TO DO THIS CALCULATION) RR-REENTRY ALTITUDE, DV-DV AVAILABLE
THR = REENTRY RANGE ANGLE
COGR = COTANGENT OF REENTRY FLIGHT PATH ANGLE
LAT1 = -31.567, LONG1 = 136.883
LAT2 = 21.117, LONG2 = 200.333
LAT3 = 29.8 , LONG3 = 264.55
LAT4 = -15.0 , LONG4 = 187.00
THR = 30° TFERR = ∞
A
K = 1
DAY = 0
LIMITS ON INCLIN. OF RETURN
INCR = LATK
INCRMAX = 38°
SGM = + 1 DOWN PLANE
INTER = + 1 1st INTERSECT.
SGM = -1
(K- NLS
-
+
B
K = K + 1
INCR - INCRMAX
-
+
INCR = INCR+2°
SET TIME OF ARRIVAL AT LS EQUAL TO PRESENT TLS = TA
INTER
-
+
SGM
-
+
INTER = -1
IAFLG = 0 COMPUTE UNRLS, LOCATION OF LANDING SITE AT TLS. (UNIT VECTOR)
STORE
DVR - DV
-
0 +
TLS=TLSS
VXR = P*MUE/RX (COGXR UNRX +(UNH*UNRX))
RFA = RX*UNRX
TEMP = (RFA*VXR)*RFA / (RFA*VXR)*RFA
RFA = UNRX*COS(TH)+TEMP*SIN(TH)*RR
DVR = VX - VXR
|TFERR| -10^-6
+
0-
TFC = (F/A^3/2)*DE+√P*A (1-COS(DE)) COGXR-(1-A)SIN(DE))
TLSS = TA + (TFX + TFC) + THR/4
TFERR = TLS - TLSS
COMPUTE TIME TO REENTRY
F=√RX^3/MUE, COGDEZ =(COT(TH/2)- COGXR)^2 P/A
SIGN = SIGN (COT(TH/2) - COGXR)
DE = SIGN COS^-1 (COGDEZ - 1)/(COGDEZ +1) + (1 - SIGN)π
COMPUTE NORMAL TO RETURN PLANE
UNH = COS(INCR)/COS^2(DEC) [Z -SIN(DEC) UNRLS]
+ SGM √(1 -(COS(INCR)/COS (DEG))^2) UNIT(Z*UNRLS)
WHERE DEC = SIN^-1 (RAZ/| RA |)
Z = (0,0,1)
* = CROSS PRODUCT
UNIT ( ) = UNIT VECTOR
TH
-
0 +
COGAM = √(1 + COGR^2) RX/RR - 1.
COGXR = SIN(TH) (1-R)/(1 - COS(TH)) -R*COGR
WHERE, R = RX/RR
|COGXR|-COGAM
+
0-
P = 2(R-1)/R^2(1+COGR^2)
-(1+COGXR^2)
A = 2 - P (1 + COGXR^2)
COMPUTE ANGLE BETWEEN UNRX AND UNRLS
SIGN = SGN ((UNH * UNRX)·UNRLS
THLS = SIGN*COS^-1(UNRX·UNRLS)
+ (1-SIGN)π
TH = THLS - THR
DVPC-DV
+
0-
COMPUTE INTERSECTION OF ORBITAL PLANE AND RETURN PLANE. UNHP = UNIT (RA*VA)
UNRX = INTER*UNIT (UNH * UNHP)
COMPUTE TIME TO GO THRU THX
COSGA = UNRA · UNVA
COGA = COSGA / √1-COSGA^2
P = (RA * VA) · (RA * VA) / MUE * RA
AA = 2 - P(1 + COGA^2) , F = √RA^3/MUE
COGTHX = COT(THX/2)
COGES = (COGTHX - COGA)^2 P/AA
SIGN = SGN (COGTHX - COGA)
DE = SIGN*COS^-1 |(COGES-1)/(COGES + 1)|
+ (1-SIGN)π , TFX = (F/√AA^3) (DE + √P*AA*COGA *(1-COS(DE)) - (1-AA) SIN(DE)
COMPUTE ANGLE BETWEEN RA AND UNRX
SIGN = SGN((UNHP*UNRA)·UNRX)
THX = SIGN*COS^-1 (UNRA · UNRX)
= (1-SIGN)π
THX-270°
0-
+
COMPUTE:
RX = P*RA/ (1-COS(THX) + P(COS(THX) - COGA*SIN (THX)))
COGX = (((+ COS(THX)) SIN(THX)) (1-RA/RX) - COGA) RX/RA
VX = √MUE*P * RA RX)* (COGX UNRX + (UNHP * UNRX))
COMPUTE DV PLANE CHANGE IF (UNHPZ) NEG,
UNHP = -UNHP
DVPC = |(1-(UNH · UNHP)^2) (1-(UNRX · UNVX)^2|^1/2 VX


A
IL = 1
IWATFG:0
≠
=
LAT (I) = WLT(IWATFG, IL)/RADIAN
LONG (I) = WLN(IWATFG, IL)/RADIAN -PI
I = 0
I = I + 1
LAT (I) = X LAT (I)/RADIAN
LONG (I) = X LONG (I)/RADIAN
I:NLS
<
≥
RA (4) = |$\overline{RA}$|
VA (4) = |$\overline{VA}$|
C
B
IWATFG:0
=
≠
EXIT
IL:LMAX(IWATFG)
=
≠
IL = IL + 1

SUBROUTINE: PEICØM

PURPOSE: To compute the target parameters (p, e, i, SQS, SGM) for the burn model guidance equations.

CALLING SEQUENCE: CALL PEICØM

NAME COMMON USED: VEHICL
BURNPR
INDS
AINPUT

SUBROUTINES REQUIRED: VCMSC

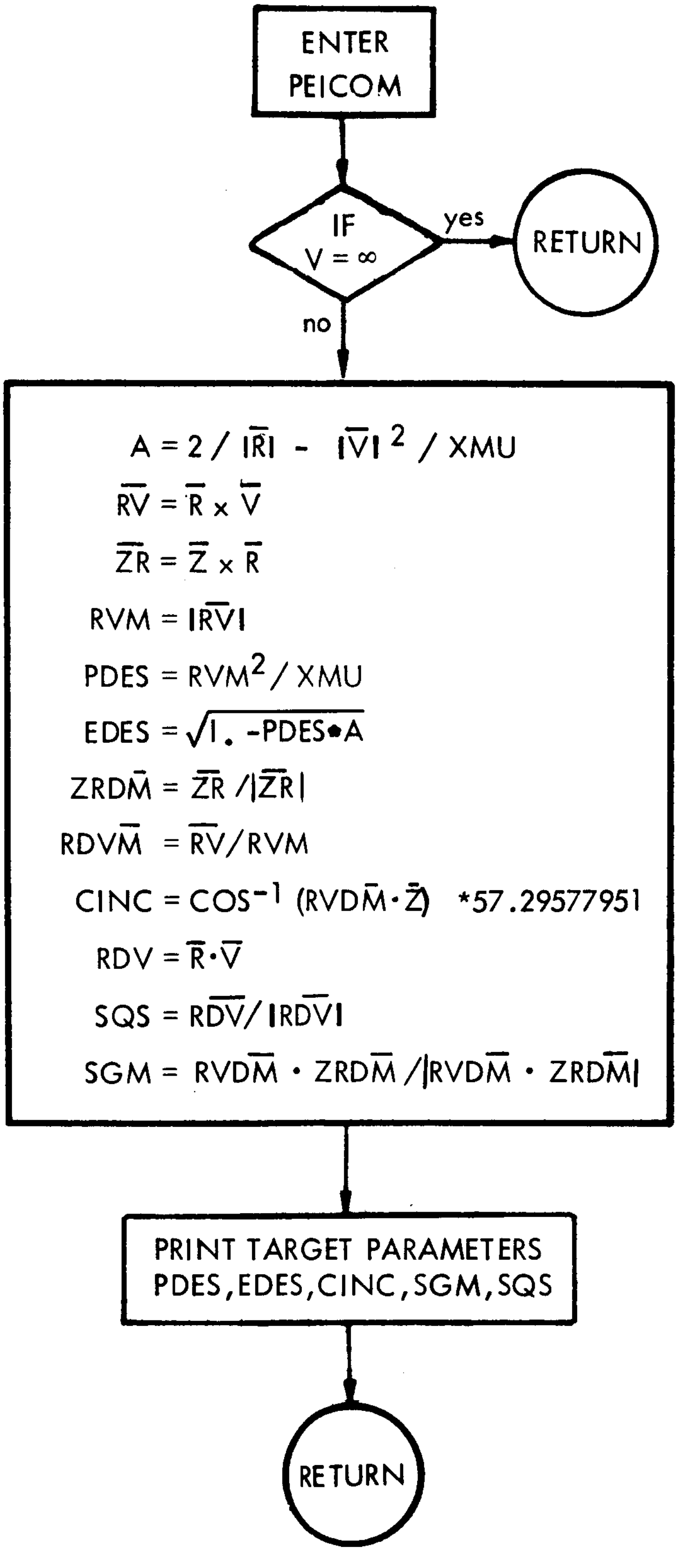
FUNCTIONS REQUIRED: SQRT

APPROXIMATE STORAGE: 193

SUBROUTINE: PEICOM

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	VEHICL	R	12	$\bar{R}$	er	Single precision vehicle position vector.
I	BURNPR	V	3	$\bar{V}_R$	er/hr	Required velocity at the end of burn.
I	AINPUT	Z	3	$\bar{Z}$		Unit vector (0,0,1).
I	INDS	XMU	1	μ	er^3/hr^2	Gravitational parameter of the central body.
O	AINPUT	PDES	1	p	er	Semi-latus rectum post abort trajectory.
O	AINPUT	EDES	1	e		Eccentricity post abort trajectory.
O	AINPUT	CINC	1	i	deg	Inclination of the post abort trajectory.
O	AINPUT	SQS	1		± 1.	Indicator defining the sign of the component of velocity at abort in the direction of $\bar{h} \times \bar{R}$.
O	AINPUT	SGM	1		± 1.	Indicator defining the sign of the radial velocity at the abort.


ENTER PEICOM
IF V = ∞
yes
RETURN
no
A = 2 / |R̄| - |V̄|² / XMU
R̄V̄ = R̄ x V̄
Z̄R̄ = Z̄ x R̄
RVM = |R̄V̄|
PDES = RVM² / XMU
EDES = √(1. -PDES*A)
ZRDM̄ = Z̄R̄ /|Z̄R̄|
RDVM̄ = R̄V̄/RVM
CINC = COS⁻¹ (RVDM̄·Z̄) *57.29577951
RDV = R̄·V̄
SQS = RD̄V̄/ |RD̄V̄|
SGM = RVDM̄ · ZRDM̄ /|RVDM̄ · ZRDM̄|
PRINT TARGET PARAMETERS
PDES,EDES,CINC,SGM,SQS
RETURN

SUBROUTINE:	PMATC
PURPOSE:	To calculate sensitivities of the velocity vector with the position vector at the lunar sphere of influence.
CALLING SEQUENCE:	CALL PMATC (CM, RS, VS, CMM1I)
NAME COMMON USED:	INM0C AINPUT C0NST INDS INTGR BURNPR INTGRK
SUBROUTINES REQUIRED:	VCMSC, LAMBS, LSCR, INV3X3
FUNCTIONS REQUIRED:	C0S, SIN, SQRT
APPROXIMATE STORAGE:	535

SUBROUTINE: PMATC

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	INM0C	RL	4	$\bar{R}_L$	er	The position vector relative to moon at time of burn initiation.
I	INM0C	RSM	4	$\bar{R}_{SM}$	er	Position relative to the moon at the lunar sphere of action.
I	INM0C	TFH	1	T_{FH}	hr	Time from $\bar{RL}$ to $\bar{RSM}$.
I	INM0C	VSS	1	V_{SS}	1/er	Square of the velocity divided by μ_E relative to the earth at lunar sphere of influence.
I		RS	4	$\bar{R}_S$	er	Position at the shift relative to the earth.
I		VS	4	$\bar{V}_S$	er/hr	Velocity at the shift relative to the earth.
I	INM0C	TS	1	T_S	hr	Time of arrival at the moon's sphere of influence measured from initial time.
I	INM0C	INCR	1	i_R	rad	Return inclination.
I	INM0C	SGM	1		± 1	Designator of the return plane.
I	AINPUT	M0DE	1			M0DE = 1, landing site. M0DE = 2, time critical. M0DE = 3, fuel critical.
I	AINPUT	C0GR	1	ctn γ_R		Cotangent of the re-entry flight path angle.
I	AINPUT	RR	1	$\lvert\bar{R}_R\rvert$	er	Magnitude of the re-entry position vector.

SUBROUTINE: PMATC (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	AINPUT	TAGG	1			= 1, abort trajectory is circumlunar from inside the sphere. = 2, abort trajectory is non-circumlunar from inside the sphere.
I	CØNST	EMU	1	μ_E	er^3/hr^2	Gravitational parameter of the earth: 19.9094165
I	CØNST	PMU	1	μ_M	er^3/hr^2	Gravitational parameter of the moon: .244883757
I	CØNST	SGMM	1	SGMM		SGMM = +1, $\theta > 180^\circ$ SGMM = -1, $\theta < 180^\circ$
I	INDS	XMU	1	μ	er^3/hr^2	Gravitational parameter of the central body.
I	INTGR	TA	1	T_A	hrs	Time of abort measured from initial time.
I	INTGR	R1	3	$\bar{R}$	er	Position of the spacecraft at time TA.
I	INTGR	V1	6	$\bar{V}$	er/hr	Velocity of the spacecraft at time TA.
I	INTGR	T	1	T_F	hrs	Time of flight from initial time to re-entry.
I	INTGR	R2	3	$\bar{R}_F$	er	Position of the spacecraft at re-entry.
Ø		CM	3,6			Perturbation matricies: $\left[\frac{\partial \bar{V}_{sm}}{\partial \bar{R}_L}\right]$

SUBROUTINE: PMATC (continued)

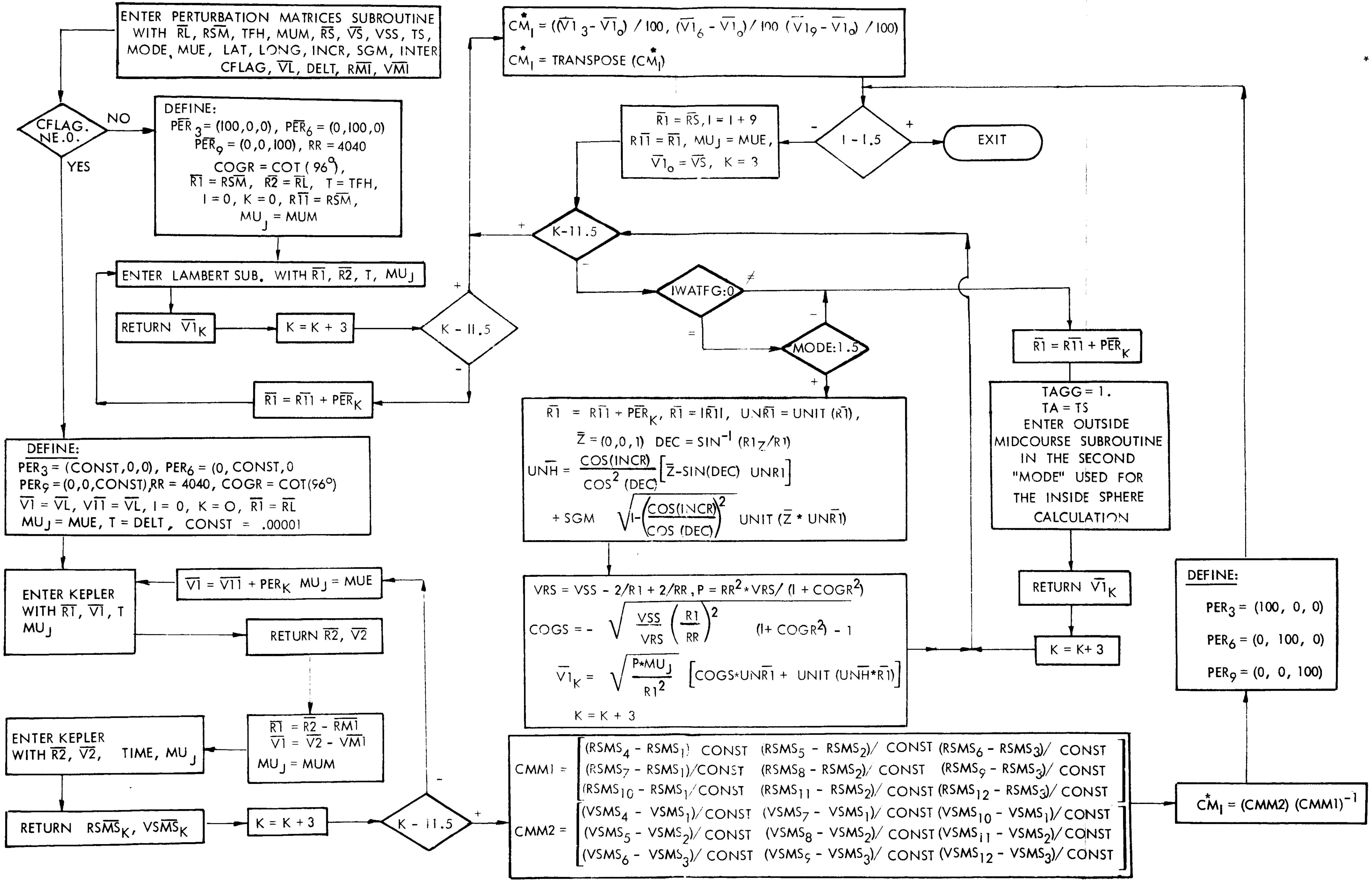
INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	INMØC	VL	4	$\bar{V}_L$	er/hr	Velocity relative to the moon at time of burn initiation.
I	INMØC	RM1	6	$\bar{R}_{M1}$	er	Moon's position at time TA + ΔT.
I	INMØC	VM1	6	$\bar{V}_{M1}$	er/hr	Moon's velocity at time TA + ΔT.
I	INMØC	DELT	1	T	hr	Time from abort to first pierce point at lunar sphere of influence.
I	AINPUT	CFLAG	1			= 0, no circumlunar logic. $\neq$ 0, do circumlunar logic.
Ø		CMM1I	3,3	$CMM1^{-1}$		Inverse of sensitivity matrix CMM1.
I	AINPUT	IWATFG	1			Land mass number = 0 if nominal trajectory impacts on water.
I	AINPUT	ØCØGR2	1			$[1 + CØGR^2]$
I	AINPUT	DV	1	ΔV_{MAX}	er/hr	Maximum allowable change in velocity.
I	AINPUT	XLAT	4	LAT	deg	Latitude of the desired landing site.
I	AINPUT	XLØNG	4	LØNG	deg	Longitude of the desired landing site.
I	CØNST	USSTER	1		miles/er	Conversion factor: 3963.20799

SUBROUTINE: PMATC (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	CONST	RADIAN	1		deg/rad	Conversion factor: 57.29577951
I	AINPUT	Z	3		Z	Unit vector (0,0,1).


ENTER PERTURBATION MATRICES SUBROUTINE WITH RL, RSM, TFH, MUM, RS, VS, VSS, TS, MODE, MUE, LAT, LONG, INCR, SGM, INTER CFLAG, VL, DELT, RMI, VMI
CFLAG. NE.0.
NO
YES
DEFINE: PER3 = (100,0,0), PER6 = (0,100,0) PER9 = (0,0,100), RR = 4040 COGR = COT (96°), R1 = RSM, R2 = RL, T = TFH, I = 0, K = 0, R11 = RSM, MUJ = MUM
ENTER LAMBERT SUB. WITH R1, R2, T, MUJ
RETURN V1K
K = K + 3
K - 11.5
+
-
R1 = R11 + PERK
DEFINE: PER3 = (CONST,0,0), PER6 = (0, CONST,0 PER9 = (0,0,CONST),RR = 4040, COGR = COT(96°) V1 = VL, V11 = VL, I = 0, K = 0, R1 = RL MUJ = MUE, T = DELT, CONST = .00001
ENTER KEPLER WITH R1, V1, T MUJ
V1 = V11 + PERK MUJ = MUE
RETURN R2, V2
R1 = R2 - RM1 V1 = V2 - VM1 MUJ = MUM
ENTER KEPLER WITH R2, V2, TIME, MUJ
RETURN RSMSK, VSMSK
K = K + 3
K - 11.5
-
+
CM*I = (V13 - V10) / 100, (V16 - V10) / 100 (V19 - V10) / 100)
CMI = TRANSPOSE (CM*I)
R1 = RS, I = I + 9 R11 = R1, MUJ = MUE, V10 = VS, K = 3
I - 1.5
-
+
EXIT
K-11.5
+
-
IWATFG:0
≠
=
MODE:1.5
-
+
R1 = R11 + PERK, R1 = |R1|, UNR1 = UNIT (R1), Z = (0,0,1) DEC = SIN⁻¹ (R1Z/R1) UNH = COS(INCR)/COS²(DEC) [Z-SIN(DEC) UNR1] + SGM √(1-(COS(INCR)/COS(DEC))²) UNIT (Z * UNR1)
VRS = VSS - 2/R1 + 2/RR, P = RR² * VRS/ (1 + COGR²) COGS = - √(VSS/VRS (R1/RR)² (1+ COGR²) - 1) V1K = √(P*MUJ/R1²) [COGS*UNR1 + UNIT (UNH*R1)] K = K + 3
R1 = R11 + PERK
TAGG = 1. TA = TS ENTER OUTSIDE MIDCOURSE SUBROUTINE IN THE SECOND "MODE" USED FOR THE INSIDE SPHERE CALCULATION
RETURN V1K
K = K+ 3
DEFINE: PER3 = (100, 0, 0) PER6 = (0, 100, 0) PER9 = (0, 0, 100)
CMM1 = [(RSMS4 - RSMS1)/ CONST (RSMS5 - RSMS2)/ CONST (RSMS6 - RSMS3)/ CONST; (RSMS7 - RSMS1)/CONST (RSMS8 - RSMS2)/ CONST (RSMS9 - RSMS3)/ CONST; (RSMS10 - RSMS1)/CONST (RSMS11 - RSMS2)/ CONST (RSMS12 - RSMS3)/ CONST]
CMM2 = [(VSMS4 - VSMS1)/CONST (VSMS7 - VSMS1)/ CONST (VSMS10 - VSMS1)/ CONST; (VSMS5 - VSMS2)/ CONST (VSMS8 - VSMS2)/ CONST (VSMS11 - VSMS2)/ CONST; (VSMS6 - VSMS3)/ CONST (VSMS9 - VSMS3)/ CONST (VSMS12 - VSMS3)/ CONST]
CM*I = (CMM2) (CMM1)⁻¹

SUBROUTINE: PRINTN

PURPOSE: To print specified trajectory parameters at specified print intervals.

CALLING SEQUENCE: CALL PRINTN (IPRINT)

NAME COMMON USED:
DINTGR
VEHICL
PERTS
VSATPT
CØNST
MISC
BURNID
AINPUT
VEH
PLANET
ELEMNT
INPUT
INDS
TINPUT
NAVERR
BURNPR

SUBROUTINES REQUIRED: VCMSC, SUBSAT, TPRINT

FUNCTIONS REQUIRED: ATAN2, SQRT

APPROXIMATE STORAGE: 2390

SUBROUTINE: PRINTN

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
O	BURNID	VRDES	3	$\bar{V}_r$	er/hr	Required velocity at end of burn.
O	BURNID	AVRDES	1	$\bar{V}_r$	er/hr	Magnitude of VRDES.
O	BURNID	VD	4	$\bar{V}_d$	er/hr	Velocity difference between actual and desired.
O	BURNID	ATM	1	a	er/hr^2	Acceleration magnitude.
O	AINPUT	RSN	4	$\bar{R}_n$	er	Position vector for navigational equations.
O	AINPUT	VSN	4	$\bar{V}_n$	er/hr	Velocity vector for navigational equations.
O	NAVERR	CGSN	3	$\bar{G}_n$	er/hr^2	Gravitational acceleration for the navigation equations.
O	NAVERR	SSG	3	$\bar{\Sigma}_g$	er/hr^2	Summation of perturbation acceleration.
O	NAVERR	DVSAN	3	$\Delta\bar{V}_{an}$	er/hr	Analytic velocity increment.
O	NAVERR	DVSIN	3	$\Delta\bar{V}_{in}$	er/hr	Integrated velocity increment.

SUBROUTINE: PTCIN

PURPOSE: To control the logical flow of the abort program when the spacecraft is within the lunar sphere of influence or on circumlunar trajectories.

CALLING SEQUENCE: CALL PTCIN

NAME COMMON USED:
INPUT
TINPUT
AINPUT
VEH
C0NST
INDS
MISC
BURNPR
RVM00N
INTGR
INM0C
INTGRK
BLANK

SUBROUTINES REQUIRED: VCMSC, ENCKE, INV3X3, LAMBS, LSCR, MATRX, MTRXMP, PMATC

UNCTIONS REQUIRED: SIN, C0S, SQRT, ABS

PPROXIMATE STORAGE: 1517

SUBROUTINE: PTCIN

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	INM0C	RL	4	$\bar{R}_L$	er	The position vector relative to the moon at time of burn initiation.
I	INM0C	RSM	4	$\bar{R}_{SM}$	er	Position relative to the moon at the lunar sphere of action.
I	INM0C	TFH	1	$\bar{T}_{FH}$	hrs	Time from $\bar{R}L$ to $\bar{R}SM$.
I	C0NST	PMU	1	μ_M	er^3/hr^2	Gravitational parameter of the moon: .244883757
I	INM0C	VL	6	$\bar{V}_L$	er/hr	Velocity relative to the moon at time of burn initiation.
I	INM0C	TL	1	T_L	hr	Time of burn initiation.
I	INM0C	RR	4	$\bar{R}_R$	er	Desired re-entry position vector.
I		VR	4	$\bar{V}_R$	er/hr	The required velocity at re-entry.
I	INM0C	TFE	1	T_{FE}	hr	Time of flight from $\bar{R}S$ to $\bar{R}R$.
I	INM0C	TS	1	T_S	hr	Time of arrival at the moon's sphere of influence measured from initial time.
I	INM0C	VSS	1	V_{SS}	1/er	Square of the velocity divided by μ_E relative to the earth at the lunar sphere of influence.
I	INM0C	RS	4	$\bar{R}_S$	er	Position at the shift relative to the earth.

SUBROUTINE: PTCIN (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	INMØC	VS	4	$\bar{V}_S$	er/hr	Velocity at the shift relative to the earth.
I	CØNST	EMU	1	μ_E	er^3/hr^2	Gravitational parameter of the earth: 19.9094165
I		LAT		LAT	deg	Latitude of the desired landing site.
I		LØNG		LØNG	deg	Longitude of the desired landing site.
I	INMØC	INCR	1	i_R	rad	Return inclination.
I	INMØC	SGM	1		± 1	Designator of the return plane.
I	AINPUT	MØDE	1			MØDE = 1. landing site. MØDE = 2, time critical. MØDE = 3. fuel critical.
I	AINPUT	DV	1	ΔV_{MAX}	er/hr	Maximum allowable change in velocity.
I	AINPUT	CØGR	1	$\text{ctn}\ \gamma_R$		Cotangent of the re-entry flight path angle.
I	AINPUT	TAGG	1			= 1, abort trajectory is circumlunar. = 2, abort trajectory is non-circumlunar.
Ø		VSM	4	V_S	er/hr	Velocity at the lunar sphere of action relative to the moon.
Ø		VLC	4	V_B	er/hr	Velocity at burn termination relative to the moon.

SUBROUTINE: PTCIN (continued)

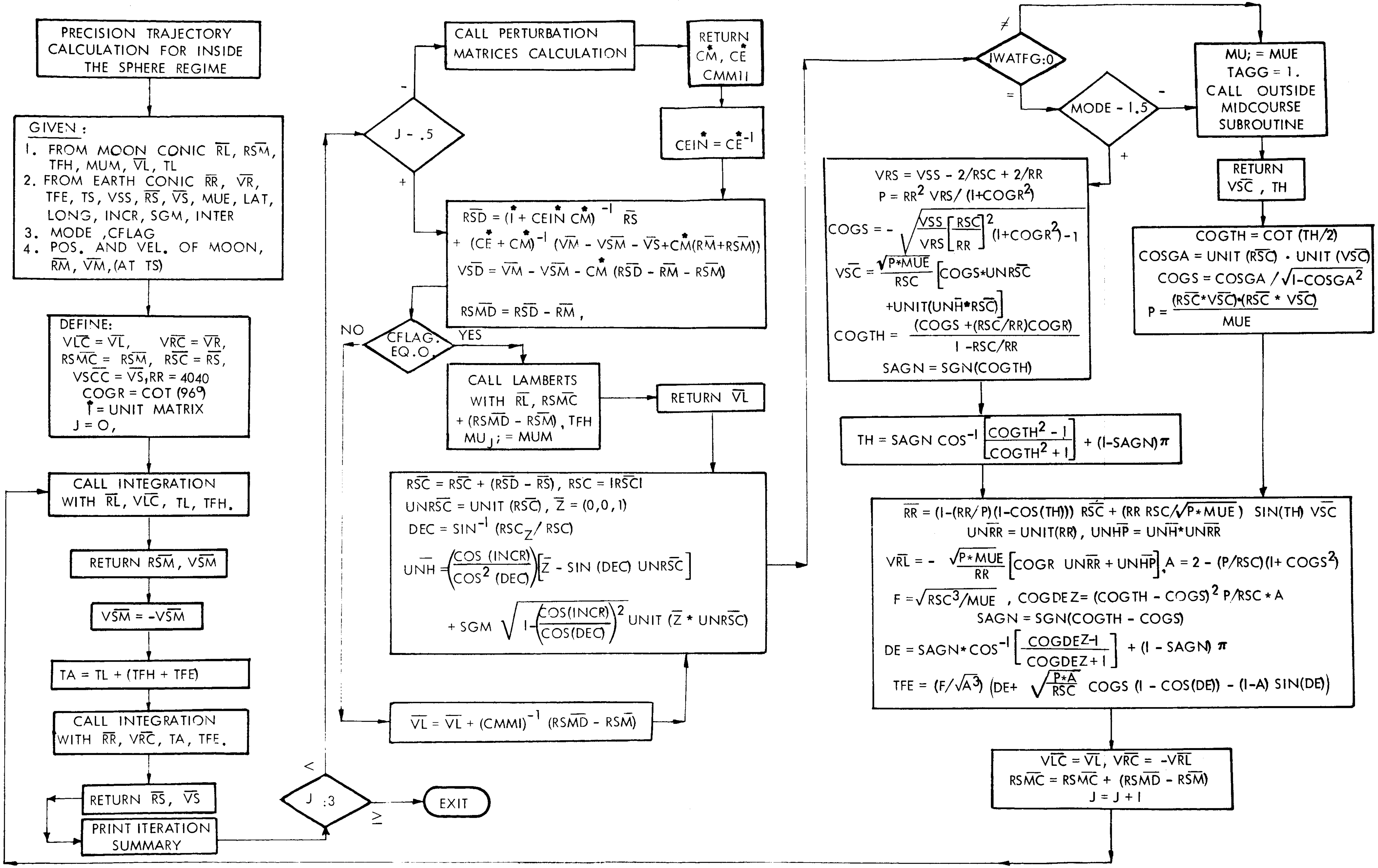
INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	AINPUT	Z	3	$\bar{Z}$		Unit vector (0,0,1).
I	INTGR	TA	1	T_A	hr	Time measured from epoch to abort.
I	BURNPR	NTPRSV	1			Input value of the number of thrust periods.
I	INPUT	X	3	R_I	er	Position at the abort time relative to the moon.
I	INPUT	XD	3	V_I	er/hr	Velocity at the abort time relative to the moon.
O		DELR	4	ΔR	er	Position mismatch at the lunar sphere of action.
O		DELV	4	ΔV	er/hr	Velocity mismatch at the lunar sphere of action.
I	RVMOON	RM	6	$\bar{R}_M$	er	Position of the moon with respect to the earth at time T_S.
I	RVMOON	VM	6	$\bar{V}_M$	er/hr	Velocity of the moon with respect to the earth at time T_S.
I	AINPUT	CFLAG	1			= 0, no circumlunar logic. ≠ 0, do circumlunar logic.
I		CMM1I	3,3	$CMM1^{-1}$		Inverse of the sensitivity matrix CMM1.
I	INMOC	VL	4	$\bar{V}_L$	er/hr	Velocity relative to the moon at time of burn initiation.

SUBROUTINE: PTCIN (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	AINPUT	IWATFG	1			Land mass number = 0 nominal trajectory impacts on water.
I	AINPUT	OCOGR2	1			$\left[1 + COGR^2\right]$
I	INMOC	THC	1	θ_r	rad	Re-entry angle.
O		VRC	4	V_B	er/hr	Re-entry velocity.


PRECISION TRAJECTORY CALCULATION FOR INSIDE THE SPHERE REGIME
GIVEN :
1. FROM MOON CONIC RL, RSM, TFH, MUM, VL, TL
2. FROM EARTH CONIC RR, VR, TFE, TS, VSS, RS, VS, MUE, LAT, LONG, INCR, SGM, INTER
3. MODE ,CFLAG
4. POS. AND VEL. OF MOON, RM, VM, (AT TS)
DEFINE:
VLC = VL, VRC = VR,
RSMC = RSM, RSC = RS,
VSCC = VS, RR = 4040
COGR = COT (96°)
I = UNIT MATRIX
J = 0,
CALL INTEGRATION WITH RL, VLC, TL, TFH.
RETURN RSM, VSM
VSM = -VSM
TA = TL + (TFH + TFE)
CALL INTEGRATION WITH RR, VRC, TA, TFE.
RETURN RS, VS
PRINT ITERATION SUMMARY
J :3
<
≥
EXIT
J - .5
-
+
CALL PERTURBATION MATRICES CALCULATION
RETURN CM, CE CMMI1
CEIN = CE^-1
RSD = (I + CEIN CM)^-1 RS
+ (CE + CM)^-1 (VM - VSM - VS + CM(RM + RSM))
VSD = VM - VSM - CM (RSD - RM - RSM)
RSMD = RSD - RM ,
CFLAG. EQ.0
NO
YES
CALL LAMBERTS WITH RL, RSMC + (RSMD - RSM), TFH MUJ; = MUM
RETURN VL
RSC = RSC + (RSD - RS), RSC = |RSC|
UNRSC = UNIT (RSC), Z = (0,0,1)
DEC = SIN^-1 (RSC_Z / RSC)
UNH = (COS (INCR) / COS^2 (DEC)) [Z - SIN (DEC) UNRSC]
+ SGM √(1 - (COS(INCR)/COS(DEC))^2) UNIT (Z * UNRSC)
VL = VL + (CMMI)^-1 (RSMD - RSM)
IWATFG:0
≠
=
MODE - 1.5
-
+
MU; = MUE
TAGG = 1.
CALL OUTSIDE MIDCOURSE SUBROUTINE
RETURN VSC , TH
COGTH = COT (TH/2)
COSGA = UNIT (RSC) · UNIT (VSC)
COGS = COSGA / √(1-COSGA^2)
P = (RSC*VSC)·(RSC * VSC) / MUE
VRS = VSS - 2/RSC + 2/RR
P = RR^2 VRS/ (1+COGR^2)
COGS = - √((VSS/VRS) [RSC/RR]^2 (1+COGR^2) - 1)
VSC = (√(P*MUE) / RSC) [COGS*UNRSC + UNIT(UNH*RSC)]
COGTH = (COGS +(RSC/RR)COGR) / (1 -RSC/RR)
SAGN = SGN(COGTH)
TH = SAGN COS^-1 [(COGTH^2 - 1)/(COGTH^2 + 1)] + (1-SAGN)π
RR = (1-(RR/P)(1-COS(TH))) RSC + (RR RSC/√(P*MUE)) SIN(TH) VSC
UNRR = UNIT(RR), UNHP = UNH*UNRR
VRL = - (√(P*MUE) / RR) [COGR UNRR + UNHP], A = 2 - (P/RSC)(1+ COGS^2)
F = √(RSC^3/MUE) , COGDEZ = (COGTH - COGS)^2 P/RSC * A
SAGN = SGN(COGTH - COGS)
DE = SAGN*COS^-1 [(COGDEZ-1)/(COGDEZ+1)] + (1 - SAGN) π
TFE = (F/√A^3) (DE+ √(P*A/RSC) COGS (1 - COS(DE)) - (1-A) SIN(DE))
VLC = VL, VRC = -VRL
RSMC = RSMC + (RSMD - RSM)
J = J + 1

SUBROUTINE: REENTY

PURPOSE: To solve for the conic which satisfies the landing site and re-entry constraints.

CALLING SEQUENCE: CALL REENTY (TFLS, THLS, AMX, NØSØ, TFM)

NAME COMMON USED:
INMØC
INTGR
INTGRK
CØNST
AINPUT

SUBROUTINES REQUIRED: VCMSC

FUNCTIONS REQUIRED: SQRT, ABS, CØS, SIN

APPROXIMATE STORAGE: 348

SUBROUTINE: REENTY

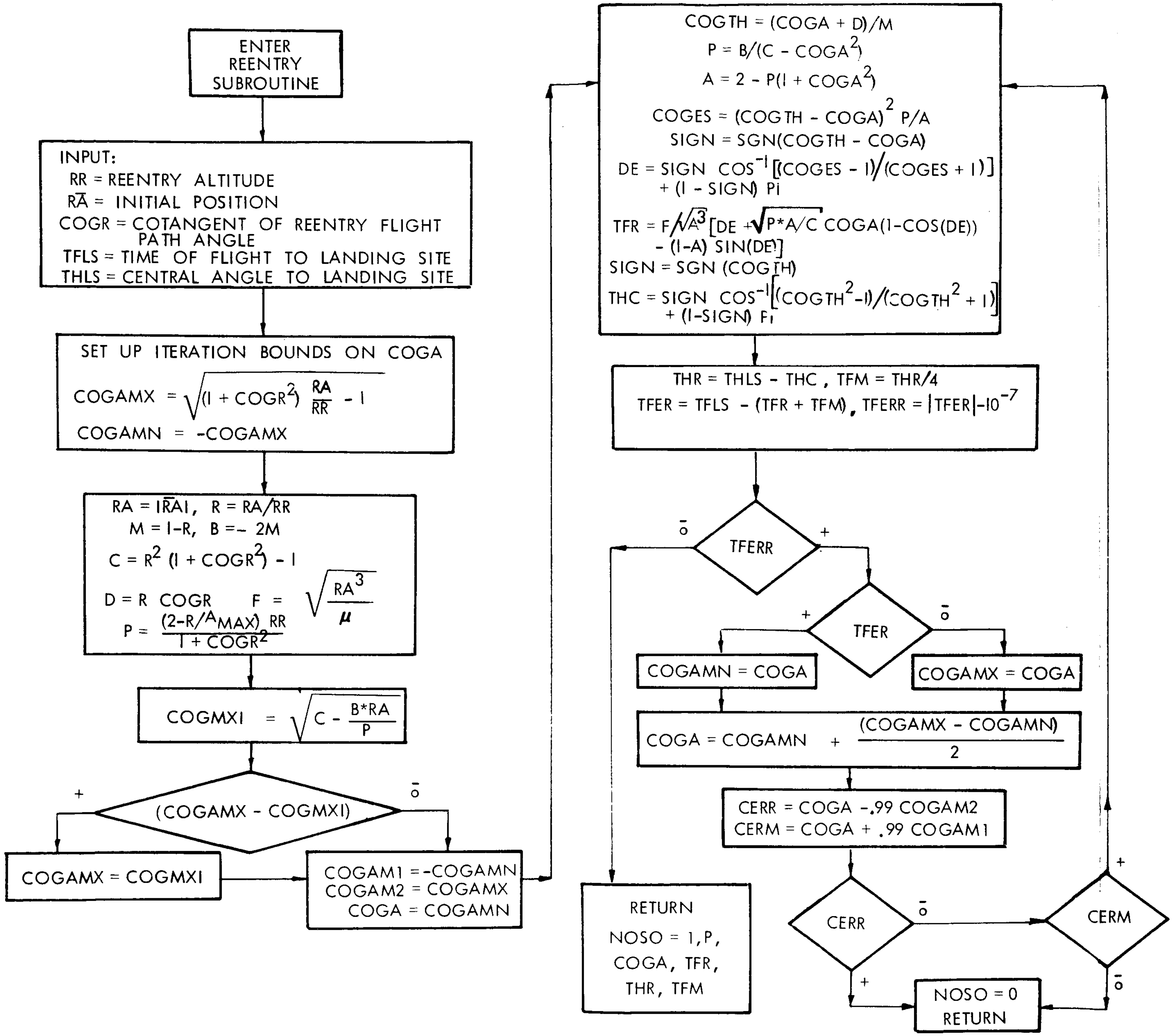
INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	INTGR	RAB	6	$\bar{R}_b$	er	Position of the spacecraft at time of abort measured from initial time.
I	AINPUT	CØGR	1	ctn γ_R		Cotangent of the re-entry flight path angle. cot (90°)
I	AINPUT	RR	1	$\|\bar{R}_R\|$	er	Magnitude of the re-entry position vector.
I		THLS	1	θ_{LS}	rad	Central angle from $\bar{R}$ to UN$\bar{R}$LS.
I		TFLS	1	TF_{LS}	hr	Time of flight to the landing site.
I		AMX	1	A_{MX}	er	Limiting value of the semi-major axis.
I	CØNST	EMU	1	μ	er^3/hr^2	Gravitational constant of the earth: 19.9094165
I	CØNST	PI	1	π		3.141592654
I	CØNST	RADIAN	1		deg/rad	57.29577951
Ø		NØSØ	1			NØSØ = 0, return no solution. NØSØ = 1, return solution.
Ø		TFM	1	T_{FM}	hr	Time of flight from re-entry to landing site.
Ø	INTGRK	TFR	1	T_{FR}	hr	Time of flight to re-entry from TA.

SUBROUTINE: REENTY (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
Ø	INTGRK	THR	1	θ_R	rad	Re-entry range angle.
Ø	INTGRK	CØGA	1	ctn γ		Cotangent of the return conic γ at position $\bar{R}$.
Ø	INTGRK	P	1	P		Return conic semi-latus rectum.
Ø	INMØC	THC	1	θ_R	rad	Re-entry angle.
I	AINPUT	ØCØGR2	1			$[1 + CØGR^2]$


ENTER REENTRY SUBROUTINE
INPUT:
RR = REENTRY ALTITUDE
R̄A = INITIAL POSITION
COGR = COTANGENT OF REENTRY FLIGHT PATH ANGLE
TFLS = TIME OF FLIGHT TO LANDING SITE
THLS = CENTRAL ANGLE TO LANDING SITE
SET UP ITERATION BOUNDS ON COGA
COGAMX = √((1 + COGR²) RA/RR - 1)
COGAMN = -COGAMX
RA = |R̄A|, R = RA/RR
M = 1-R, B = - 2M
C = R² (1 + COGR²) - 1
D = R COGR   F = √(RA³/μ)
P = (2-R/AMAX) RR / (1 + COGR²)
COGMX1 = √(C - B*RA/P)
(COGAMX - COGMX1)
+
0̄
COGAMX = COGMX1
COGAM1 = -COGAMN
COGAM2 = COGAMX
COGA = COGAMN
COGTH = (COGA + D)/M
P = B/(C - COGA²)
A = 2 - P(1 + COGA²)
COGES = (COGTH - COGA)² P/A
SIGN = SGN(COGTH - COGA)
DE = SIGN COS⁻¹[(COGES - 1)/(COGES + 1)] + (1 - SIGN) Pi
TFR = F/√A³ [DE + √(P*A/C) COGA(1-COS(DE)) - (1-A) SIN(DE)]
SIGN = SGN (COGTH)
THC = SIGN COS⁻¹[(COGTH²-1)/(COGTH² + 1)] + (1-SIGN) Pi
THR = THLS - THC, TFM = THR/4
TFER = TFLS - (TFR + TFM), TFERR = |TFER|-10⁻⁷
TFERR
0̄
+
TFER
+
0̄
COGAMN = COGA
COGAMX = COGA
COGA = COGAMN + (COGAMX - COGAMN)/2
CERR = COGA -.99 COGAM2
CERM = COGA + .99 COGAM1
RETURN
NOSO = 1, P, COGA, TFR, THR, TFM
CERR
0̄
+
CERM
+
0̄
NOSO = 0
RETURN

SUBROUTINE: SYMBOL

PURPOSE: To store program input quantities in their assigned locations.

CALLING SEQUENCE: None

NAME COMMON USED:
INPUT
AUTO
CONST
INDS
MISC
TINPUT
AINPUT
BURNPR

SUBROUTINES REQUIRED: None

FUNCTIONS REQUIRED: None

APPROXIMATE STORAGE: 487

SUBROUTINE: SYMBØL

INPUT AND OUTPUT: ADDITIONAL INPUT

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	AINPUT	NAVFL	1			Input flag to use navigation equations.
I	AINPUT	DUR	1	ΔU	er	Input position error, navigation equations.
I	AINPUT	DVR	1	ΔV	er	Input position error, navigation equations.
I	AINPUT	DWR	1	ΔW	er	Input position error, navigation equations.
I	AINPUT	DDUR	1	$\Delta \dot{U}$	er/hr	Input velocity error, navigation equations.
I	AINPUT	DDVR	1	$\Delta \dot{V}$	er/hr	Input velocity error, navigation equations.
I	AINPUT	DDWR	1	$\Delta \dot{W}$	er/hr	Input velocity error, navigation equations.
I	AINPUT	SQS	1			Indicator defining the sign of velocity at the abort radial.
I	AINPUT	PDES	1	P	er	Semi-latus rectum post abort trajectory.
I	AINPUT	EDES	1	e		Eccentricity post abort trajectory.
I	AINPUT	CINC	1	i	deg	Inclination post abort trajectory relative to the earth's equator.
I	AINPUT	SGM	1			Indicator defining the sign of the component of the post abort velocity in the direction of $\underline{h} \times \underline{R}$.

SUBROUTINE: SYMBØL (continued)

INPUT AND OUTPUT: ADDITIONAL INPUT

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	AINPUT	UKV	3	$\bar{Z}$		Unit vector (0,0,1).
I	AINPUT	IAMØDE	1			Analytic mode type: 1 - landing site. 2 - time critical. 3 - fuel critical.
I	AINPUT	AVFUEL	1	ΔV	er/hr	Available fuel.
I	AINPUT	CØGR	1	ctn γ_R		Cotangent of the re-entry flight path angle.
I	AINPUT	RR	1	$\lvert\bar{R}_R\rvert$	er	Magnitude of the re-entry position vector.
I	AINPUT	NLS	1			Number of landing sites (NLS $\leq$ 4).
I	AINPUT	ALAT	4	LAT	deg	Latitudes of the possible landing sites.
I	AINPUT	ALØN	4	LØNG	deg	Longitudes of the possible landing sites.
I	BURNPR	VR	3	$\bar{V}_R$	er/hr	Velocity required at end of burn.
I	BURNPR	BURNFL	1			= -1, non-iterative run. = 0, impulsive burn no burn print. = 2, impulsive burn, burn print. = 3, integrated burn no burn print. = 4, integrated burn, burn print.
I	BURNPR	DELTI	1	ΔT_1	hrs	Minimum time from initial time to beginning of abort (.016666666) if not input.

SUBROUTINE: SYMB0L (continued)

INPUT AND OUTPUT: ADDITIONAL INPUT

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	AINPUT	H20FG	1			= 1, compute a water landing site. = 0, do not use water landing logic.
I	AINPUT	CFLAG	1			= 0, no circumlunar logic. = 1, do circumlunar logic.
I	AINPUT	RPMIN	1	R_{PMIN}	er	Minimum allowable lunar pericynthian altitude.
I	INPUT	URMAX	1	U_{RMAX}	er/hr	Magnitude of the maximum allowable re-entry velocity.
I	BURNPR	BURNFL	1			= -1, non-iterative run. = 0, impulsive burn, no burn print. = 2, impuslive burn, burn print.
						= 3, integrated burn, no burn print. = 4, integrated burn, burn print.

SUBROUTINE:	TCFC
PURPOSE:	To establish the conic trajectory satisfying the re-entry constraints and which will return the spacecraft in the shortest time with the available fuel, or will return the spacecraft with the minimum fuel.
CALLING SEQUENCE:	CALL TCFC
NAME COMMON USED:	CØNST BURNPR AINPUT INTGR INTGRK ØTPT
SUBROUTINES REQUIRED:	LAMBS, LATLØN, VCMSC
FUNCTIONS REQUIRED:	SIN, CØS, ABS, SQRT
APPROXIMATE STORAGE:	652

SUBROUTINE: TCFC

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	INTGR	RAB	6	$\bar{R}$	er	Position of the spacecraft at time TA.
I	INTGR	VAB	6	$\bar{V}$	er/hr	Velocity of the spacecraft at time TA.
I	AINPUT	DV	1	ΔV	er/hr	The maximum allowable change in velocity if non-zero. If = 0, compute minimum velocity transfer.
I	INTGR	TA	1	TA	hrs	Time of abort measured from initial time.
I	AINPUT	CØGR	1	$\text{ctn}\,\gamma_R$		Cotangent of the re-entry flight path angle.
I	AINPUT	RR	1	$\bar{R}_R$	er	Magnitude of the re-entry position vector.
I	AINPUT	MØDE	1			MØDE = 1, landing site. MØDE = 2, time critical. MODE = 3, fuel critical.
I	CØNST	EMU	1	μ	er^3/hr^2	Gravitational parameter of the earth. 19.9094165
I	CØNST	USSTER	1		$\frac{\text{statute mi.}}{\text{er}}$	Conversion factor: 3963.20799
I	CØNST	PI	1	π		3.141592654
Ø	INTGR	TF	1	TF	hr	Total time of flight from initial time to re-entry.
Ø	INTGR	TBURN	1	T_B	hr	Time of burn initiation measured from initial time.

SUBROUTINE: TCFC (continued)

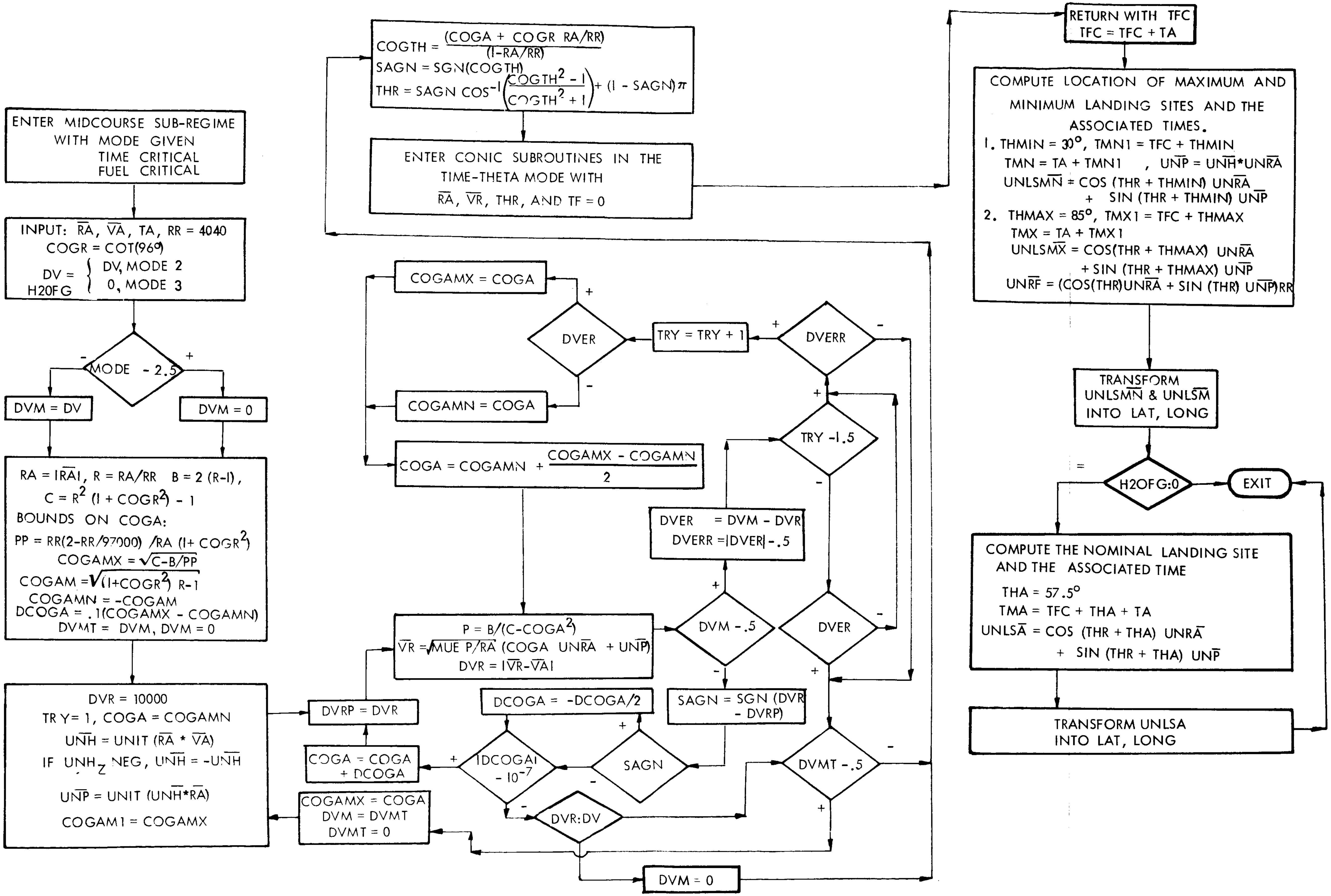
INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
Ø	BURNPR	BURNVR	3	V_R	er/hr	Velocity required at end of burn.
Ø		MINLAT	1	θ_{min}	rad	Latitude of the landing site corresponding to the minimum re-entry range angle.
Ø		MINLØN	1	λ_{min}	rad	Longitude of the landing site corresponding to the minimum re-entry range angle.
Ø		MAXLAT	1	θ_{max}	rad	Latitude of the landing site corresponding to the maximum re-entry range angle.
Ø		MAXLØN	1	λ_{max}	rad	Longitude of the landing site corresponding to the maximum re-entry range angle.
I	CØNST	RADIAN	1		deg/rad	57.29577951
Ø	AINPUT	INØSØF	1			= 0, if no solution has been computed. = 1, if a solution has been computed.
I	AINPUT	H2ØFG	1			Input flag for water landing logic.
I	AINPUT	ØCØGR2	1			$\left[1 + COGR^2\right]$
Ø	ØTPT	DVR	1	ΔV_r	er/hr	Required velocity change for the computed analytic solution.
Ø	INTGR	UNRF	6	$\bar{R}$	er	Desired position vector at re-entry.
Ø		ALAT	1	LAT	deg	Nominal landing site's latitude. Computed only if H2ØFG = 1.

SUBROUTINE: TCFC (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
O		ALON	1	LONG	deg	Nominal landing site's longitude. Computed only if H2OFG = 1.


ENTER MIDCOURSE SUB-REGIME WITH MODE GIVEN TIME CRITICAL FUEL CRITICAL
INPUT: RA, VA, TA, RR = 4040
COGR = COT(96°)
DV = DV, MODE 2
H2OFG 0, MODE 3
MODE - 2.5
-
+
DVM = DV
DVM = 0
RA = |RA|, R = RA/RR B = 2 (R-1),
C = R² (1 + COGR²) - 1
BOUNDS ON COGA:
PP = RR(2-RR/97000) /RA (1+ COGR²)
COGAMX = √C-B/PP
COGAM = √(1+COGR²) R-1
COGAMN = -COGAM
DCOGA = .1(COGAMX - COGAMN)
DVMT = DVM, DVM = 0
DVR = 10000
TRY = 1, COGA = COGAMN
UNH = UNIT (RA * VA)
IF UNHz NEG, UNH = -UNH
UNP = UNIT (UNH*RA)
COGAM1 = COGAMX
COGTH = (COGA + COGR RA/RR) / (1-RA/RR)
SAGN = SGN(COGTH)
THR = SAGN COS⁻¹ ((COGTH² - 1)/(COGTH² + 1)) + (1 - SAGN)π
ENTER CONIC SUBROUTINES IN THE TIME-THETA MODE WITH RA, VR, THR, AND TF = 0
COGAMX = COGA
DVER
+
-
COGAMN = COGA
TRY = TRY + 1
DVERR
+
-
TRY -1.5
+
-
COGA = COGAMN + (COGAMX - COGAMN)/2
DVER = DVM - DVR
DVERR = |DVER| - .5
P = B/(C-COGA²)
VR = √MUE P/RA (COGA UNRA + UNP)
DVR = |VR-VA|
DVM -.5
+
-
DVER
-
+
DVRP = DVR
COGA = COGA + DCOGA
DCOGA = -DCOGA/2
SAGN = SGN (DVR - DVRP)
|DCOGA| - 10⁻⁷
+
-
SAGN
+
-
DVMT -.5
-
+
COGAMX = COGA
DVM = DVMT
DVMT = 0
DVR:DV
DVM = 0
RETURN WITH TFC
TFC = TFC + TA
COMPUTE LOCATION OF MAXIMUM AND MINIMUM LANDING SITES AND THE ASSOCIATED TIMES.
1. THMIN = 30°, TMN1 = TFC + THMIN
TMN = TA + TMN1 , UNP = UNH*UNRA
UNLSMN = COS (THR + THMIN) UNRA + SIN (THR + THMIN) UNP
2. THMAX = 85°, TMX1 = TFC + THMAX
TMX = TA + TMX1
UNLSMX = COS(THR + THMAX) UNRA + SIN (THR + THMAX) UNP
UNRF = (COS(THR)UNRA + SIN (THR) UNP)RR
TRANSFORM UNLSMN & UNLSM INTO LAT, LONG
H2OFG:0
=
EXIT
COMPUTE THE NOMINAL LANDING SITE AND THE ASSOCIATED TIME
THA = 57.5°
TMA = TFC + THA + TA
UNLSA = COS (THR + THA) UNRA + SIN (THR + THA) UNP
TRANSFORM UNLSA INTO LAT, LONG

SUBROUTINE: TCUT

PURPOSE: To control the initiation and termination of the thrusting phases.

CALLING SEQUENCE: CALL TCUT (INDIC)

NAME COMMON USED:
DINTGR
VEH
VEHICL
BURNID
PERTS
TINPUT
INPUT
INDS
AUTO
MISC
NAVERR
BURNPR
INTGR

SUBROUTINES REQUIRES: INITAL, NAVIER, VECT, PEICOM, VCMSC, SUMR, DERIV, RKINT

FUNCTIONS REQUIRED: EXP

APPROXIMATE STORAGE: 423

SUBROUTINE: TCUT

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I		INDIC	1			Initialization indicator.
I	DINTGR	T	1	T	hrs	Current time double precision.
I/0	TINPUT	NTPR	1			Number of thrust print cycles.
I	TINPUT	TTR	1	T_T	hrs	Time to start thrust.
I	INPUT	TSTART	1	T_o	hrs	Epoch time in hours from 0^h day of epoch.
I	VEH	R	12	$\bar{R}$	er	Double precision position vector.
0	INTGR	SR	6	$\bar{R}_T$	er	Position at start of thrust.
I	VEHICL	R0	12	$\bar{R}$	er	Single precision position vector.
I	VEHICL	RD0	12	$\bar{V}$	er/hr	Single precision velocity vector.
0	BURNID	XR	4	$\bar{R}_F$	er	Position required.
0	BURNID	XDR	4	ΔV_F	er/hr	Velocity difference required.
0	INDS	ITHRST	1			= 1, start thrust = -1, end thrust

SUBROUTINE: TCUT (continued)

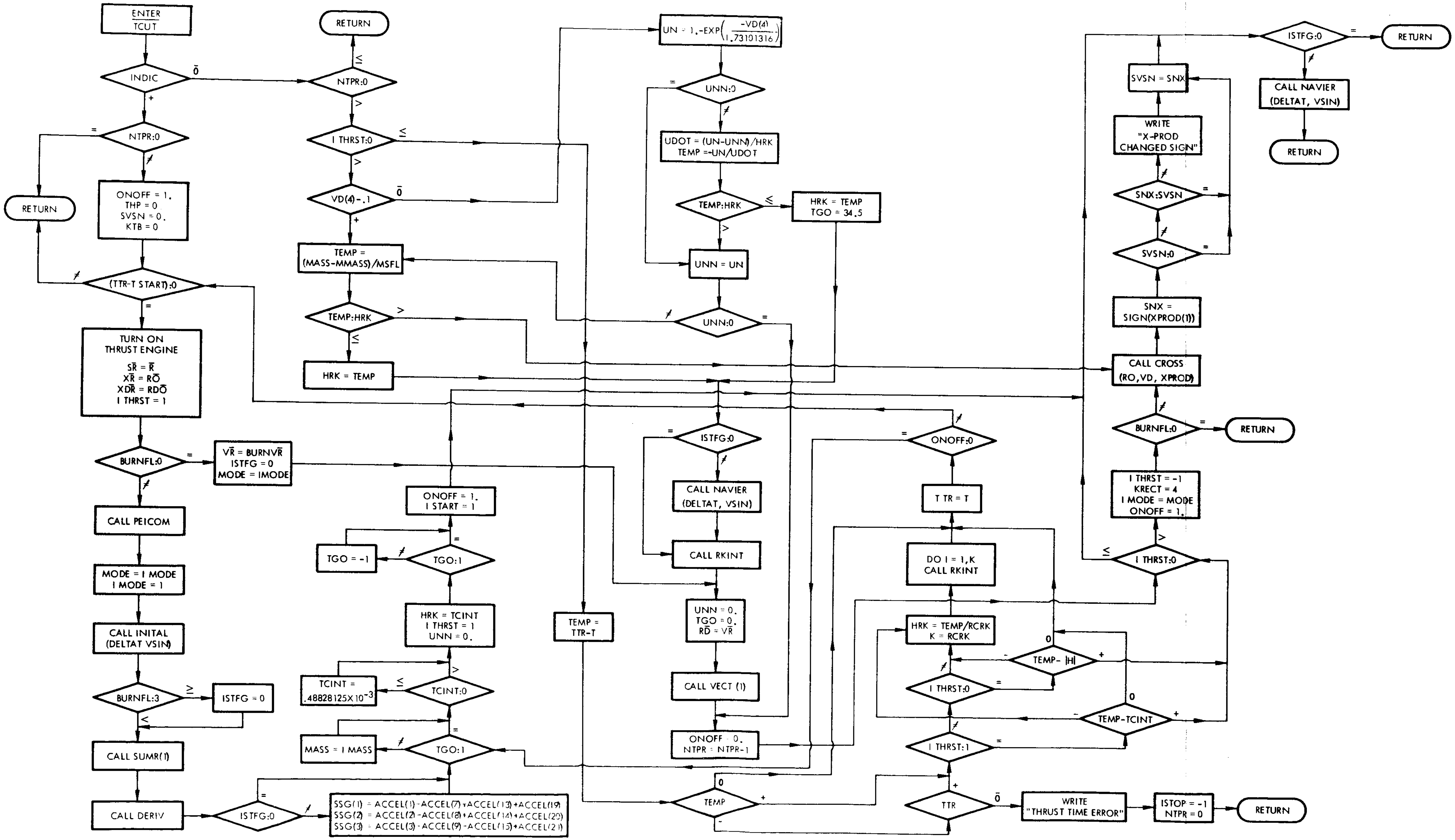
INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	BURNPR	BURNFL	1			= -1, non-iterative run. = 0, impulsive burn no burn print. = 2, impulsive burn, burn print.
						= 3, integrated burn no burn print. = 4, integrated burn, burn print.
O	BURNID	VR	3	V_r	er/hr	Required velocity at thrust termination.
I	BURNPR	BURNVR	3	V_r	er/hr	Required velocity at thrust termination.
O	NAVERR	ISTFG	1			= 1, use navigation errors. = 0, do not use navigation errors.
I	INDS	IMODE	1			Integration type: = 0, Encke = 1, Cowell
O	NAVERR	SSG	3	Σ_g	er/hr^2	Summation of perturbation accelerations.
I	PERTS	ACCEL	30		er/hr^2	Perturbation accelerations double precision.
I	BURNID	TGO	1	t_{go}	hr	Thrust time to go.
I/O	BURNID	MASS	1	W	lbs	Current mass of the vehicle.
I	TINPUT	IMASS	1	W_o	lbs	Input mass of the vehicle.
O	TINPUT	TCINT	1	T_c	hrs	Cowell integration step size.

SUBROUTINE: TCUT (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
O	AUTO	HRK	1	T	hrs	Integration step size runge-kutta.
I	BURNID	VD	4	ΔV	er/hr	Velocity difference.
I	TINPUT	MMASS	1	W_m	lbs	Minimum mass during thrust.
I	TINPUT	MSFL	1	$\dot{W}$	lbs/hr	Mass flow rate.
O	VEH	RD	12	$\bar{V}$	er/hr	Double precision velocity vector of the vehicle.
O	INDS	KRECT	1			Rectification code.
O	MISC	ISTOP	1			= -1, thrust time error.


ENTER
TCUT
INDIC
NTPR:0
ONOFF = 1.
THP = 0
SVSN = 0.
KTB = 0
RETURN
(TTR-T START):0
TURN ON
THRUST ENGINE
SR̄ = R̄
XR̄ = RŌ
XDR̄ = RDŌ
I THRST = 1
BURNFL:0
VR̄ = BURNVR̄
ISTFG = 0
MODE = IMODE
CALL PEICOM
MODE = I MODE
I MODE = 1
CALL INITAL
(DELTAT VSIN)
BURNFL:3
ISTFG = 0
CALL SUMR(1)
CALL DERIV
ISTFG:0
SSG(1) = ACCEL(1)-ACCEL(7)+ACCEL(13)+ACCEL(19)
SSG(2) = ACCEL(2)-ACCEL(8)+ACCEL(14)+ACCEL(20)
SSG(3) = ACCEL(3)-ACCEL(9)-ACCEL(15)+ACCEL(21)
RETURN
NTPR:0
I THRST:0
VD(4)-.1
TEMP =
(MASS-MMASS)/MSFL
TEMP:HRK
HRK = TEMP
ONOFF = 1.
I START = 1
TGO = -1
TGO:1
HRK = TCINT
I THRST = 1
UNN = 0.
TCINT =
.48828125X10⁻³
TCINT:0
MASS = I MASS
TGO:1
TEMP =
TTR-T
UN = 1.-EXP(-VD(4)/1.73101316)
UNN:0
UDOT = (UN-UNN)/HRK
TEMP =-UN/UDOT
TEMP:HRK
HRK = TEMP
TGO = 34.5
UNN = UN
UNN:0
ISTFG:0
CALL NAVIER
(DELTAT, VSIN)
CALL RKINT
UNN = 0.
TGO = 0.
RD̄ = VR̄
CALL VECT (1)
ONOFF = 0.
NTPR = NTPR-1
TEMP
ONOFF:0
T TR = T
DO I = 1,K
CALL RKINT
HRK = TEMP/RCRK
K = RCRK
I THRST:0
TEMP- |H|
TEMP-TCINT
I THRST:1
TTR
WRITE
"THRUST TIME ERROR"
ISTOP = -1
NTPR = 0
RETURN
SVSN = SNX
WRITE
"X-PROD
CHANGED SIGN"
SNX:SVSN
SVSN:0
SNX =
SIGN(XPROD(1))
CALL CROSS
(RO,VD, XPROD)
BURNFL:0
RETURN
I THRST = -1
KRECT = 4
I MODE = MODE
ONOFF = 1.
I THRST:0
ISTFG:0
RETURN
CALL NAVIER
(DELTAT, VSIN)
RETURN

SUBROUTINE:	THRUS1
PURPOSE:	To compute the components of acceleration due to the thrusting of the spacecraft and using the MIT guidance equations.
CALLING SEQUENCE:	CALL THRUS1
NAME COMMON USED:	DINTGR VEHICL BURNID PERTS NAVERR TINPUT AINPUT C0NST INDS
SUBROUTINES REQUIRED:	VCMSC
FUNCTIONS REQUIRED:	SQRT, C0S
APPROXIMATE STORAGE:	301

SUBROUTINE: THRUS1

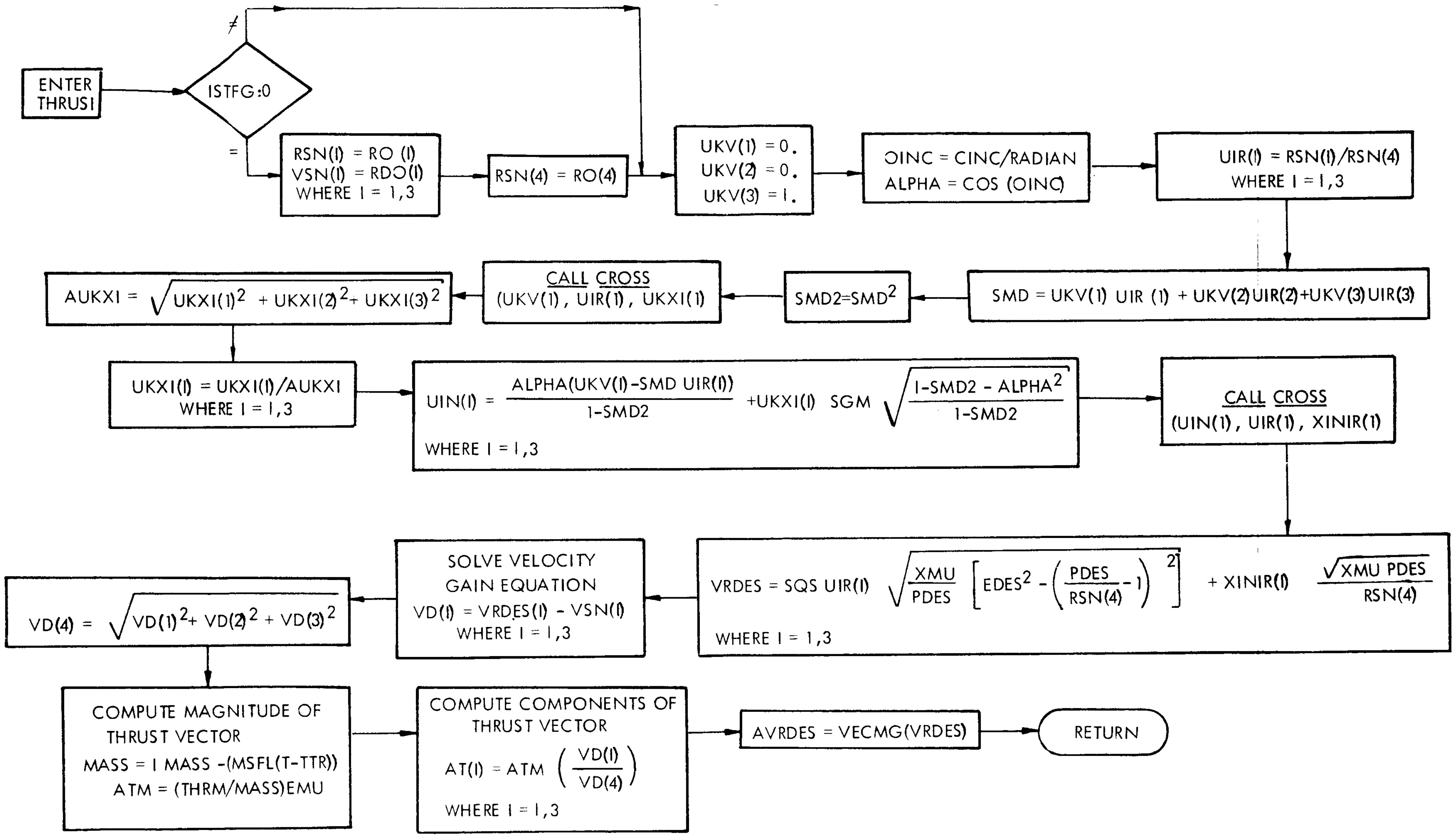
INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	NAVERR	ISTFG	1			= 1, navigation equations are to be used.
I	AINPUT	RSN	4	$\bar{R}_N$	er	Position vector for navigation equations.
I	AINPUT	VSN	3	$\bar{V}_N$	er/hr	Velocity vector for navigation equations.
I	VEHICL	R0	12	$\bar{R}$	er	Single precision position vector of the vehicl at time T.
I	VEHICL	RD0	12	$\bar{V}$	er/hr	Single precision velocity vector of the vehicle at time T.
I	C0NST	RADIAN	1	r	rad/deg	Conversion factor: 57.29577951
I	TINPUT	TTR	1	T_T	hrs	Time to initiate thrust.
I	TINPUT	IMASS	1	W	lbs	Input mass of the vehicle.
I	TINPUT	THRM	1		lbs	Thrust magnitude.
I	TINPUT	MSFL	1	$\dot{W}$	lbs/hr	Mass flow rate.
0	BURNID	VRDES	3	$\bar{V}_R$	er/hr	Required velocity.
0	BURNID	VD	4	$\overline{\Delta V}$	er/hr	Velocity to be gained.

SUBROUTINE: THRUS1 (continued)

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
O	BURNID	MASS	1	W	lbs	Current mass of the vehicle.
O	BURNID	ATM	1	$\lvert A \rvert$	er/hr^2	Acceleration magnitude.
O	BURNID	AVRDES	1	$\lvert V_R \rvert$	er/hr	Magnitude of VRDES.
O	PERTS	AT	6		er/hr^2	Acceleration components due to thrusting.
I	CONST	EMU	1	μ	er^3/hr^2	Gravitational parameter of the earth. 19.9094165
I	DINTGR	T	1	T	hrs	Current time double precision.
I	INDS	XMU	1	μ	er^3/hr^2	Gravitational parameter of the central body.
I	AINPUT	PDES	1	P	er	Semi-latus rectum post abort trajectory.
I	AINPUT	EDES	1	e		Eccentricity post abort trajectory.
I	AINPUT	SQS	1			Indicator for the sign of the radial velocity component at the abort.
I	AINPUT	CINC	1	i	deg	Inclination of the post abort trajectory.


ENTER THRUSI
ISTFG:0
≠
=
RSN(I) = RO (I)
VSN(I) = RDO(I)
WHERE I = 1,3
RSN(4) = RO(4)
UKV(1) = 0.
UKV(2) = 0.
UKV(3) = 1.
OINC = CINC/RADIAN
ALPHA = COS (OINC)
UIR(I) = RSN(I)/RSN(4)
WHERE I = 1,3
SMD = UKV(1) UIR (1) + UKV(2)UIR(2)+UKV(3)UIR(3)
$SMD2=SMD^2$
CALL CROSS
(UKV(1), UIR(1), UKXI(1))
$AUKXI = \sqrt{UKXI(1)^2 + UKXI(2)^2 + UKXI(3)^2}$
UKXI(I) = UKXI(I)/AUKXI
WHERE I = 1,3
$UIN(I) = \frac{ALPHA(UKV(I)-SMD\ UIR(I))}{1-SMD2} + UKXI(I)\ SGM \sqrt{\frac{1-SMD2 - ALPHA^2}{1-SMD2}}$
WHERE I = 1,3
CALL CROSS
(UIN(1), UIR(1), XINIR(1))
$VRDES = SQS\ UIR(I) \sqrt{\frac{XMU}{PDES} \left[EDES^2 - \left(\frac{PDES}{RSN(4)} - 1\right)^2\right]} + XINIR(I) \frac{\sqrt{XMU\ PDES}}{RSN(4)}$
WHERE I = 1,3
SOLVE VELOCITY GAIN EQUATION
VD(I) = VRDES(I) - VSN(I)
WHERE I = 1,3
$VD(4) = \sqrt{VD(1)^2 + VD(2)^2 + VD(3)^2}$
COMPUTE MAGNITUDE OF THRUST VECTOR
MASS = I MASS -(MSFL(T-TTR))
ATM = (THRM/MASS)EMU
COMPUTE COMPONENTS OF THRUST VECTOR
$AT(I) = ATM \left(\frac{VD(I)}{VD(4)}\right)$
WHERE I = 1,3
AVRDES = VECMG(VRDES)
RETURN

SUBROUTINE: WLSCN

PURPOSE: To control the logic which will insure that the abort trajectory impact point will be in a water area. This is an option which will be exercised only if the nominal impact is on land and the proper inputs have been made to request a water landing. The computed trajectory is the minimum time solution for the time critical mode and is the minimum fuel solution for the fuel critical mode.

CALLING SEQUENCE: CALL WLSCN (LAT, L0NG)

NAME COMMON USED:
WLSC0N
AINPUT
C0NST
I0UT
RVM00N
INTGRK
INTGR
INM0C
INPUT

SUBROUTINES REQUIRED: ANALYT, ENCKE, INM0

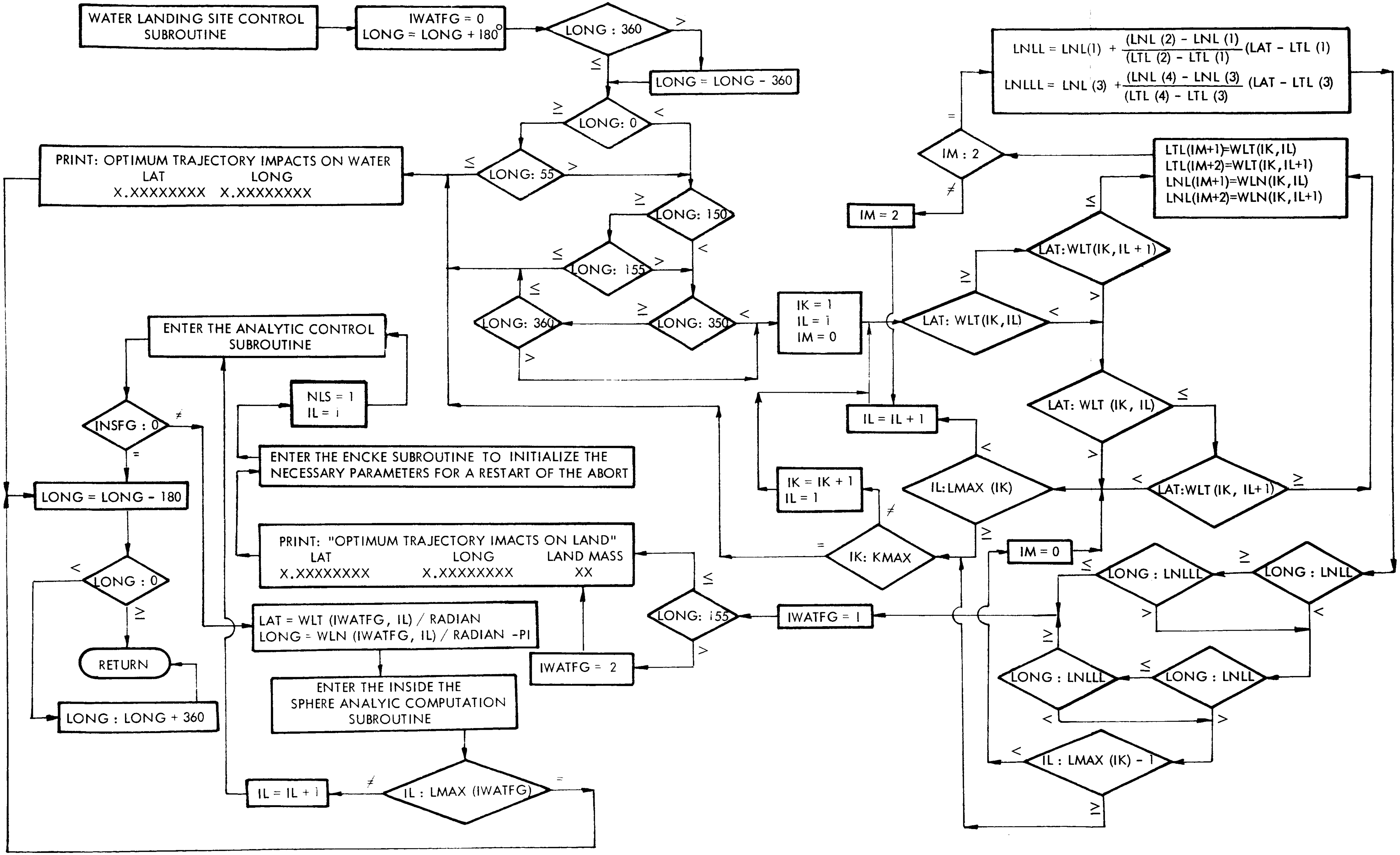
FUNCTIONS REQUIRED: None

APPROXIMATE STORAGE: 412

SUBROUTINE: WLSCN

INPUT AND OUTPUT:

I/O	NAMED COMMON	SYMBOLIC NAME OR LOCATION	PROGRAM DIMENSION	MATH SYMBOL	DATA DIMENSIONS OR UNITS	DEFINITIONS
I	WLSCØN	IMAX	6			Maximum number of landing sites per land mass.
I	WLSCØN	KMAX	1			Maximum number of land masses.
I	WLSLØN	WLT	(6,20)	LAT	deg	Latitudes of the landing sites surrounding the land masses.
I	WLSCØN	WLN	(6,20)	LØNG	deg	Longitudes of the landing sites surrounding the land masses.
Ø	AINPUT	INSFG	1			= 1, the abort point is inside the lunar sphere of action.
Ø	AINPUT	IWATFG	1			Land mass number = 0 if nominal trajectory impacts on water.
I	CØNST	RADIAN	1		deg/rad	Conversion factor: 57.29577951
I/Ø		LAT	1	LAT	deg	Latitude of the nominal trajectory.
I/Ø		LØNG	1	LØNG	deg	Longitude of the nominal trajectory.
Ø	IØUT		85			Trajectory data necessary for the integrated phase when inside the sphere.


WATER LANDING SITE CONTROL SUBROUTINE
IWATFG = 0
LONG = LONG + 180°
LONG : 360
>
≤
LONG = LONG - 360
LONG: 0
≥
<
LONG: 55
≤
>
PRINT: OPTIMUM TRAJECTORY IMPACTS ON WATER
LAT LONG
X.XXXXXXXX X.XXXXXXXX
LONG: 150
≥
<
LONG: 155
≤
>
LONG: 360
LONG: 350
≤
≥
<
>
IK = 1
IL = 1
IM = 0
ENTER THE ANALYTIC CONTROL SUBROUTINE
NLS = 1
IL = 1
INSFG : 0
≠
=
ENTER THE ENCKE SUBROUTINE TO INITIALIZE THE NECESSARY PARAMETERS FOR A RESTART OF THE ABORT
LONG = LONG - 180
PRINT: "OPTIMUM TRAJECTORY IMACTS ON LAND"
LAT LONG LAND MASS
X.XXXXXXXX X.XXXXXXXX XX
LONG : 0
<
≥
LAT = WLT (IWATFG, IL) / RADIAN
LONG = WLN (IWATFG, IL) / RADIAN -PI
RETURN
LONG : LONG + 360
ENTER THE INSIDE THE SPHERE ANALYIC COMPUTATION SUBROUTINE
IL = IL + 1
≠
IL : LMAX (IWATFG)
=
LONG: 155
≤
>
IWATFG = 2
IWATFG = 1
IK: KMAX
=
≠
IK = IK + 1
IL = 1
IL = IL + 1
IL: LMAX (IK)
<
≥
IM = 2
IM : 2
=
≠
LNLL = LNL(1) + (LNL (2) - LNL (1))/(LTL (2) - LTL (1)) (LAT - LTL (1))
LNLLL = LNL (3) + (LNL (4) - LNL (3))/(LTL (4) - LTL (3)) (LAT - LTL (3))
LTL(IM+1)=WLT(IK,IL)
LTL(IM+2)=WLT(IK,IL+1)
LNL(IM+1)=WLN(IK,IL)
LNL(IM+2)=WLN(IK,IL+1)
LAT:WLT(IK,IL + 1)
≤
≥
>
LAT: WLT(IK,IL)
<
LAT: WLT (IK, IL)
≤
>
LAT:WLT (IK, IL+1)
<
≥
IM = 0
LONG : LNLLL
LONG : LNLL
≤
≥
>
<
LONG : LNLLL
LONG : LNLL
≥
≤
<
>
IL : LMAX (IK) - 1
<
≥

8. CONCLUSIONS AND RECOMMENDATIONS

The MIT based abort logic is seen to be efficient, compact and free from indeterminacy. It is a powerful tool for analysis; however, if it is to be considered as a candidate for real-time computation, it is recommended that the program be given a more thorough evaluation. This evaluation should be performed by persons more familiar with the requirements of a real-time logic than were the developers of this simulation. Additionally, it is felt that the simulation would benefit by being used and subsequently critized by those working in areas which might use the program as an analytical tool.

The major uncorrected flaw in the logic is a lack of flexibility in specifying the parameters for the post-abort trajectory. This is evidenced, particularly, in those abort trajectories generated inside the moon's sphere of action.

While RW has enjoyed the direction and cooperation of MSC/MAB during the performance of this task, it is recommended that further development of this program be suspended until MAB has had an opportunity to use the simulation in order to better define those areas in which the logic should be extended and improved.

REFERENCES

1. "Apollo Return to Earth Trajectories," William Marscher, MIT Instrumentation Laboratory, September 30, 1964.

2. "Powered Flight Phases of CSM," E. M. Copps, Jr., MIT, Instrumentation Laboratory, May 29, 1964.

APPENDIX

The following pages contain sample input for the various modes of operation in the program.

```
ID     BCD 0          GUIDC MODEL NAVC ERRORS CHECK
YEAR   DEC 1968
DAYS   DEC 133.
HRS    DEC 3.807366
MINS   DEC 0.
SECS   DEC 0.
INJECT DEC 11
X      DEC -5.11059934E+01
Y      DEC -7.31625199E+00
Z      DEC -2.15868056E+00
DX     DEC -4.82641834E-01
DY     DEC -1.58042888E-01
DZ     DEC -7.88067633E-02
GAMETH DEC 0.0
NTPR   DEC 1
TTR    DEC 0.
IMASS  DEC 22000.
MMASS  DEC 7796.
TCINT  DEC .13888889E-03
MSFL   DEC 251884.983
THRM   DEC 21900.
T1S    DEC 0.
T1D    DEC     0.
T1E    DEC 100.
ITHPR  DEC 20
ROW10  DEC 1.0
ROW11  DEC 1.0
IVSFS  DEC 1
ISCALE DEC 5
OSCALE DEC 5
SQS    DEC     -1.
SGM    DEC 1.
PDES   DEC 1.91544555
CINC   DEC 38.86206543
EDES   DEC .998535132
NAVFL  DEC     1
RMINE  DEC     1.019110183
BURNFL DEC     -1.
       TRA     1,4
```

```
ID      BCD 0      INSIDE THE SPHERE TIME CRITICAL MODE
YEAR    DEC 1968
HRS     DEC     1.72732213
DAYS    DEC     128.
MINS    DEC 0.
SECS    DEC 0.
INJECT  DEC 21
X       DEC +1.03344817
Y       DEC -1.39833421
Z       DEC -.764017713
DX      DEC -.614073455
DY      DEC +.467433101
DZ      DEC +.261752167
GAMETH  DEC 0.0
NTPR    DEC 1
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .13888889E-03
MSFL    DEC 251884.983
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC     0.
T1E     DEC 100.
ITHPR   DEC 20
TTR     DEC 0.
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 5
RMINE   DEC     1.019110183
AVFUEL  DEC 1.0
IAMODE  DEC 2
BURNFL  DEC     2.
DELTI   DEC 0.
H2OFG   DEC 1
        TRA     1,4
```

```
ID      BCD 0      INSIDE THE SPHERE TIME CRITICAL MODE
YEAR    DEC 1968
HRS     DEC     1.72732213
DAYS    DEC     128.
MINS    DEC 0.
SECS    DEC 0.
INJECT  DEC 21
X       DEC +1.03344817
Y       DEC -1.39833421
Z       DEC -.764017713
DX      DEC -.614073455
DY      DEC +.467433101
DZ      DEC +.261752167
GAMETH  DEC 0.0
NTPR    DEC 1
TTR     DEC 0.
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .13888889E-03
MSFL    DEC 251884.983
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC     0.
T1E     DEC 100.
ITHPR   DEC 20
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 5
RMINE   DEC     1.019110183
AVFUEL  DEC 1.0
IAMODE  DEC 2
BURNFL  DEC     2.
DELTI   DEC 0.
RPMIN   DEC     .275
        TRA     1,4
```

```
ID      BCD 0      INSIDE THE SPHERE TIME CRITICAL MODE
YEAR    DEC 1968
DAYS    DEC 127.
HRS     DEC 17.
MINS    DEC 2.
SECS    DEC 23.360
INJECT  DEC 21
X       DEC 5.8734676
Y       DEC -4.8885217
Z       DEC -2.7250792
DX      DEC -.53728276
DY      DEC .38007233
DZ      DEC .21391531
GAMETH  DEC 0.0
NTPR    DEC 1
TTR     DEC 0.
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .13888889E-03
MSFL    DEC 251884.983
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC 0.
T1E     DEC 100.
ITHPR   DEC 20
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 5
RMINE   DEC 1.01911003
AVFUEL  DEC 10.
IAMODE  DEC 2
BURNFL  DEC      0.
DELTI   DEC 0.
        TRA      1,4
```

```
ID     BCD 0      INSIDE THE SPHERE TIME CRITICAL MODE
YEAR   DEC 1968
DAYS   DEC 127.
HRS    DEC 17.
MINS   DEC 2.
SECS   DEC 23.360
INJECT DEC 21
X      DEC 5.8734676
Y      DEC -4.8885217
Z      DEC -2.7250792
DX     DEC -.53728276
DY     DEC .38007233
DZ     DEC .21391531
GAMETH DEC 0.0
NTPR   DEC 1
TTR    DEC 0.
IMASS  DEC 22000.
MMASS  DEC 7796.
TCINT  DEC .13888889E-03
MSFL   DEC 251884.983
THRM   DEC 21900.
T1S    DEC 0.
T1D    DEC 0.
T1E    DEC 100.
ITHPR  DEC 20
ISCALE DEC 5
OSCALE DEC 5
RMINE  DEC 1.01911003
AVFUEL DEC 10.
IAMODE DEC 2
BURNFL DEC     2.
DELTI  DEC 0.
       TRA     1,4
```

```
ID      BCD 0     INSIDE THE SPHERE TIME CRITICAL MODE
YEAR    DEC 1968
HRS     DEC      1.72732213
DAYS    DEC      128.
MINS    DEC 0.
SECS    DEC 0.
INJECT  DEC 21
X       DEC +1.03344817
Y       DEC -1.39833421
Z       DEC -.764017713
DX      DEC -.614073455
DY      DEC +.467433101
DZ      DEC +.261752167
GAMETH  DEC 0.0
NTPR    DEC 1
TTR     DEC 0.
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .13888889E-03
MSFL    DEC 251884.983
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC      0.
T1E     DEC 100.
ITHPR   DEC 20
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 5
RMINE   DEC      1.019110183
AVFUEL  DEC 1.0
IAMODE  DEC 2
BURNFL  DEC      2.
DELTI   DEC 0.
        TRA      1,4
```

```
ID      BCD 0      INSIDE THE SPHERE LANDING SITE MODE
YEAR    DEC 1968
DAYS    DEC     128.
HRS     DEC     1.72732213
MINS    DEC 0.
SECS    DEC 0.
INJECT  DEC 21
X       DEC +1.03344817
Y       DEC -1.39833421
Z       DEC -.764017713
DX      DEC -.614073455
DY      DEC +.467433101
DZ      DEC +.261752167
TTR     DEC 0.
NTPR    DEC 1
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .13888889E-03
MSFL    DEC 251884.983
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC     0.
T1E     DEC 100.
ITHPR   DEC 20
GAMETH  DEC 0.0
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 5
RMINE   DEC     1.019110183
AVFUEL  DEC 2.0
IAMODE  DEC 1
BURNFL  DEC     2.
DELTI   DEC 0.
        TRA     1,4
```

```
ID     BCD 0       INSIDE THE SPHERE LANDING SITE MODE
YEAR   DEC 1968
DAYS   DEC     128.
HRS    DEC     1.72732213
MINS   DEC 0.
SECS   DEC 0.
INJECT DEC 21
X      DEC +1.03344817
Y      DEC -1.39833421
Z      DEC -.764017713
DX     DEC -.614073455
DY     DEC +.467433101
DZ     DEC +.261752167
GAMETH DEC 0.0
NTPR   DEC 1
IMASS  DEC 22000.
MMASS  DEC 7796.
TCINT  DEC .13888889E-03
MSFL   DEC 251884.983
THRM   DEC 21900.
T1S    DEC 0.
T1D    DEC     0.
T1E    DEC 100.
ITHPR  DEC 20
ROW11  DEC 1.0
ISCALE DEC 5
OSCALE DEC 5
RMINE  DEC     1.019110183
AVFUEL DEC 2.0
IAMODE DEC 1
BURNFL DEC     0.
DELTI  DEC 0.
       TRA     1,4
```

```
ID     BCD 0         OUTSIDE THE SPHERE MIDCOURSE TIME CRITICAL MODE
YEAR   DEC 1968
DAYS   DEC 127.
HRS    DEC 21.307366
MINS   DEC 4.
SECS   DEC 0.
INJECT DEC 11
X      DEC 3251.3853
Y      DEC 1311.0588
Z      DEC 670.85189
DX     DEC -11396.533
DY     DEC 25463.529
DZ     DEC 16750.553
ISCALE DEC 7
OSCALE DEC 7
RALTFT DEC 400000.
TMAX   DEC 20.
GAMETH DEC 0.0
TITLE  DEC 1.
ROW11  DEC 1.
T1S    DEC 0.
T1D    DEC      0.
T1E    DEC 100.
TTR    DEC 0.
IMASS  DEC 58200.
MMASS  DEC 21534.
THRM   DEC 21500.
MSFL   DEC 247284.35
NTPR   DEC 1
TCINT  DEC .00013888888
ITHPR  DEC 20
IAMODE DEC 2
DELTI  DEC 0.
BURNFL DEC 4.
AVFUEL DEC 1.72036941
       TRA     1,4
```

```
 ID     BCD 0      OUTSIDE MIDCOURSE TIME CRITICAL MODE INSUFFICIENT FUEL
 YEAR   DEC 1968
 DAYS   DEC 128.
 HRS    DEC 8.557367
 MINS   DEC 0.
 SECS   DEC 0.
 INJECT DEC 11
 X      DEC 19.9579664
 Y      DEC 1.03184061
 Z      DEC 1.63626613
 DX     DEC -1.18906009
 DY     DEC -.207651395
 DZ     DEC -.0735126412
GAMETH  DEC 0.0
NTPR    DEC 1
TTR     DEC 0.
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .13888889E-03
MSFL    DEC 251884.983
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC     0.
T1E     DEC 100.
ITHPR   DEC 20
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 5
RMINE   DEC     1.019110183
AVFUEL  DEC 0.01
IAMODE  DEC 2
BURNFL  DEC     2.
DELTI   DEC 0.
NAVFL   DEC     1
        TRA     1,4
```

```
ID      BCD 0      OUTSIDE THE SPHERE MIDCOURSE TIME CRITICAL MODE
YEAR    DEC 1968
HRS     DEC 21.5740331
DAYS    DEC 127.
MINS    DEC 0.
SECS    DEC 0.
INJECT  DEC 11
X       DEC .336702049
Y       DEC .914666367
Z       DEC .564179498
DX      DEC -3.97111687
DY      DEC 1.55343063
DZ      DEC 1.18236409
GAMETH  DEC 0.0
NTPR    DEC 1
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .13888889E-03
MSFL    DEC 251884.983
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC 0.
T1E     DEC 100.
ITHPR   DEC 20
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 5
RMINE   DEC     1.019110183
BURNFL  DEC     2.
AVFUEL  DEC 10.
IAMODE  DEC 2
        TRA     1,4
```

```
ID      BCD 0          OUTSIDE THE SPHERE MIDCOURSE FUEL CRITICAL MODE
YEAR    DEC 1968
DAYS    DEC 128.
HRS     DEC 8.557367
MINS    DEC 0.
SECS    DEC 0.
INJECT  DEC 11
X       DEC 19.9579664
Y       DEC 1.03184061
Z       DEC 1.63626613
DX      DEC -1.18906009
DY      DEC -.207651395
DZ      DEC -.0735126412
GAMETH  DEC 0.0
NTPR    DEC 1
TTR     DEC 0.
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .13888889E-03
MSFL    DEC 251884.983
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC 0.
T1E     DEC 100.
ITHPR   DEC 20
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 5
RMINE   DEC 1.019110183
BURNFL  DEC 0.
AVFUEL  DEC 0.
IAMODE  DEC 3
DELTI   DEC 0.
H2OFG   DEC 1
        TRA     1,4
```

```
ID      BCD 0       OUTSIDE THE SPHERE MIDCOURSE FUEL CRITICAL MODE
YEAR    DEC 1968
DAYS    DEC 128.
HRS     DEC 8.557367
MINS    DEC 0.
SECS    DEC 0.
INJECT  DEC 11
X       DEC 19.9579664
Y       DEC 1.03184061
Z       DEC 1.63626613
DX      DEC -1.18906009
DY      DEC -.207651395
DZ      DEC -.0735126412
GAMETH  DEC 0.0
NTPR    DEC 1
TTR     DEC 0.
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .13888889E-03
MSFL    DEC 251884.983
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC 0.
T1E     DEC 100.
ITHPR   DEC 20
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 5
RMINE   DEC     1.019110183
BURNFL  DEC     0.
AVFUEL  DEC 0.
IAMODE  DEC 3
DELTI   DEC 0.
        TRA     1,4
```

```
ID      BCD 0           OUTSIDE THE SPHERE FUEL CRITICAL MODE
DELTI   DEC 3.
YEAR    DEC 1968
DAYS    DEC 127.
HRS     DEC 87.867572
MINS    DEC 0.
SECS    DEC 0.
INJECT  DEC 21
X       DEC -.28797049
Y       DEC -.061378553
Z       DEC -.026726072
DX      DEC -.20621356
DY      DEC 1.0737393
DZ      DEC .52199079
GAMETH  DEC 0.0
NTPR    DEC 1
TTR     DEC 0.
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .1388889E-03
TMAX    DEC 130.
MSFL    DEC 251884.983
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC      0.
T1E     DEC 120.
ITHPR   DEC 20
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 7
RMINE   DEC 1.01910943
BURNFL  DEC 2.
AVFUEL  DEC 0.
IAMODE  DEC 3
        TRA      1,4
```

```
ID     BCD 0       OUTSIDE THE SPHERE MIDCOURSE LANDING SITE MODE
YEAR   DEC 1968
DAYS   DEC 128.
HRS    DEC 8.557367
MINS   DEC 0.
SECS   DEC 0.
INJECT DEC 11
X      DEC 19.9579664
Y      DEC 1.03184061
Z      DEC 1.63626613
DX     DEC -1.18906009
DY     DEC -.207651395
DZ     DEC -.0735126412
GAMETH DEC 0.0
NTPR   DEC 1
TTR    DEC 0.
IMASS  DEC 22000.
MMASS  DEC 7796.
TCINT  DEC .13888889E-03
MSFL   DEC 251884.983
THRM   DEC 21900.
T1S    DEC 0.
T1D    DEC 0.
T1E    DEC 100.
ITHPR  DEC 20
ROW11  DEC 1.0
ISCALE DEC 5
OSCALE DEC 5
RMINE  DEC     1.019110183
AVFUEL DEC 10.
IAMODE DEC 1
DELTI  DEC 0.
       TRA     1.4
```

```
ID      BCD 0       OUTSIDE THE SPHERE MIDCOURSE LANDING SITE MODE
YEAR    DEC 1968
DAYS    DEC 128.
HRS     DEC 8.557367
MINS    DEC 0.
SECS    DEC 0.
INJECT  DEC 11
TTR     DEC 0.
GAMETH  DEC 0.0
X       DEC 19.9579664
Y       DEC 1.03184061
Z       DEC 1.63626613
DX      DEC -1.18906009
DY      DEC -.207651395
DZ      DEC -.0735126412
NTPR    DEC 1
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .13888889E-03
MSFL    DEC 251884.983
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC 0.
T1E     DEC 100.
ITHPR   DEC 20
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 5
RMINE   DEC     1.019110183
BURNFL  DEC     3.
AVFUEL  DEC 10.
IAMODE  DEC 1
DELTI   DEC 0.
        TRA     1,4
```

```
ID      BCD 0      OUTSIDE THE SPHERE ORBITAL LANDING SITE MODE
YEAR    DEC 1968
HRS     DEC 22.5990914
DAYS    DEC 127.
MINS    DEC 0.
SECS    DEC 0.
INJECT  DEC 11
X       DEC -2.06012061
Y       DEC -.192658760
Z       DEC -.0225902689
DX      DEC .0704910582
DY      DEC -2.13674304
DZ      DEC -1.36129381
GAMETH  DEC 0.0
NTPR    DEC 1
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .13888889E-03
MSFL    DEC 251884.983
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC 0.
T1E     DEC 100.
ITHPR   DEC 20
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 5
RMINE   DEC     1.019110183
BURNFL  DEC     2.
NAVFL   DEC 1
IAMODE  DEC 1
AVFUEL  DEC 10.
        TRA     1,4
```

```
ID      BCD 0       OUTSIDE THE SPHERE ORBITAL LANDING SITE MODE
YEAR    DEC 1968
HRS     DEC 22.5990914
DAYS    DEC 127.
MINS    DEC 0.
SECS    DEC 0.
INJECT  DEC 11
X       DEC -2.06012061
Y       DEC -.192658760
Z       DEC -.0225902689
DX      DEC .0704910582
DY      DEC -2.13674304
DZ      DEC -1.36129381
GAMETH  DEC 0.0
NTPR    DEC 1
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .13888889E-03
MSFL    DEC 251884.983
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC 0.
T1E     DEC 100.
ITHPR   DEC 20
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 5
RMINE   DEC     1.019110183
NAVFL   DEC 1
IAMODE  DEC 1
AVFUEL  DEC 10.
BURNFL  DEC 0.
        TRA     1,4
```

```
ID      BCD 0          CIRCUMLUNAR TIME CRITICAL DELTI = 10 HRS
YEAR    DEC 1968
DAYS    DEC      29.
HRS     DEC      6.
MINS    DEC      33.
SECS    DEC      3.84
X       DEC      36.147020878
Y       DEC      -22.58387863
Z       DEC      -13.34722365
DX      DEC      .63429661313
DY      DEC      -.245776879
DZ      DEC      -.1525852232
INJECT  DEC 11
GAMETH  DEC 0.0
NTPR    DEC 1
TTR     DEC 0.
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .13888889E-03
MSFL    DEC      251884.98
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC 0.
T1E     DEC 100.
ITHPR   DEC 20
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 5
RMINE   DEC 1.01910943
IAMODE  DEC 2
BURNFL  DEC 2.
DELTI   DEC      10.
AVFUEL  DEC      10.
CFLAG   DEC      1.
RPMIN   DEC      .25
URMAX   DEC      6.22
        TRA 1,4
```

```
ID      BCD 0           CIRCUMLUNAR TIME CRITICAL DELTI = 0 HRS
YEAR    DEC 1968
DAYS    DEC     29.
HRS     DEC     6.
MINS    DEC     33.
SECS    DEC     3.84
X       DEC     36.147020878
Y       DEC     -22.58387863
Z       DEC     -13.34722365
DX      DEC     .63429661313
DY      DEC     -.245776879
DZ      DEC     -.1525852232
INJECT  DEC 11
GAMETH  DEC 0.0
NTPR    DEC 1
TTR     DEC 0.
IMASS   DEC 22000.
MMASS   DEC 7796.
TCINT   DEC .13888889E-03
MSFL    DEC     251884.98
THRM    DEC 21900.
T1S     DEC 0.
T1D     DEC 0.
T1E     DEC 100.
ITHPR   DEC 20
ROW11   DEC 1.0
ISCALE  DEC 5
OSCALE  DEC 5
RMINE   DEC 1.01910943
IAMODE  DEC 2
BURNFL  DEC 2.
DELTI   DEC 0.
AVFUEL  DEC     10.
CFLAG   DEC     1.
RPMIN   DEC     .25
URMAX   DEC     6.22
        TRA 1,4
```